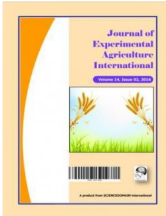

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Role of Combined Ash and Terbuphos as Preplanting Corm Treatment to Manage Corm Borer Weevils (*Cosmopolites sordidus*) on Plantains and Stimulate Growth

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JNO and ANF designed the study, wrote the protocol. Authors ILKM and LTN collected the data. Authors JNO and ILKM wrote the first draft of the manuscript. Authors JNO, NC and OD performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

The banana borer weevil, *Cosmopolites sordidus* is the most important pest that causes significant damage to banana and plantain in Cameroon. Most farmers in Buea Sub-Division, South West Region, Cameroon, believe that applying a combination of Terbuphos (Counter 10G®) and Wood Ash (from rubber plants) as seed treatments helps to protect suckers from the banana weevil and stimulate plant growth better than their sole forms. The main objective of this research was to evaluate the efficacy of a bio-stimulant botanical pesticide (i.e., combined wood ash and oil palm bunch residue ash) and a conventional synthetic insecticide (Terbufos) applied as seed treatment to manage *C. sordidus* and stimulate the growth of plantains. Laboratory and field experiments (complete randomized blocks) were carried out at the research station of IRAD Ekona, Southwest Cameroon. The experimental setup comprised the following treatments; 5 g Wood Ash/5 g Terbuphos, 10 g Wood Ash/10 g Terbuphos, 30 g Wood Ash/30 g Terbuphos, 20 g Wood Ash only and 20 g Terbuphos only, and the control (neither ash nor Terbuphos) replicated three times each. The results demonstrated significant treatment effects (P=0.05 and $F_{5,54}$), with differences in weevil mortality, repulsion, oviposition on the surface of the corm, number of larvae inside the corm and plant growth parameters for treatments with Terbuphos compared to the control. Meanwhile, ash treatments did not show any mortality effect on insects. However, Wood Ash showed non-mortality effects in the laboratory as compared to the control, although it was not significantly different (P=.05 and $F_{5,54}$). 20 g Terbuphos only, followed by the combination of 5 g Wood Ash and 5 g Terbuphos per 1 L of water had the most effective results in enhancing growth parameters and survival of the plants (Percentage Coefficient of Infestation of 30.2 and 65.6 as compared to the 97.9 for the control).

Keywords: Ash; bio-stimulant; crop protection; Musa spp; pest.

1. INTRODUCTION

Plantains and bananas (*Musa spp*) are of significance to humans [1] with major role as food security crops [2,3]. Pests and crop nutritional deficiencies limit the production of the crops in Sub-Saharan Africa, which requires sustainable alternative management practices without negative externalities [4].

A major insect pest of *Musa* spp is *Cosmopolites sordidus* [5,6,7]. In Cameroon, these weevils are found in all production zones [6,8]. Damage is caused by the borer larvae which have the ability to live within the plant tissues where they feed, thereby disrupting the normal functioning of the plant. Tunneling causes death of suckers, snapping, toppling, and deterioration of root system and reduced nutrient uptake or shortened plant life [9,10].

Due to the hidden nature of the larvae, management is difficult [5] and scientists generally agree that no single control strategy could provide complete check on the weevil [11]. This suggests that integration of management options has a better chance [5]. In Cameroon, the efficacies of several classical insecticides have been evaluated for managing these borer weevils [6,12]. However, the use of chemicals alone cannot provide proper control of the pest for many years because of the potential ability to develop resistance to chemicals [13].

The most commonly used synthetic insecticide in Cameroon is Terbuphos (Counter® 10G), an organophosphate which is usually mixed with ash as pre-planting corm treatment for bananas and plantains. Farmers claim that this combination helps to protect the plant from borer weevils and nematodes better than their sole forms and that the Ash also helps to stimulate plant growth. Despite these claims, there seems to be no scientific study or data concerning the effects of combining Ash and Terbuphos for managing the weevils (*C. sordidus*) and stimulating plant growth performances.

Meanwhile, considering the high cost of commercial fertilizer and their adverse effects on the environment [14] farmers are seeking alternative sources of fertilizer that are cheap and environmentally friendly [15]. Wood Ash and palm bunch residue ash (OPBRA) have been reported to be rich in essential elements such as Potassium (K), Calcium (Ca), Phosphorus (P) and Magnesium (Mg), which are important elements needed for the growth of plants [16]. In addition, ash has been reported to have insecticidal properties [17,14] and the fertilizing properties [18] have been reported for other crops. Despite these potentials, the use of ash as fertilizer and insecticide to manage *C. sordidus* has not been fully exploited by researchers and farmers.

