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Economic Evaluation of Weed Control and Herbicide Residues on Cassava (*Manihot esculenta* Crantz) in Ghana

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Abstract

A study on economic evaluation of some weed management strategies and herbicide residues analysis on roots of cassava (*Manihot esculenta* Crantz) was conducted during 2014 and 2015 cropping season in Kumasi, Ghana. Cost and benefits were computed from the use of two manual weedings (hoeing and cutlassing), two pre-emergence herbicides (Butachlor 60% EC and Terbulor 500 EC) with two-supplemenatary hoe weeding, weed-free and weedy check. These were evaluated using two varieties of cassava, Ampong (Early branching) and Dokuduade (Late branching). The treatment was a factorial laid out in a randomized complete block design (RCBD) with four replicates. Partial farm budgeting were used for economic analysis of data and herbicide residues analysis in roots of cassava were determined using Gas Chromatography-Electron Capture Detector (GC-ECD). Results showed that Terbulor 500 EC with two supplementary hoe weeding was more economical, profitable and beneficial than those other treatments applied in the production of cassava. In addition, the average concentration of Terbulor 500 EC (0.003 mg/kg) and Butachlor 60% EC (0.001 mg/kg) residues in roots of cassava varieties were below the maximum residue limit (MRL) of 0.01 mg/kg set by Ghana Standards Authority for cassava. In conclusion, Terbulor 500 EC with two supplementary hoe weeding was more effective and financially rewarding and both herbicides had lower residual effects on cassava.

Keywords: cassava, economic evaluation, herbicide residues, weed control

1. Introduction

Cassava (*Manihot esculenta* Crantz) is grown nearly by every farming family in Ghana and it is used as animal feed, source of income, agro-industrial uses and accounts for a daily calories intake of 30% (Food and Agricultural Organization [FAO], 2006; Iyagba, 2010).

Hand pulling, hand slashing and hoeing are the most widespread weed control methods used by subsistence farmers in Africa (Chikoye et al., 2002), but proved to be inefficient due to drudgery, time consuming, labour intensive and expensive (Vissoh et al., 2004; Ekeleme, 2013). Herbicides are effective when applied to young and actively growing weeds, but less than 5% use of herbicides are adopted by smallholder farmers in Africa (Overfield et al., 2001; Udensi et al., 2012). Thus, it could be attributed to poor communications among farmers, extension agents and researchers (Ellis-Jones et al., 2003). In Ghana, weed control is one of the greatest constraints for subsistence cassava farmers. Chikoye et al. (2004), reported that crop losses are due to untimely weeding and 50% of yield reduction in cassava production was due to late and insufficient weeding (IITA, 2007). Herbicides are manufactured under strict regulations to reduce impact on human health and the environment, but only 1% of these herbicides are effective and 99% of their residues could be a threat to the environment, human beings, wildlife and other non-target organisms (Zhang et al., 2011; Eskenazi et al., 2008). Herbicide residues in crops are unavoidable even when applied correctly, thus serious concerns have been raised about health risks resulting from herbicide residues in food items by the environmentalists, consumers, producers, processors and marketers (Darko & Acquaah, 2007; Damalas & Eleftherohorinos, 2011).

Thus, the ultimate objectives of this study were to evaluate economic profitability of some weed management strategies and determine herbicide residues in roots of cassava.

2. Materials and Methods

The experiment was conducted at Crop and Soil Sciences crop field, Kwame Nkrumah University of Science and Technology Kumasi, located on Latitude 06°43′N and Longitude 01°36′W. The rainfall pattern of the experimental area was bimodal, which tolerates two cropping seasons within a year. The climatic weather conditions observed during the experimental period were mean annual temperature of 28.9 °C, 1450 mm rainfall and 84.4% relative humidity.

A tractor was used to slashed, plough and harrowed two weeks later and plots lay out. Plot sizes were 4 m × 6 m with 0.5 m between plots and 1 m between replications. Stem cuttings of 20 cm long were planted on the flat at a spacing of 1 m × 1 m. Terbulor 500 EC and Butachlor 60% EC (Pre-emergence herbicides) were applied at a rate of 4 l/ha a day after planting using a CP3 knapsack sprayer.

2.1 Experimental Design and Treatments

The experiment was a factorial with treatments arranged in a randomized complete block design (RCBD) with four replicates. Six weed control methods: Butachlor 60% EC (4 l/ha) with two supplementary hoe weeding (2 and 4 months after planting), Terbulor 500 EC (4 l/ha) with two supplementary hoe weeding (2 and 4 months after planting), Three hoe weeding (1, 2 and 4 months after planting), Three cutlass weeding (1, 2 and 4 months after planting), weedy check and weed-free (Weeding fortnightly) were evaluated under two varieties of cassava (Ampong-Early branching and Dokuduade-Late branching).

