Research Article

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Direct financial cost of weed control in smallholder rubber plantations

Abstract: A survey was conducted to provide information on weed types, control strategies, and their estimated costs to smallholder rubber outgrowers in Western Ghana. A total of 80 farmers with rubber trees aged 1–4 years were randomly selected for the study. This represents 10.2% of the total number of farmers (783) who fall within this target group in the districts. The results show that smallholder rubber plantation farmers are dealing with diverse weed species, most of which are reported as global weeds. *Chromolaena odorata*, *Scleria boivinii*, and *Mimosa pudica* were the most reported species. Manual weeding and application of herbicides are the major control methods adopted by the farmers in the study area with a small percentage (16%) also using cover cropping. The two major control methods cost farmers an estimated average amount of Ghc 618.24 ± 26.25 (US \$140.51 ± 5.91) for one-time weed control per hectare. The average estimated cost of one-time manual weeding per hectare was higher than that of herbicide application per hectare. This estimated amount is only a fraction of the total economic cost of weeds to the farmers. The farmers are likely to spend more if, for example, the costs of yield loss due to weeds are captured. The study thus indicates that the cost of weed management is high for rubber outgrowers and essentially farmers are investing heavily in weed management to keep weed competition on-plantation relatively low. Given that the core objective of rubber growing is to maximize profits, this study recommends the application of herbicides to control weeds in rubber plantations since average estimated cost of herbicide application per hectare was lower than one-time manual weeding per hectare. This recommendation should, however, be weighed against the possible environmental impact of herbicides, which was not assessed in this study.

Keywords: plantation cost, rural household, sustainable development, weed control, rubber estate

1 Introduction

Globally, smallholder rubber plantation developers (herein referred to as farmers) are estimated to contribute to over 80% of the production of natural rubber (Diaby et al. 2013). Unfortunately, majority of these farmers in most rubber producing countries are struggling to maintain their farms mostly due to limited access to capital and inputs (Gouyon et al. 1993; Dove 2002; Liu et al. 2006; Fox and Castella 2013; Nath et al. 2013). A huge investment in planting and maintenance is required at the initial stage to ensure healthy rubber trees and high quality latex (Goswami and Challa 2007). In the current study area, for example, data from the Ghana Rubber Estate indicate that for the first 4 years, a farmer spends about Ghc 5,860 (US \$1,331.81) as the maintenance cost per hectare of rubber plantation (600 trees) (ROPP 2019). This includes cost of weed control, fertilizer application, and pruning. Although some farmers intercrop with rice, maize, and other crops to obtain income, this is not able to offset the cost of maintaining the rubber plantation (Manivong 2007; Fox and Castella 2013).

Weeds, defined as plants growing where they are not wanted, are one of the major worries of smallholder rubber farmers, especially before canopy closure, due to their manifold impacts on farms (Yogaratnam et al. 1991; Gouyon et al. 1993; Goswami and Challa 2007). They compete with young rubber plants (seedlings and saplings) for resources including soil moisture, light, and nutrients.

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They also act as hosts for many pests and diseases of rubber and sometimes contain growth-suppressing substances. Furthermore, the stress that is caused by weeds can increase the crop's susceptibility to attacks from pests and diseases. Thus, weed interference reduces the growth of young rubber plants, consequently increasing the time required for the plants to reach maturity. *Imperata cylindrica*, for example, could reduce the growth of rubber crops, especially at the immature stage, by up to 50% (Grist et al. 1998). Smallholder farmers thus spend a substantial part of their effort and resources, implementing effective weed control to ensure low mortality, fast early growth, and increased productivity (Goswami and Challa 2007; Benny et al. 2016; Llewellyn et al. 2016; Saunders et al. 2017). In West Garo Hills in India, for instance, weed control constituted 8.72% of the total maintenance cost and 2.68% of the total cost of rubber production. It was also the second highest labour-intensive operation after tapping (Goswami and Challa 2007).