Hence, the main objective of this research was to evaluate the efficacy of a bio-stimulant botanical pesticide (i.e. Wood Ash and OPBRA) and a commercial synthetic insecticide as corm treatment for managing *C. sordidus* and improving the growth of plantains.

2. MATERIALS AND METHODS

2.1 Study Site

The research was carried out at the Institute of Agricultural Research for Development (IRAD) located at Ekona (its geographical coordinates are 4º14' 0" north, 9º20' 4" east), Muyuka sub-division of Fako Division, South west Region, Cameroon. Ekona is situated on the Northeastern slopes of Mount Cameroon at 450 meters above sea level [19] and is a fairly warm area with heavy rains during the rainy season, with a mean temperature in the dry season being 24.40ºC and 23.70ºC in the rainy season, with high annual humidity of 76 - 90% [20]. The average annual temperature is 22.8ºC and the rainfall averages 2719 mm. The soils are volcanic and very fertile, making Ekona a suitable agricultural area.

2.2 Trapping, Collection, Rearing and Sexing of Weevils

Adult weevils of *C. sordidus* were obtained from banana plants around Ekona research center and from traps which were set in the field using pseudostem traps [21] and maintained in the laboratory. Using a hand lens and a light microscope, the sexes were differentiated based on curvature of the last abdominal segment which is more inwardly curved in males than in females as well as punctuations on the rostrum [22].

2.3 Laboratory Experiments

Transparent plastic containers (13 cm x 13 cm x 7 cm) with perforated lids for aeration were used. The plantain variety used in the field and in the laboratory was “Ebanga”. A knife was used to remove the roots and other materials from the corm, making sure there were no holes, eggs, larvae or weevils. This was to ensure that the corms were clean and uninfested.

2.3.1 Use of combined wood ash and terbuphos on mortality, repulsion, oviposition and number of larvae in the corm

The treatments (T) were, T1 = control (water), T2 = (5 g Wood Ash + 5 g terbuphos)/1 l of water, T3 = 10 g Wood Ash + 10 g Terbuphos)/1 l of water, T4 = (30 g Wood Ash + 30 g Terbuphos)/1 l of water, T5 = (20 g Wood Ash only)/1 l of water, T6 = (20 g Terbuphos only)/1 l of water. The ash used was collected from households that burnt rubber wood as fuel wood.

Clean corms of size 4 cm x 4 cm were soaked in the various treatments for 10 minutes and air-dried for 15-20 minutes after which they were placed in plastic containers. 10 weevils (5 males and 5 females) were introduced in each container away from the corms and the container covered. Observations and data were recorded for 10days, in which case cumulative number of dead adults, number of weevils repelled and numbers of eggs laid on corm surfaces were counted daily and recorded. Using a forcep, the weevils were moved away from the corm daily after each record. After 15 days, the corms were dissected using a knife, a blade and a magnifying table lens and the numbers of larvae in the corms were counted and recorded.

2.3.2 Use of combined terbuphos and oil palm bunch residue ash (opbra) on mortality, repulsion, oviposition and number of weevil larvae in corm

The experiment was conducted following the same protocol as for wood ash with same observations, and with the following treatments (T); T1 = control (water), T2 = (5 g OPBRA + 5 g terbuphos)/1 l of water, T3 = 10 g opbra + 10 g terbuphos)/1 l of water, T4 = (30 g OPBRA + 30 g Terbuphos)/1 l of water, T5 = (20 g OPBRA only)/1 l of water, T6 = (20 g Terbuphos only)/1l of water. OPBRA was obtained from a local oil palm processing mill.

2.4 Field Experiment

A randomized complete block design was used in the field and consisted of 6 treatments based on the results obtained in the laboratory whereby the minimum effective dose of the various treatments was used. The treatments were as follows; T1 = control (water), T2 = (5 g Wood Ash + 5 g Terbuphos)/1l of water, T3 = 5 g OPBRA + 5 g Terbuphos)/1l of water, T4 = (20 g Wood Ash only)/1 l of water, T5 = (20 g OPBRA only)/1 l of water, T6 = (20 g Terbuphos only)/1 l of water.