2.2 Data Collection and Crop Products Extraction

Data on weed biomass and density were assessed within 0.25 m^2 quadrats thrown thrice randomly in each plot. Data was also collected on yield, cost of weed control methods and total returns of various weed management strategies. In addition, 2 kg of plant samples were collected eleven months after planting from plots sprayed with Butachlor 60% EC and Terbulor 500 EC herbicides for residual analysis. Soils adhering to roots was brushed, rinsed with distilled water, chopped and blended using a grinder. Each of the 10.0±0.1 g comminuted homogenous samples was placed in a 50 ml centrifuge tube and 10 ml of acetonitrile added and vortex for 1 minute. A mixture of 4±0.2 g Magnesium Sulphate Anhydrous, 1±0.05 g Sodium Chloride, 1±0.05 g Trisodium Citrate Dehydrate and 0.5±0.03 g Disodium Hydrogencitrate Sesquihydrate were added and immediately vortex for 1 minute and centrifuged for 5 minutes at 300 U/minute. A 6 ml aliquot of each extract was transferred into a polypropylene (PP) centrifugation tube, which contains 150 mg Primary-Secondary Amine (PSA) and 900 mg Magnesium Sulphate. The tube was closed and shaken vigorously for 30 seconds and centrifuge for 5 minutes at 300 U/minute. The 4 ml of each cleaned extract was transferred into a round bottom flask and the pH was quickly adjusted to about 5.0 by adding 40 µl of 5% Formic Acid solution in Acetonitrile (v/v). The filtrate was concentrated below 40 °C on the rotary evaporator just to dryness and re-dissolved by adding 1 ml of Ethyl Acetate using pipette. The extracts were then transferred into a 2 ml standard opening vial for measurement by the Gas Chromatography-Electron Capture Detecor (GC-ECD).

The Gas Chromatography-Electron Capture Detector (GC-ECD) was used to analyse herbicide residues extracted from roots of cassava. In addition, economic assessments of various weed control measures were analysed using Joshua and Gworgwor (2001) formulas:

$$\text{Sales revenue} = \text{Root yield (t/ha)} \times \text{Prevailing market price (GH¢/ha)} \tag{1}$$

$$\text{Net revenue} = \text{Sales revenue - Total cost of production} \tag{2}$$

$$\text{Cost-benefit ratio (CBR)} = \text{Total cost of production/Sales revenue} \tag{3}$$

$$\text{Yield increase over weedy check} = \frac{Y_t - Y_c}{Y_t} \times 100 \tag{4}$$

Where, Y_t is Yield of cassava in t/ha of treatment and Y_c is yield of weedy check in t/ha. Yields obtained were sold at the prevailing market price of GH¢ 251 per tonne in Kumasi.

2.3 Data Analysis

Data from yield, weed density and biomass were subjected to ANOVA using the PROC GLM procedure in SAS version 9.3 (SAS Institute Inc, Cary, NC) and means were separated using the Student Newman-Keuls (SNK) multiple range test at 5% probability ($p < 0.05$).

3. Results and Discussion

3.1 Weed Management Strategies on Yield, Weed Density and Biomass in Dokuduade Production

The results in Table 1 showed that Terbulor + 2 hoe weeding produced significantly the highest yield (22.81 t/ha) with 65.49% yield increase over weedy check treatment, which was comparable to weed-free and Butachlor plus two hoe weeding treatments. Cutlass weeding recorded the least percentage yield increase (23.66%) over weedy check, while the lowest yield (7.87 t/ha) was produced under weedy check treatment. The higher yields observed in plots sprayed with Terbulor + 2 hoe weedings could be attributed to non-photoxic effect of the herbicide which led to better utilization of growth resources than other treatments. The result agrees with P. M. Olorunmaiye and K. S. Olorunmaiye (2009), who reported that yield of cassava significantly increase when pre-emergence herbicide was supplemented with two hoe weeding. In addition, total weed density (5.75 m^2) and biomass (9.72 g) were significantly lower in Terbulor + 2 hoe weeding, which shows effectiveness over hoe and cutlass weeding methods. This result agrees with the report of low weed density and biomass by Mahadi et al. (2007). Hoe weeding significantly recorded lower weed density (8.75 m^2) and biomass (18.35 g) than cutlassing (Table 1), which could be attributed to rapid growth of nodes on stems partly cut-off under cutlass weed control method. However, weedy check treatment had significantly greater weed density (32.00 m^2) and biomass (37.34 g) than other control methods evaluated in this study.