Although weed control presents one of the major maintenance costs to smallholder rubber plantations, there has been very little research on the economics of weed control, particularly the direct costs of weed control under young rubber trees, in most countries (Goswami and Challa 2007; Manivong 2007). Available information is mostly from Asia, where the bulk of rubber plantations are situated. In countries such as Ghana, where the rubber industry is not yet fully developed (for more background on rubber cultivation in Ghana see Lambert 2016), there is limited information on the cost dynamics of rubber plantation development, especially cost related to weed control. This limits our ability to apply cost–benefit analysis to different control methods to develop cost-effective weed management strategies for smallholder rubber plantations in such countries (Llewellyn et al. 2016; Saunders et al. 2017).

The Rubber Outgrower Plantation (ROP) project used for this study is a smallholder scheme managed by The Ghana Rubber Estates Limited (GREL) with support from the Government of Ghana, banks, and development partners (Delarue 2009; Paglietti and Sabrie 2012). GREL provides farm inputs including seedlings, fertilizers, cover crops, extension services, and other technical assistance to support the farmers to develop their plantations. GREL funds 50% of the cost of these technical assistance from its own resources and charges the balance to farmers, deducting it from the payments it makes for their rubber (supply of cup lumps) (Delarue 2009; Paglietti and Sabrie 2012). With loans from national banks, the farmers cover other maintenance costs but are required to sell their rubber exclusively to GREL. The ROP project is currently in its fifth phase and has 2,202 farmers who have farms of age 1–4 years in the Western Region (Plantation manager, January 2018, personal communication).

For ROP and similar projects around the world to be sustainable, particularly in developing countries, more information on common weeds of young rubber plantations and the costs of available control strategies are essential. With this viewpoint, the current study was conducted to contribute to bridging this information gap by addressing the following research questions: (1) What common weed species are smallholder rubber plantation farmers in the Western Region of Ghana dealing with? (2) What weed control methods are being used by smallholder rubber plantations and how significant are their cost to farmers? The results are expected to stimulate general awareness of weed issues, influence decisions, and serve as a reference tool for planners, policymakers, and financial institutions in formulating suitable policy packages for smallholder rubber plantation programmes.

2 Weed management in plantations

Weeds compete with young plants in plantation; they also act as hosts for many pests and diseases and sometimes contain growth-suppressing substances. Furthermore, the stress that is caused by weeds can increase the crop's susceptibility to attacks from pests and diseases. Thus, weed interference reduces the growth of young plantation plants, consequently increasing the time required for the plants to reach maturity (Yogaratnam et al. 1991; Gouyon et al. 1993; Goswami and Challa 2007). Farmers therefore rely on diverse weed control approaches before and after planting as effective means to improve tree growth, soil characteristics, and eventually profitability (Tu et al. 2001; Stringer et al. 2009).

Weeds also present economic cost to the farmers. The cost of weed control in plantation development is a function of the direct financial costs such as yield losses or downgrades, reduction in quality and price and cleaning costs from plant contamination plus expenditure for weed control, and the opportunity cost of lost production. These costs in monetary terms are very substantial both to the farmer and national economies at large. For example, in 2014 a conservative estimate that focused on only the loss of production of crops in New Zealand for some weed species was NZ $1,658 million (~US $1,442 million, 2014 rate) (Saunders et al. 2017). When the total costs were considered in Ethiopia, Kenya, Malawi, Rwanda, Tanzania, and Uganda, the annual loss incurred by smallholder maize farmers due to the impacts of five
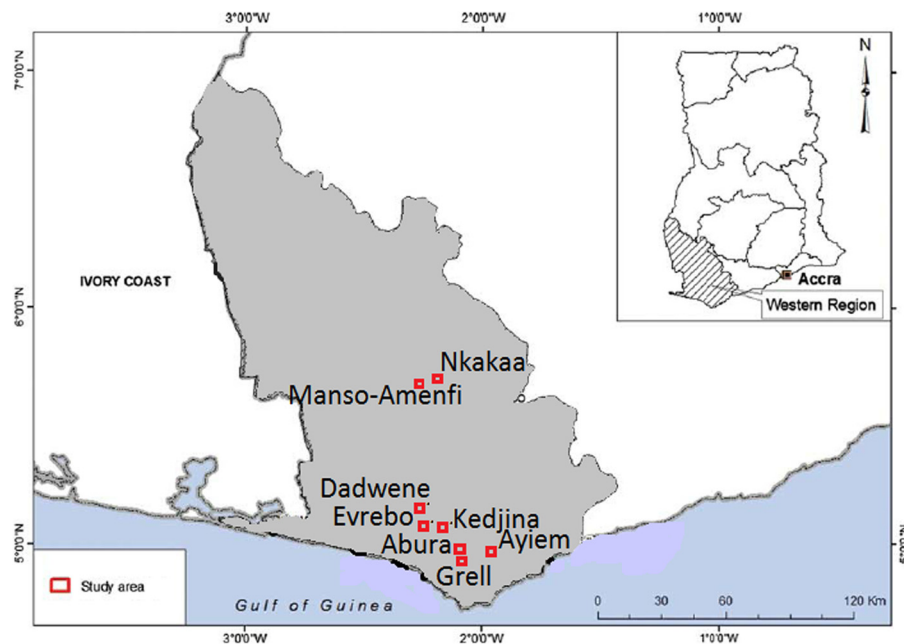
Figure 1: Map of Ghana showing Western Region and the eight selected communities.