The treatments were replicated thrice with each replicate having 10 plants. The suckers used on the field were pared or cleaned using a knife by removing the roots, other debris and the outer skin of the corm and available holes caused by larvae of *C. sordidus*. After that, they were soaked in the various treatment solutions in bags for 10 minutes, after which they were removed and air-dried for 20 minutes. The treated suckers were then -planted in the dug holes. Each treatment consisted of 30 plants, resulting in a grand total of 180 plants planted in the field. One week after planting, weevils were introduced in the field at the rate of 10 weevils per plant (i.e. 5 males and 5 females).

2.5 Plantain Performance

The assessment of plantain growth parameters such as the height of plants, the stem girth and the number of healthy leaves (i.e. leaves with little or no damaged areas and brown/black spots) was performed once per month within seven months (March to September) of field experimental period.

2.6 Corm Damage Assessment

At the end of the field experiment, corm damage by *C. sordidus* was assessed using Coefficient of Infestation (CI) [23] for peripheral or external damage and percentage coefficient of infestation (PCI) for internal damage [24,25]. Entire plants were dug up and the soil around them was removed and then washed to count healthy roots. Thereafter, CI was obtained by using a sharp knife to pare 50% of each corm, and the level of damage was estimated using the CI indices below:

0 = No weevil gallaries
5 = Traces of weevil gallaries
10 = Intermediate between 5 and 20
20 = Gallaries present on approximately¼ of the sampled zone
30 = Intermediate between 20 and 30
40 = Gallaries on approximately ½ of sampled zone
60 = Gallaries on approximately ¾ of sampled zone
100 = Gallaries present on totality of sampled zone

To estimate the PCI, entire corms were uprooted, pared and then sectioned cross-wise directly on the collar. The total internal area of the sectioned corm was divided into eight sections and each section was examined for weevil damage. The number of damage or infested section was considered as a fraction of eight and expressed as a percentage (PCI = t⁄8 ×100, where t is the number of weevil infested sections, 8 = total number of sections cut).

2.7 Data Analysis

Using descriptive statistics, the mean, variance and standard deviations of percentage mortality, percentage repulsion, numbers of eggs laid on corm surface, numbers of larvae within corms, plant growth parameters and weevil damage in the field were obtained. The data were log (n+1) transformed to normalize the data or enable data homogeneity, thereby eliminating or reducing errors. The transformed data were analysed using analysis of variance (ANOVA), and for cases where there were significant differences or statistical differences (rejection of null hypotheses), the means were separated by Tukey's HSD test [26] at 5% or 1% level of significance. Using the Statdisk Software Version 9.1 [27] selected variables were subjected to correlation and regression analysis (both involving use of scattergrams with embedded linear trends, coefficient of determination, and product moment correlation coefficient). These analyses were carried out at significant levels (α) = .05 or .01.

3. RESULTS

3.1 Laboratory Experiments

3.1.1 Mortality and non – mortality effects of combined wood ash and terbuphos

From Fig. 1 no mortality of weevils was recorded in the control and significant statistical differences occurred between the control and 20 g Terbuphos and between 20 g Wood Ash and 20 g Terbuphos according to Tukey's HSD test at 95% confidence level {($F_{5,54}$) = 7.58, Tukey's value (T) = 17.7, *P* = .05}.

As for repulsion (Fig. 1) only the control had zero percentage of repelled weevils while all treatments containing Terbuphos recorded the same level of repulsion which was greater than the control and 20 g Wood Ash only. 20 g Terbuphos recorded the highest level of repulsion with a mean percentage repulsion of 95.7%. There was no significant difference between the control and 20 g Wood Ash only ($F_{5,54}$ = 71.58, T = 79, *P* = .05). However, 20 g Wood Ash recorded some level of repellence as some of the weevils were observed to still walk around in the test container and away from the corm treated with Wood Ash, as compared to those in the control which remained attached to the corms. Also, weevils in 20 g Wood Ash were less active as compared to those in the control, In addition to this, all weevils in 20 g Wood Ash were found to remain only on the corm surfaces, while those in the control were able to bore and live inside the corms.

Eggs laid on the surface of corms were seen only in the control whereas none were found on corms of the 20 g Wood Ash treatments and in all the treatments with Terbuphos. There was no significant difference between the control and all the other treatments ($F_{5,54}$ = 5.62, T = 0.68, P = .05) (Fig. 2). After dissection of corms, no larvae were found in the treatments with Terbuphos. Although there were more larvae in the control than in 20 g Wood Ash, there was no significant difference between these two treatments according to Tukey's Test at 95% confidence level ($F_{5,12}$ = 16.5, T = 4, P = .05), (Fig. 2).