Table 1. Effect of weed management strategies on yield, weed density and biomass in Dokuduade production

Treatment	Yield (t/ha)	Weed density (m^2)	Weed biomass (g)
Hoe weeding	14.75^{bc}	8.75^{d}	18.35^{cb}
Cutlass weeding	10.31^{cd}	22.00^{b}	26.97^{b}
Weed-free	20.00^{ab}	7.27^{d}	12.45^{c}
Butachlor + 2 hoe-weeding	16.93^{ab}	13.50^{c}	20.75^{cb}
Terbulor + 2 hoe-weeding	22.81^{a}	5.75^{d}	9.72^{c}
Weedy	7.87^{d}	32.00^{a}	37.34^{a}

Note. Means within columns with no common letter (s) are significantly different according to Student Newman-Keuls (SNK) multiple range test at 5% probability ($p < 0.05$).

3.2 Weed Management Strategies on Yield, Weed Density and Biomass in Ampong Production

Terbulor + 2 hoe weeding had significantly higher yield (35.12 t/ha) which was comparable to weed-free (32.31 t/ha) but significantly higher than other weed control methods (Table 2). Terbulor + 2 hoe weeding recorded 72.09% yield increase over weedy check treatment, while cutlassing had the lowest percentage yield increase (32.69%) over weedy check. In addition, weedy check significantly produced the lowest yield (9.80 t/ha), which could have been due to intense weed competition with the crop. There was no significant difference between weed-free and Butachlor + 2 hoe weeding treatment effect under yield. However, hoe weeding significantly produced maximum yield (22.18 t/ha) than cutlass weed control method (14.56 t/ha), which could be attributed to the effectiveness of hoeing method that led to reduced weed competition thus higher yield. Terbulor + 2 hoe-weeding significantly reduced weed density (3.00 m^2) and biomass (2.40 g) which is comparable to weed-free treatment (Table 2). This could have been due to the phytotoxic effect of this treatment on weed density and biomass. In addition, weedy check recorded significantly maximum weed density (27.80 m^2) and biomass (35.20 g) than other weed management strategies (Table 2).

Table 2. Effect of weed management strategies on yield, weed density and biomass in Ampong production

Treatment	Yield (t/ha)	Weed density (m^2)	Weed biomass (g)
Hoe weeding	22.18^{bc}	6.25^{cd}	5.60^{c}
Cutlass weeding	14.56^{cd}	17.00^{b}	24.27^{b}
Weed-free	32.31^{ab}	4.25^{d}	4.20^{c}
Butachlor + 2 hoe-weeding	28.06^{ab}	9.50^{c}	13.17^{c}
Terbulor + 2 hoe-weeding	35.12^{a}	3.00^{d}	2.40^{c}
Weedy	9.80^{d}	27.80^{a}	35.20^{a}

Note. Means within columns with no common letter (s) are significantly different according to Student Newman-Keuls (SNK) multiple range test at 5% probability ($p < 0.05$).

3.3 Economic Assessment of Weed Control Methods in Dokuduade Cassava Production

Terbulor + 2 hoe weeding had the highest sales revenue (5725.31 GH₵/ha) and net revenue (5448.40 GH₵/ha) compared to three hoe weeding and other treatments, which could have been due to higher crop value and lower cost of production (Table 3). The weedy check treatment recorded the lowest sales and net revenues (1975.37 GH₵/ha) compared to the other weed management startegies evaluated in this study. Similarly, Khan et al. (2005) and Imoloame et al. (2010) reported herbicide use to be more profitable than hoe weeding in the production of various crops. This result also agrees with the report of Chikoye et al. (2002) that chemical weed control in cassava was cheaper than hoe weeding. The highest cost of production (830.74 GH₵/ha) was observed under weed-free treatment followed by three hoe weeding (553.82 GH₵/ha), which could be attributed to high cost of labour/ha than the cost of buying herbicides required to spray an equivalent area. Terbulor + 2 hoe weeding recorded the lowest (1:0.04) cost-benefit ratio followed by Butachlor 60% EC + 2 hoe weeding (1:0.07) compared to hoe weeding and other treatments. The lowest cost-benefit ratio recorded by Terbulor + 2 hoe weeding indicates that the use of herbicides are more beneficial and economical than hoe and cutlass weeding in the production of Dokuduade variety. This result confirms the report of Joshua and Gworgwor (2001) that herbicide use are more profitable than hoe weeding in the production of varous crops. In addition, Nazeer et al. (2004) similarly reported optimum cost-benefit ratio with the application of herrbicides compared to weedy check and other weed control methods.