major invasive species, including *Parthenium hystero-phorus*, was estimated to be US $0.9–1.1 billion (Boy and Witt 2013). Similarly, in Australia, the total cost of weeds (revenue loss plus expenditure) to Australian grain growers was estimated to be Au $3,318 million (~US $2,522 million, 2016 rate) (Llewellyn et al. 2016). In Ghana, the Environmental Protection Agency and the Volta River Authority together spend over US $2,327,038 per year for controlling waterweeds (MESTI 2014).

In weed management, all farmers weigh the benefits gained in the form of yield (or other useful products) against the things lost (cost) in the form of labour and cash given up (Emerton and Howard 2008). They consider the cost of changing from one practice to another and the economic benefits resulting from that change. For instance, they recognize that if they eliminate weeds from their field, they are likely to benefit by having improved yield. On the other hand, they realize that they must give up a lot of time and effort for manual

and mechanical weed control methods, or that, alternatively, they must give up some cash to purchase herbicides and then expend some time and effort to apply them.

3 Materials and methods

3.1 The survey

We randomly selected 23% of the districts (3 out of the 13 districts) in the Western Region with farmers having rubber trees aged 1–4 years and working in partnership with GREL. We considered only the first 4 years because this is the period that farmers actively control weeds in the rubber plantations. After 4 years, there is canopy closure and the resulting shade limits weed growth. All the communities from these three districts with farmers within this category were then listed and eight were randomly selected (Figure 1). This number was based on logistical and time constraints. The list of targeted farmers from these eight communities was obtained from GREL, and respondents were randomly selected from the list. A total of 80 farmers, representing 10.2% of the total number of targeted farmers (783) in the districts, were selected for the studies (Table 1).

Household heads or persons nominated by the family/household members served as respondents of the survey, which took place between January and February 2018.

Table 1: Distribution of smallholder farmers across the three selected districts in the Western Region of Ghana

District	Number of farmers selected	Total number of farmers
Ahanta West	25	134
Amenfi Central	27	193
Nzema East	28	456
Total	**80**	**783**

A face-to-face administration of structured questionnaires was used to obtain information from the respondents. Information obtained include demographic characteristics of farmers, common weeds on farms, weed control methods and their relative cost of application, frequency of control, and plantation sizes. Respondents were asked to list the five most common troublesome weeds in their farms and the challenges they currently face. We ranked these challenges and the weed list based on the percentage of farmers who mentioned a particular challenge or weed.

Informed consent: Informed consent has been obtained from all individuals included in this study.

Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance with the tenets of the Helsinki Declaration, and has been approved by Department of Silviculture and Forest Management, KNUST, Research Ethics Committee.