3.1.2 Mortality and non – mortality effects of combined OPBRA and Terbuphos

Not all weevils in treatments containing Terbuphos were found dead after 15 days, as some were able to shake their antennae or legs although very weak and unable to walk. No mortalities were recorded in the control and sole 20 g OPBRA treatment (Fig. 3). Although mortality of weevils varied among treatments comprising Terbufos, these were not significantly different ($F_{5,54}$ = 3.19, T = 9.2, P = .05) (Fig. 3). The highest percentage of dead weevils was recorded in 30 g Terbuphos+30 g OPBRA with mean percentage mortality of 22%, and followed by 18.7% for 20 g Terbuphos. All the treatments containing Terbuphos had above 90% repulsion and were not significantly different ($F_{5,54}$ = 2.39, TS = 79.80, P = .05). However, they were greater than and significantly different from the control and sole 20 g OPBRA treatments ($F_{5,54}$ = 2.39, TS = 79.80, P = .05) (Fig. 3). 20 g Terbuphos recorded the highest level of repulsion with a mean repulsion of 96.7% followed by 94% for 30 g Terbuphos/30g OPBRA. There was no significant difference between the control and 20 g OPBRA as revealed by Tukey's Test at 95% confidence interval level ($F_{5,54}$ = 2.39, TS = 79.80, P = .05). OPBRA was observed to actually show greater repellence as compared to Wood Ash, with at least one weevil found away from the corm each day. In the 20g OPBRA treatment, weevils were less active compared to the control.

With the exception of corms in the control, no eggs were found on corm surfaces of the other treatments and according to ANOVA, there were significant differences between the treatments (Critical F = 2.39, Test statistic $(F)_{5,54}$ = 3.86, P = .05) (Fig. 4). Although no eggs were found on the OPBRA treated corm surfaces, larvae were found inside the corms after dissection. The control had the highest mean number of larvae (16.7) as compared to a mean of 12.3 in 20 g OPBRA and these were significantly different ($F_{5,12}$ = 21, T = 3.2, P = .05). Meanwhile, no larva was found in treatments with Terbuphos.

3.2 Field Experiment

3.2.1 Effects of combined OPBRA and terbuphos on plantain growth

The best treatment to enhance the growth and survival of the plants was the 20 g of Terbufos only (Table 1) and this was significantly different from other treatments ($F_{5,24}$ = 4.57, T = 2.4, P = .05). Although there were variations in the parameters, there were no significant differences between the sole Wood Ash and sole OPBRA treatments. However, combination of Wood Ash with Terbufos significantly enhanced growth parameters and survival of the plants compared to combination with OPBRA (Table 1). The 20 g sole Terbufos treatment had no dead plants but this was not significantly different from the treatment consisting of combination of wood ash and Terbufos ($F_{5,24}$ = 4.57, T = 2.4, P = .05).

3.2.2 Association between plantain growth parameters and dead plants

From Table 2, the parameters or variables compared were strongly correlated and these correlations were highly significant at α = .01. With the exception of association of mean healthy roots and mean dead plants, all other pairs had coefficient of determination values (R^2) above 0.9. In addition, only associations of mean healthy roots/leaves with mean number of dead plants were negatively correlated.

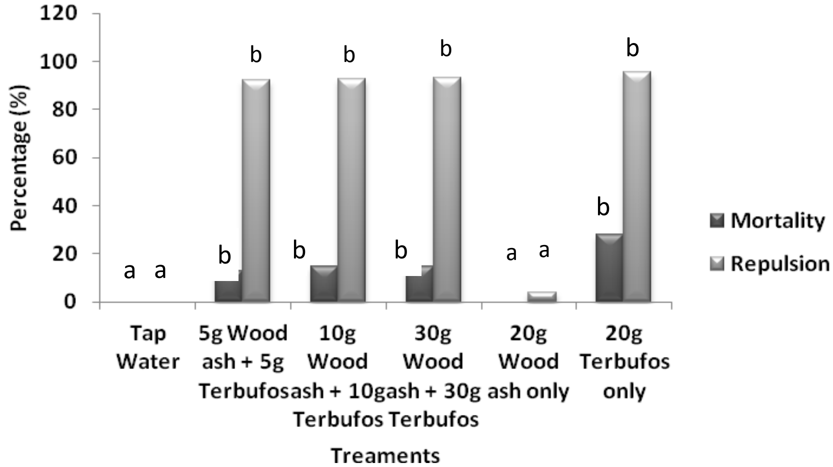

Fig. 1. Cumulative mean percentage of dead and repelled weevils after applying the different treatments wood ash and Terbufos in the laboratory bars with the same letters are not significantly different from each other according to Tukey's HSD 95% confidence interval