Table 3. Economic assessment of weed management strategies in the production of Dokuduade variety

Treatment	Yield (t/ha)	Total cost of production (GH₵/ha)	Sales revenue (GH₵/ha)	Net revenue (GH₵/ha)	Cost benefit ratio (CBR)
Hoe weeding	14.75	553.82	3702.25	3148.43	1:0.14
Cutlass weeding	10.31	484.60	2587.81	2103.21	1:0.18
Weed-free	20.00	830.74	5020.00	4189.26	1:0.16
Butachlor + 2 hoe-weeding	16.93	311.53	4249.43	3937.90	1:0.07
Terbulor + 2 hoe-weeding	22.81	276.91	5725.31	5448.40	1:0.04
Weedy	7.87	0.00	1975.37	1975.37	-

3.4 Economic Assessment of Weed Control Methods in Ampong Cassava Production

Table 4 shows the cost-benefit analysis for the production of Ampong variety under some weed management strategies. The highest sales revenue (GH₵/ha 8815.12) and Net revenue (GH₵/ha 8538.21) was recorded under Terbulor + 2 hoe weeding, while the lowest (GH₵/ha 2459.80) was observed under weedy check treatment. This result agrees with Kehinde (2002), who reported optimum net returns obtained with the application of herbicides compared with the other weed control methods. The cost benefit ratio was lower (1:0.03) under Terbulor + two hoe weeding followed by Butachor + two hoe weeding (1:0.04), while Cutlass weeding recorded the highest cost-benefit ratio (1:0.13). This agrees with the report of Joshua and Oni (2002) that herbicide use is more profitable than hoe weeding in the production of various crops. In addition, Weed-free (weeding fortnightly) treatment resulted in the highest total cost of production for both varieties followed by hoe weeding. This result confirms the report of Adigun and Lagoke (2003) that hoe weeding is costly.

Table 4. Economic assessment of weed management strategies in the production of Ampong variety

Treatment	Yield (t/ha)	Total cost of production (GH₵/ha)	Sales revenue (GH₵/ha)	Net revenue (GH₵/ha)	Cost benefit ratio (CBR)
Hoe weeding	22.18	553.82	5567.18	5013.36	1:0.09
Cutlass weeding	14.56	484.60	3654.56	3169.96	1:0.13
Weed-free	32.31	830.74	8109.81	7279.07	1:0.10
Butachlor + 2 hoe-weeding	28.06	311.53	7043.06	6731.53	1:0.04
Terbulor + 2 hoe-weeding	35.12	276.91	8815.12	8538.21	1:0.03
Weedy	9.80	0.00	2459.80	2459.80	-

3.5 Herbicide Residues Analysis

Plots sprayed with Terbulor 500 EC (4 l/ha) and Butachlor 60% EC (4 l/ha) recorded lower concentration of residues 0.003 mg/kg and 0.001 mg/kg repectively in both varieties of cassava, while herbicide residues were not detected in control treatments (Table 5). The average concentration of Terbulor 500 EC (0.003 mg/kg) and Butachlor 60% EC (0.001 mg/kg) in these varieties were below the maximum residue limit of 0.01 mg/kg in cassava set by Ghana Standards Authority. This result agrees with the report of Rao et al. (2012) that Butachlor residues detected in rice grain were below the maximum residue limit of 0.5 mg/kg.

Table 5. Analysis of herbicide residues in roots of cassava

Sample code	Cassava variety	Concentration (mg/kg)	Test conducted	Maximum residue limit (mg/kg)
BUT	Ampong and Dokuduade (Control)	-		
	Ampong and Dokuduade (Treated)	0.001	Butachlor	0.01
TER	Ampong and Dokuduade (Control)	-		
	Ampong and Dokuduade (Treated)	0.003	Terbulor	0.01

4. Conclusion

Terbulor 500 EC with two supplementary hoe weeding significantly increase yield, sales and net revenues and lower cost-benefit ratio for both varieties. Thus, found to be more profitable, economical and beneficial making it a potential alternative to those other weed control methods. Better weed control was obtained in plots where Terbulor was supplemented with two hoe weeding and Ampong variety. Weed-free and hoe weeding treatments resulted in the highest cost of production for both varieties than other weed control methods. Samples of cassava extracted and analysed contain relatively low concentration of herbicide residues. In addition, it is profitable and economical to produce Ampong than Dokuduade variety due to maximum yield, cost-benefit ratio, sales and net revenues.

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