3.2 Estimation of cost

The cost of weed control in rubber production is a function of the direct financial costs and the opportunity cost of lost production. The current study only measured the direct financial cost, considering the whole weed community and not specific species. In the study area, GREL recommends four times of weed control in the first year (three times manual weeding and one-time herbicide application), three times in year 2 (two times manual weeding and one-time herbicide application), twice in year 3 (one-time manual weeding and one-time herbicide application), and once in year 4 (manual weeding). We used the April 2018 exchange rate of the US $ to Ghana cedis (Ghc) in all our conversions (1 dollar to 4.4 Ghc).

3.3 Manual or hand weeding cost

3.3.1 Weeding cost per hectare (W_C)

Here manual weeding includes mechanical uprooting and use of cutlass and hoes for the removal of weeds. Each farmer's cost of weeding per hectare (once a year) was estimated by determining the hired labour cost for weeding per hectare of farm (W_C). This amount was

directly obtained from the interviews and confirmed from farm labourers. In the study areas, the labourers are not hired on yearly basis nor are they paid on a daily basis. They usually take the job on contract basis and charge per hectare. So the total amount paid by the farmer is based on the farm size. The use of labour input from family members in the control of weeds was negligible in the study area.

The average cost of weeding per hectare (aW_C) (once in a year) for a farmer in the study area was estimated by summing each farmer's cost of weeding per hectare, i.e. the hired labour cost for weeding per hectare of farm (W_C) for all farmers and then dividing by the total number of respondents engaged in manual weeding (see equation (1)):

$$aW_C = \frac{\sum W_C}{N}, \qquad (1)$$

where N is the total number of respondents who use manual weeding as a weed control measure.

3.4 Cost of herbicide application

3.4.1 Herbicide application cost per hectare

Each farmer's cost for herbicide application per hectare (H_C) (once a year) was estimated by adding the product of "cost of a bottle of herbicide" and "number of bottles of herbicides used per hectare" to the "per hectare cost of hiring labour to apply the herbicide." The price of a bottle of herbicide was estimated based on the national averages obtained from leading agro-chemical shops.

Equation (2) was used to estimate the average herbicides cost per hectare (aH_C) for one-time application in a year:

$$aH_C = \frac{\sum H_C}{N}, \qquad (2)$$

where N is the total number of respondents who use herbicides as a weed control measure.

3.5 Total financial cost of weed control per hectare

The total financial cost of one-time weed control per hectare (F_C) was obtained by summation of the one-time cost of weeding per hectare (W_C) and one-time cost for herbicide application per hectare (H_C). The average total financial cost per hectare (aF_C) for one-time manual weeding

Table 2: Sociodemographic characteristics of smallholder out-growers surveyed from eight communities in the Western Region of Ghana (*n* = 80), the challenges they faced in their plantations, weed control method employed, and their frequency per year

Variables	Percentage of respondents
Education level	
None	25
Basic	10
Junior high school	40
Senior high school	14
Tertiary	11
Sex	
Female	24
Male	76
Age (years)	
<30	9
30–39	29
40–49	26
50–59	19
>59	17
Age of plantation (years)	
1	27
2	25
3	25
4	23
[a]**Challenges faced in plantation**	
Disease	42
Monetary	25
Beating up	30
Weeds	100
Termites	60
Fertilizer	15
[a]**Weed control method**	
Weeding	100
Herbicides	84
Use cover cropping	16
Weed control frequency per year	
Once	1
Twice	15
Thrice	59
Four times	25

[a] Respondents selected more than one option.

and one-time herbicide application for a farmer in the study area was estimated by using equation (3):

$$aF_C = \frac{\sum (W_C + H_C)}{N} \qquad (3)$$

3.6 Statistical analysis

We analysed data collected from the field with SPSS. Sociodemographic data on the farmers, weed species, control strategies, and their estimated costs to smallholder farmers were summarized and tabulated. We tested for the effect of different socioeconomic factors on the estimated per hectare cost for the different weed control strategies using one-way ANOVA. The estimated costs were log transformed. All assumptions for the test including normality, linearity, and homoscedasticity were assessed to ensure no violation.