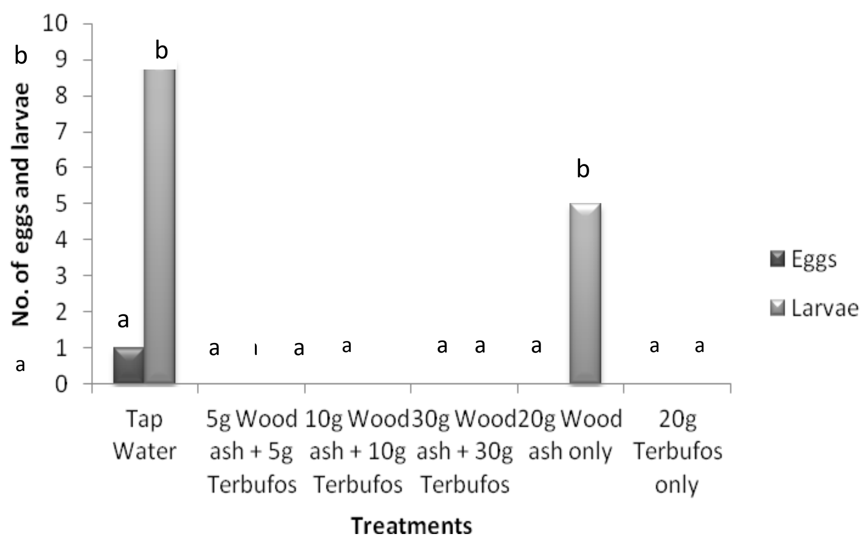

Fig. 2. Mean number of eggs on corm surface and larvae in dissected corms in the laboratory for different Wood Ash treatments (T1 = Control (water), T2 = (5 g Wood Ash + 5 g Terbuphos)/1 L of water, T3 = 10 g Wood Ash + 10 g Terbuphos)/1L of water, T4 = (30 g Wood Ash + 30 g Terbuphos)/1 L of water, T5 = (20 g Wood Ash only)/1 L of water, T6 = (20 g Terbuphos only)/1 L of water). Bars with the same letters are not significantly different from each other according to Tukey's HSD 95% confidence interval.

3.2.3 Effects of combined Ash and Terbuphos on corm damage by weevils

The least damage in the outer and inner cylinder of the corms was in the sole 20 g Terbuphos treatments (34.4 and 30.2% for the outer and inner cylinder respectively) followed by 5 g Wood Ash /5 g Terbuphos while the highest damage occurred in the control with 100 CI for outer cylinder and 97.9 PCI for inner cylinder. These treatments were significantly different from each other according to Tukey's Test at 95% confidence level ($F_{5,66}$ = 11.89, T = 11.8, P = .05 for external corm damage and $F_{5,66}$ = 7.8, T = 15.2, P = .05 for internal corm damage.) (Table 3). Generally, treating plants before planting demonstrated some level of protection of the corms. This is shown by less outer and inner damage of the corms in 5 g OPBRA/5 g Terbuphos, 20 g Wood Ash and 20 g OPBRA as compared to the control, but there were no significant differences between these treatments as revealed by Tukey's Test at 95% confidence interval ($F_{5,66}$ = 11.89, T = 11.8, P = .05 for external corm damage and $F_{5,66}$ = 7.8, T = 15.2, P = .05 for internal corm damage.). Furthermore, there was a strong positive and highly significant correlation between the external corm damage indices (CI) and the internal corm damage estimates (PCI) (r = 0.9984, critical r = 0.9172, and α = .01)

3.2.4 Association of internal corm damage (PCI) with growth parameters and dead plants

With exception of the mean number of dead plants, the internal corm damage estimate (PCI) was negatively correlated to the plantain growth parameters (Table 4).

4. DISCUSSION

In this study, the different Ashes showed repellence to the weevils more than the control although the difference was not statistically significant (P = .05) (Figs. 1 and 3). This indicates that it could be used in the field to reduce weevil population infesting the plants. This is in conformity with [17] where insect population decreased on maize plants treated with Wood Ash as compared to the control treatment. Although Ash showed no mortality on the weevils, it made them less active and less mobile. Continuous application or increased dose could cause mortality and [28] reported toxicity of Wood Ash to Colorado potato beetles. The fact that fewer eggs and no eggs were found on the corm surfaces of the control and Ash treatments as compared to the number of larvae found inside the corm, confirms their habit of laying eggs in holes created by the ovipositing females as reported by [5].