4 Results

4.1 Demography of respondents

We surveyed more men (76%) than women (24%). Respondents were mainly over 30 years old (91%) and majority (80%) have formal education (Table 2). The farm size (rubber plantation only) of the respondents ranges from 0.5 to 13.5 hectares with an average of 2.2 ± 0.2 hectare. The total farm size (rubber plantation only) for all the 80 respondents was 178.3 hectare. The age of the farms of the respondents ranged from 1 year to 4 years with a mean age of 2.4 ± 0.1 years. When asked of the major challenges faced in their plantations all the respondents indicated weeds to be the major challenge followed by termites (60%) and disease (42%) (Table 2).

4.2 Common troublesome weeds of the rubber plantations

Table 3 provides a list of the 16 species reported by the respondents as common troublesome weed species in their plantations. The species belong to 11 families and were mostly perennial herbs. Majority (75%) of the species are classified as global agriculture or environmental weeds as per the global compendium of weeds (Randall 2017). The most reported species were *Chromolaena odorata*, reported by 81% of the respondents; *Scleria boivinii* by 39%; and *Mimosa pudica*, reported by 31% of the respondents.

4.3 Weed control practices and their associated cost

Manual or hand weeding and use of herbicides were the two major weed control practices adopted by the farmers,

Table 3: Common weed species troubling smallholder farmers in Western Ghana

Species	Family	Life span	Life form	Global Weed	Status in Ghana	% of respondents who identified each weed as a challenge[a]
Chromolaena odorata	Asteraceae	P	Herb	Y	Alien	81
Ageratum conyzoides	Asteraceae	P	Herb	Y	Alien	29
Momodica boivinii	Cucurbitaceae	P	Shrub	N	Native	21
Scleria boivinii	Cyperaceae	A	Sedge	Y	Native	39
Alchornea cordifolia	Euphorbiaceae	P	Tree	Y	Native	16
Mimosa pudica	Fabaceae	P	Herb	Y	Alien	31
Pueraria phaseoloides	Fabaceae	P	Herb	Y	Alien	18
Centrosema pubescens	Fabaceae	P	Herb	Y	Alien	16
Amphimas pterocarpoides	Fabaceae	P	Tree	N	Native	23
Griffonia simplicifolia	Fabaceae	P	Shrub	Y	Native	17
Anthocleista nobilis	Loganiaceae	P	Tree	N	Native	16
Sida acuta	Malvaceae	P	Herb	Y	Native	24
Thaumatococcus daniellii	Marantaceae	P	Herb	Y	Native	19
Eleusine indica	Poaceae	A	Grass	Y	Native	30
Urera rigida	Urticaceae	P	Shrub	N	Native	16
Lantana camara	Verbenaceae	P	Shrub	Y	Alien	29

Life span: A – annual, P – perennial; global weed: Y – yes, N – no, global weeds according to Randall (2017).

[a] Respondents could mention more than one species.

with a few also using cover cropping (Table 2). Cover cropping was only common after year 1 of the plantation establishment and the crops were given to them free by GREL. Overall, more than half (59%) of the farmers indicated that they use this combined approach thrice a year (manual weeding two times and one-time herbicides) (Table 2).

4.3.1 Cost associated with manual or hand weeding

Weeding includes removal of all plants likely to compete with and suppress trees in young plantations. All respondents indicated that they use manual weeding to control weeds in their farms, with frequency of weeding in a year ranging from one to four times, and a mean of 2.3 ± 0.1 times per year. The cost of one-time manual weeding per hectare per farmer ranged from Ghc 100 (US $22.73) to Ghc 900 (US $204.55) with an estimated average cost (using equation (1)) of Ghc 332.24 ± 16.33 (US $75.51 ± 3.71) (Table 4).

Overall, average estimated cost of one-time manual weeding per hectare was not influenced by the age of the plantation [$F_{(3,76)} = 2.390$, $p > 0.05$], gender of farmer [$F_{(1,78)} = 1.684$, $p > 0.05$], and education level of respondents [$F_{(4,75)} = 0.94$, $p > 0.05$] (Table 5). It was, however, influenced by the district where the plantation is located [$F_{(2,77)} = 3.421$, $p < 0.05$] with farmers in Amenfi Central spending more than those in the other districts (Tables 4 and 5).

4.3.2 Cost of herbicide application

The common herbicides used by farmers are glyphosate and paraquat derivatives such as Gramozone, Sunphosate, Adwuma wura, and Ogyatanaa. Majority (84%) of the farmers indicated that they apply herbicides on their farms to control the spread of weed species (Table 2). Application of herbicides depended on the age of the plantation, with 59, 85, 95, and 100% of farmers who have plantations aged 1, 2, 3, and 4 years, respectively, indicating that they use herbicides. All the respondents reported to apply herbicides only once per year, usually in the dry season, due to high labour and herbicide costs. The estimated cost of herbicide application per hectare ranged from Ghc 120 (US $27.27) to Ghc 720 (US $163.64) with an average per hectare cost (using equation (2)) of Ghc 286 ± 13.86 (US $65 ± 3.15). The average cost of application of herbicides per hectare was only influenced by the district where a farm is located [$F_{(2,64)} = 12.182$, $p < 0.05$] (Table 5), with cost of herbicide application being higher in Amenfi Central (Table 4).

4.3.3 Total financial cost of weed control

Overall, the average total financial cost of one-time weed control per hectare per farmer (using equation (3)) was Ghc 618.24 ± 26.25 (US $140.51 ± 5.91). Farmers with 2-year

Table 4: Average financial cost of one-time weed control incurred by smallholder rubber plantation farmers in the Western Region of Ghana. All amounts are in (Ghc)

	Average one-time herbicide application cost per hectare (Ghc)	Average cost of one-time weeding per hectare (Ghc)	Average cost of one-time weed control per hectare (Ghc)
Ahanta West	303.24 ± 26.25	333.48 ± 24.24	636.72 ± 41.69
Year 1	445.67 ± 110.16	333.33 ± 60.09	779.00 ± 169.73
Year 2	268.33 ± 50.09	323.87 ± 40.77	592.20 ± 77.00
Year 3	327.06 ± 24.61	338.38 ± 56.26	665.44 ± 70.35
Year 4	219.33 ± 19.16	336.33 ± 41.66	555.67 ± 50.97
Nzema East	219.30 ± 12.28	272.25 ± 9.66	491.55 ± 18.07
Year 1	276.90 ± 41.45	300.00 ± 16.33	576.90 ± 54.65
Year 2	207.39 ± 17.86	304.72 ± 23.88	512.11 ± 27.79
Year 3	190.56 ± 3.59	245.83 ± 1.18	436.39 ± 3.80
Year 4	204.76 ± 6.46	243.28 ± 15.31	448.04 ± 10.82
Amenfi Central	346.12 ± 25.52	399.28 ± 39.23	745.40 ± 55.59
Year 1	296.75 ± 50.25	324.25 ± 53.12	621.00 ± 64.44
Year 2	445.00 ± 66.52	493.89 ± 111.76	938.89 ± 158.19
Year 3	337.78 ± 31.33	338.56 ± 50.56	676.33 ± 61.42
Year 4	288.50 ± 25.51	415.42 ± 64.77	703.92 ± 79.25
Overall	286.00 ± 13.86	332.24 ± 16.33	618.24 ± 26.25
Year 1	321.96 ± 37.15	315.15 ± 20.60	637.11 ± 50.35
Year 2	309.18 ± 37.07	377.12 ± 45.07	686.29 ± 74.30
Year 3	287.34 ± 20.07	309.21 ± 26.76	596.55 ± 39.98
Year 4	236.72 ± 13.21	326.51 ± 29.53	563.23 ± 38.66

1 US $ = 4.4 Ghc, April, 2018 exchange rate.

plantations spend more on weed control followed by year 1, but these expenses dropped as the age of the trees increased (Table 4).