All weevils in Ash treatments were found on the surface of the corms as compared to those in the control that was found underneath the corms. This suggests that, ash creates an environment which is not favourable for the adult weevils and therefore supports the hypothesis that a combination of Ash and Terbuphos is the best-bet treatment for controlling the pest as compared to their sole forms. Fewer larvae observed in Ash treatments as compared to the control although not significantly different (P = .05) showed that Ash has an effect on weevil oviposition as well as egg hatching and therefore reducing the number of larvae and their damage within corms.

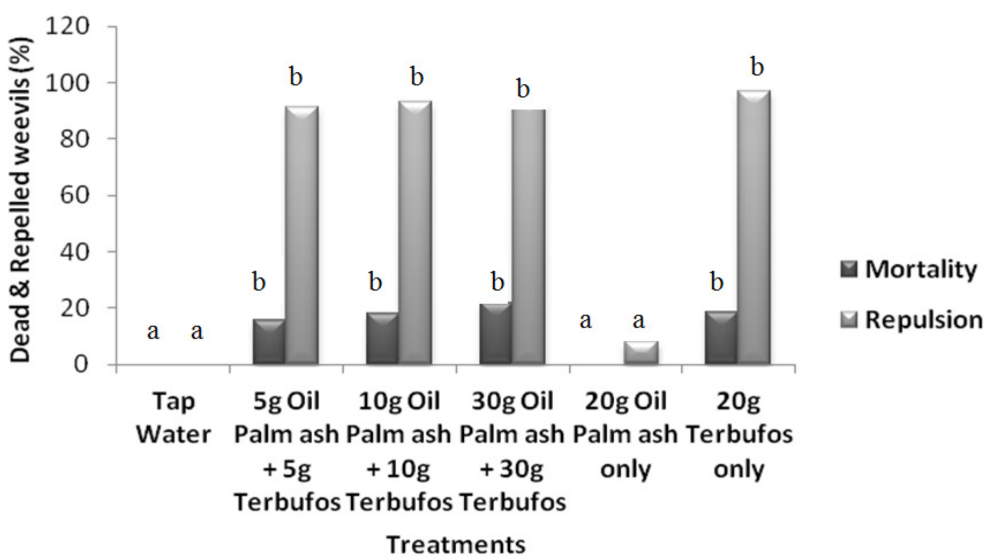

Fig. 3. Mean percentage of weevils dead and repelled from the different treatments (t1 = control (water), t2 = (5 g OPBRA + 5 g TERBUPHOS)/1 l of water, t3 = 10 g OPBA + 10 g TERBUPHOS)/1 l of water, t4 = (30 g OPBRA + 30 g terbuphos)/1 l of water, t5 = (20 g OPBRA only)/1 l of water, t6 = (20 g terbuphos only) per 1l of water). Bars with the same letters are not significantly different from each other according to tukey's hsd 95% confidence interval