5 Discussion

Economic losses and costs associated with weeds in smallholder rubber plantations are important for farmers, governments, investors, and for the entire industry, particularly when making decisions about plantation development, investments, and product pricing. This study shows that smallholder rubber plantation farmers in the Western Region of Ghana are dealing with diverse species of weeds, with most of these species reported as global weeds. Although a small percentage of farmers use cover cropping, the study reveals that manual weeding and application of herbicides are the major weed control

method used by the farmers. These two control methods, however, constitute significant cost to farmers.

We estimated an average amount of Ghc 618.24 ± 26.25 (US $140.51 ± 5.91) for one-time weed control per hectare. The actual cost for weed control per hectare for the first 4 years if a farmer follows the GREL recommendation would be Ghc 3,109.78 (US $777.45) (based on the mean cost for each year in Table 5). This amount is about 53% of the total farm maintenance cost incurred by the farmers in the 4 years of the rubber tree. In India, the expenses incurred on weeding during the first 6 years till the plantation come to commercial yielding stage was Rs 6,986.00 (US $179.12, 2007 rate) per hectare, which represents 30.98% (the highest expenditure) of the total cost of establishments (Goswami and Challa 2007). Many of these smallholder rubber plantation farmers from developing countries attempting to control weeds have low incomes and are confronted with other serious financial constraints (Bagnall-Oakeley et al. 1996). If the estimate is made for all the 2,202 farmers working in partnership with GREL and having plantations aged between 1 and 4 years, an amount of Ghc 3,267,398.0 (US $742,590.55) is expected to be spent on one-time weed control in a year for the total of 5,285 hectares they cultivate. This estimate is only from farmers working with GREL; the national estimates would be even higher. Thus, huge financial resources which could have been put into alternative investments are lost to weeds every year, with grievous implications for a developing country such as Ghana.

The average amount for one-time weed control per hectare estimated is only a fraction of the total economic cost of weed to the farmers. The farmers are thus likely to spend more, if, for example, the reduction in yield from weeds (which was not captured here) is included. If this cost is also extrapolated to the national level, it is likely to be very substantial. For example, in 2014 a conservative estimate that focused on only the loss of production of crops in New Zealand for some weed species was NZ $1,658 million (~US $1,442 million, 2014 rate) (Saunders et al. 2017). When the total costs were considered in Ethiopia, Kenya, Malawi, Rwanda, Tanzania, and Uganda, the annual losses incurred by smallholder maize farmers due to the impacts of five major invasive species, including *Parthenium hysterophorus* was estimated to be US $0.9–1.1 billion (Boy and Witt 2013). Similarly, in Australia, the total cost of weeds (revenue loss plus expenditure) to Australian grain growers was estimated to be Au $3,318 million (~US $2,522 million, 2016 rate) (Llewellyn et al. 2016).

The weed control methods identified in the study area are common to all rubber farmers (Yogaratnam et al. 1991). Manual weeding is very effective as it involves selective and gradual removal of weeds around the trees. It is however difficult, time consuming, and expensive compared to herbicide application. In the current study, the average estimated cost of one-time manual weeding per hectare was higher than that of herbicide application per hectare. This is similar to the studies of George and Brennan (2002) who reported that herbicides were the most cost-effective weed control option compared with other alternative weed control methods available to commercial growers of eucalypt plantations. Thus, on the basis of financial expenditure or monetary outlay on the two weed control practices, herbicide application offers a cost-effective means of weed management on rubber plantations. However, herbicides have phytotoxic effect on the rubber plants, affect farmers' health, and impact the environment in general. Indeed, several studies (Buckelew et al. 2000; Ahn et al. 2001; Marshall 2001; Isenring 2010) have elucidated the impact of herbicide application on the environment, especially biodiversity. Isenring (2010) reported that herbicides reduce food sources for birds and mammals, which can result in a substantial decline in rare species populations. By changing vegetation structure, herbicides can render habitats unsuitable for certain species, thereby threatening insects, farmland birds, and mammals. In his work on biodiversity, herbicides, and non-target plants, Marshall (2001) noted that though herbicides provide a useful tool for farmers, they are capable of affecting non-target plants. He maintained that a number of farmland birds, invertebrates, and plants have shown population declines due partly to herbicide application. Currently, in Ghana, the use of herbicides to control weeds in farming systems is on the rise and many experts have attributed the decline in soil fertility, decreasing crop yields, and declining population of certain species such as giant snails (*Achatina achatina*), edible wild mushrooms, and taro

(*Colocasia esculenta*) to the indiscriminate use of herbicides. The negative environmental impacts of herbicide application impose external costs or externalities on society. Thus, though the private cost of herbicide application on rubber plantations may be low, the social costs (private costs plus external costs) may be quite high. Hence, if the environmental external costs of herbicide application are internalized, the social cost of herbicide weed control in rubber plantations may far exceed manual weed control, thereby making the use of herbicides prohibitive. This has policy implications in terms of regulating the use of herbicides in farming systems in Ghana.

For both herbicides and manual weed control methods, the estimated cost was significantly different in the three districts surveyed based on the ANOVA results. Farmers in the Amenfi Central district spend more than those in the remaining two districts. This might be due to differences in labour cost, since the cost of herbicides is constant. Labour cost is an important factor in plantation development but is usually ignored by smallholder farmers in calculating the cost of production, especially in places where family members mostly supplied the number of man days used in farming (Goswami and Challa 2007; Benny et al. 2016). In a similar study in Papua New Guinea, labour cost was 80% of the total costs of production of vegetables (Goswami and Challa 2007; Benny et al. 2016). To reduce labour requirements, more appropriate timing of planting, training of farm labour in more efficient methods, and use of improved farming technology for weed control are required. Nevertheless, our result indicates that if other maintenance costs are held constant, famers in the Nzema East are likely to have higher profits in rubber plantation than those in Ahanta West and Amenfi Central districts due to the least cost of weed management recorded in the district.

We acknowledge limitations of such studies including the potential over- or under-estimation of costs and time spent managing weeds by farmers. Also, the study did

Table 5: Result of one-way ANOVA showing the effect of district, gender, farmers' education level, and age of plantation on average cost of manual weeding and cost of application of herbicides per hectare

Source	Cost of manual weeding*			Cost of application of herbicides*		
	Mean square	F	p	Mean square	F	p
District	0.088	3.421	0.038	0.223	12.182	0.000
Gender	0.045	1.684	0.198	0.043	1.758	0.190
Education	0.026	0.940	0.446	0.047	2.051	0.098
Age of plantation	0.062	2.390	0.075	0.036	1.507	0.221

*Cost was per hectare and log transformed for the analysis.

not provide information regarding farmer's annual income, which would have helped put the cost estimated in perspective. Actual effect of weeding practices on weed communities and the impact of weeds on yield need to be exploited to provide a holistic information. Nevertheless, the study provides an estimate of the financial costs of managing weeds to contribute to the very few studies published in this arena.

6 Conclusion

This study indicates that the cost of weed management is high for rubber out-growers. Essentially farmers are investing about 53% of the total maintenance cost of plantations within the first 4 years, in weed management mostly through manual weeding and herbicide application to keep on-plantation weed competition relatively low. This highlights the need to strengthen the smallholders' access to different forms of capital assets as well as policy and institutional interventions to secure financial incentives and credit facilities. The current study may also be used to inform policymakers on the seriousness of the weed problem to smallholder farmers.

Given that the core objective of rubber growing is to maximize profits, this study recommends the application of herbicides to control weeds in rubber plantations, especially in short-term projects, since average estimated cost of herbicide application per hectare was lower than one-time manual weeding per hectare. We should be quick to note that this recommendation does not take into consideration possible external environmental costs of herbicide use, which may increase the social cost of herbicide application, since this was not assessed in the present study. If environmental external costs associated with herbicide use to control weeds in rubber plantations are internalized, the social costs of herbicide use may far exceed manual weeding cost. Internalization of the external costs of herbicide application requires a policy intervention from policymakers in Ghana with regards to either banning or regulating herbicide use in farming systems. It is therefore important to conduct empirical studies to measure the environmental impact of herbicide application (e.g. effects on farmers' health, soil fertility, crop yield, biodiversity, etc.) in different farming and plantation systems to provide holistic information to serve as a guide for policymakers.

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