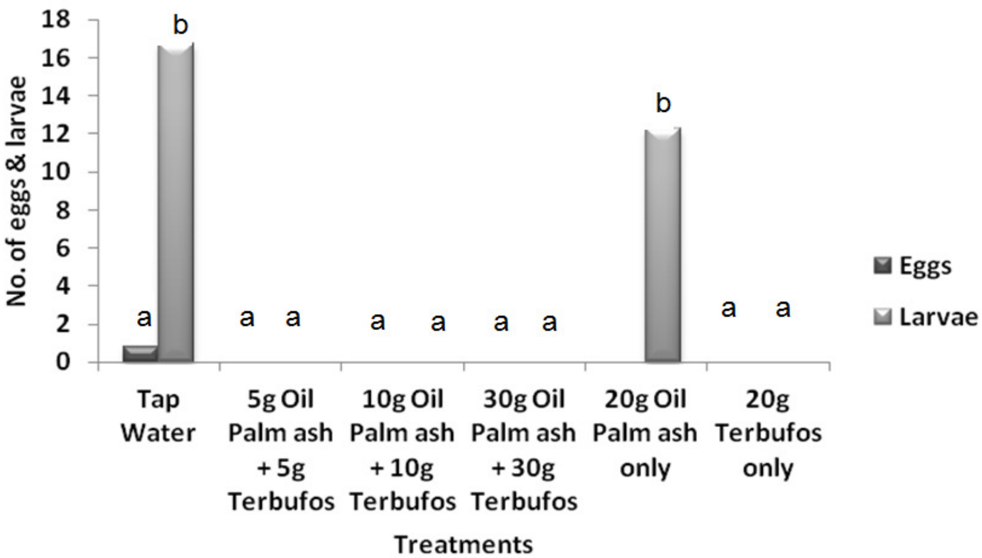

Fig. 4. Mean number of eggs laid on corm surface and number of weevil larvae inside the corm (t1 = control (water), t2 = (5 g OPBRA + 5 g terbuphos)/1 l of water, t3 = 10 g OPBRA + 10 g terbuphos)/1l of water, t4 = (30 g OPBRA + 30 g terbuphos)/1 l of water, t5 = (20 g OPBRA only)/1 L of water, T6 = (20 g Terbuphos only)/1 L of water). Bars with the same letters are not significantly different from each other according to Tukey's HSD 95% confidence interval.

Table 1. Mean numbers (±SE) of dead plants, number of healthy leaves, healthy roots, the girth and the height of plants from the different treatments in the field. Means with the same letters within a column are not significantly different from each other according to Tukey's HSD 95% confidence level

Treatments	No. dead plants	No. healthy leaves	No. healthy roots	Girth (Cm)	Height (Cm)
Control (Tap water)	7.8 ± 0.21a	0.9 ± 0.04 a	8.1 ± 0.43 a	5.5 ± 0.24 a	22.5 ± 0.37 a
(5 g wood ash + 5 g Terbuphos)/1 l of water	1.6 ±0.11 b	2.7 ± 0.1 b	25.5 ± 0.47 b	11.2 ± 0.13 b	59.8 ± 0.38 b
(5 g OPBRA + 5 g terbuphos)/1 l of water	5.2 ± 0.18 c	1.3 ± 0.06 a	6.4 ± 0.36 a	6.8 ± 0.21 a	31.8 ± 0.30 a
(20 g wood ash only)/1 l 0f water	5.2 ± 0.18 c	1.8 ± 0.08 c	17.6 ± 0.55 a	7.7 ± 0.18 a	39.8 ± 0.23 a
(20 g oil palm bunch residue ash only)/ 1 l of Water	4.8 ± 0.18 c	1.8 ± 0.07 c	13.2 ± 0.45 a	8 ± 0.16 a	44.8 ± 0.31 a
(20 g terbuphos only)/1 l of water).	0 ± 0 b	3.9 ± 0.13 d	50 ± 0.44 c	15.3 ± 0.13 c	88.7 ± 0.48 c

Concerning plantain growth and weevil damage in the field, the results showed that pre-planting treatments were very effective in ensuring plant survival despite the presence of the pest. The significant differences between the control and all other treatments implied that, Ash and Terbuphos improved protection against the banana weevil and stimulated growth parameters. [14] reported a significantly improved effect of palm bunch ash on yield of groundnuts while [17] reported a reduction in insect population, number of damaged leaves and number of holes on maize plants when maize seeds were treated with Wood Ash before planting.

The application of 20 g Terbuphos only showed the highest improved effect on plant survival, plant height, plant girth and number of healthy leaves. This could be due to the high

Table 2. Coefficient of determinations (R^2), product moment correlation coefficients (r) and regression equations between plantain growth parameters and dead plants

Parameters (Mean values)	Regression equation	Statistic			Significance level (α)	Observation
		R^2	Critical r	r		
Height/Healthy Roots	y = 0.6645x-1.696	0.9399	0.9172	0.9695	.01	Highly significant
Height/Healthy Leaves	y = 0.0457x-.1221	0.9938	0.9172	0.9969	.01	Highly significant
Healthy Roots / Girth	y = 4.396x-19.797	0.9490	0.9172	0.9742	.01	Highly significant
Healthy Leaves / Girth	y = 3.3018x+2.2596	0.9929	0.9172	0.9172	.01	Highly significant
Healthy Roots / No. Dead Plants	y = -5.122x+41.134	0.795	0.811	-0.8917	.05	Significant
Healthy Leaves /No. Dead Plants	y = -0.3717+3.5905	0.9359	0.9172	-0.9674	.01	Highly significant

Table 3. Mean coefficient of infestation (CI) and percentage coefficient of infestation (PCI) as a result of *C. sordidus* damage on corms in the field. Means with the same letters in a column are not significantly different from each other according to Tukey's HSD 95% confidence interval

Treatments	External corm damage (CI)	Internal corm damage (PCI)
Control (Tap water)	100 ± 0.0a	97.9 ± 0.27a
(5 g Wood Ash + 5 gTerbuphos)/1 l of water	68.8 ± 0.57b	65.6 ± 0.62b
(5 g OPBRA + 5 gTerbuphos)/1 l of water	91.7 ± 0.45ac	90.6 ± 0.54a
(20 g Wood Ash only)/1 l 0f water	88.5 ± 0.47ad	86.5 ± 0.52 a
(20 g OPBRA only)/1 l of Water	85.4 ± 0.52cd	86.5 ± 0.57a
(20 g Terbuphos only)/1 l of water).	34.4 ± 0.53e	30.2 ± 0.63c

Table 4. Coefficient of determinations (R^2), product moment correlation coefficients (r), and regression equations for internal corm damage estimates (Percentage Coefficient of Infestation - PCI) with growth parameters and dead plants

Parameters (Mean values)	Regression equation	Statistics			Significant level (α)	Remarks
		R^2	r	Critical r		
PCI and height	Y = -0.9303x+118.8	0.9688	-.9843	0.9172	0.01	Strong negative and highly significant
PCI and healthy leaves	Y = -0.0426x+5.3144	0.9675	-.9836	0.9172	0.01	Strong negative and highly significant
PCI and healthy roots	Y = -0.6372x+68.695	0.9674	-.9836	0.9172	0.01	Strong negative and highly significant
PCI and girth	Y = -0.1425x+19.945	0.9855	-.9927	0.9172	0.01	Strong negative and highly significant
PCI and dead plants	Y = 0.1057x-3.9589	0.8792	0.9377	0.9172	0.01	Strong positive and highly significant

concentration and degree of effectiveness of the active ingredient over calcium carbonate found in Wood Ash. In addition, Terbufos is an effective nematicide with insecticidal effects in Cameroon [6]. Protection of the roots allowed adequate water and minerals to enter the plant and ensure healthy growth and survival.

Besides the effects of Terbuphos and Ash on weevils, plant growth essential elements like Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) from Ash may have also added to the nutrient supply of the suckers and aided increase in their growth parameters [16]. [14] reported that Ash contains varying amounts of essential elements like Ca, P, K and Mg, which are vital elements needed by plants for growth. [29] further reported that application of kitchen residue Ash and palm bunch Ash increased plant height and stem diameter for maize. Meanwhile, Ash and Ash-derived composts have high liming potential and reportedly improved soil physical, biological and chemical properties [30,31]. However, the combination of Ash and Terbuphos is advantageous for seed/corm treatment to control pests and stimulate plant growth through nutrient supply for the local smallholder farmers because there is no agrochemical that can be used as seed treatment to achieve both pest control and enhance nutrient supply [17].

Twenty grams (20 g) Terbuphos had the highest number of healthy roots and the least damage in the outer and inner cylinder of corms (Table 1 and 3), indicating that the plants had the most effective protection against weevil damage, giving the plants a chance to develop more roots. [32] reported that weevil attack interferes with root initiation, destroys existing roots and weakens the support structure of the plant. The 20g Ash only also had increased root number although not significantly different from the control. This suggests that, if the Ash was applied constantly, there could be great significant differences. [29] reported an increase in maize roots as a result of the use of kitchen Ash. Five gram (5 g) Wood Ash/5 g Terbuphos also had significant increase in plant growth parameters and root number better than using Ash only (20 g Wood Ash only or 20 g OPBRA only) and the control, indicating its effectiveness as pre-planting seed treatment. The highest number of dead plants and decreased growth parameters observed in the control is due to the fact that neither ash nor Terbuphos was applied. This demonstrates the importance of corm management/treatment practices for reducing pest infestation and plantain damage. Hence, the more farmers ignore the use of insecticidal solutions or plant biomass materials on their farm, the more the farm is exposed to high infestation and nutrient deficiency, which eventually result in dead plants and low yield.

5. CONCLUSION

Wood Ash and OPBRA increased plantain growth and reduced damage by the borer weevils. However, when combined with Terbuphos and applied on corms before planting, wood Ash demonstrated better performance. considering the fact that there is no locally available commercial agrochemical that can be used for both seed treatment and pest control while simultaneously supplying nutrients to the soil and stimulating plant growth, the combination of Ash and Terbuphos as corm treatment before planting is the best-bet sustainable alternative for controlling banana weevils, improving soil characteristics and stimulating plant growth as compared to their sole application forms. Therefore, the results show the incorporation of two important concepts; integrated pest management and integrated soil fertility management to enhance productivity of smallholder plantain production systems in sub-Saharan Africa.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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