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Absence of Effects of Herbicides Use on Yam Rots: A Case Study in Wulensi, Ghana

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Abstract: Yam farmers in Ghana have, over the years, used herbicides for weed control, particularly glyphosate. Although this has been helpful to them, there are complaints and concerns, among the yam farmers and a section of the public, that the yam tuber rots easily under the use of herbicides. This study, therefore, was set up at the field level to investigate the possibility of herbicides use causing yam rot. Two yam varieties, "laribako" and "olodo", were grown under the conditions of chemical weed control (use of glyphosate) and manual weed control in three replicate sites in Wulensi in the Nanumba traditional area of northern Ghana. The study revealed that there was no difference in rots between herbicide treated yams and manually weeded yams, but that there was a difference in rots between "laribako" and "olodo" yam varieties. The results also showed that there was no difference in yield between herbicide treated yams and manually weeded yams. Based on the findings, it can be concluded that, there was no difference in yam rot and yield between herbicides treated and manually weeded yams, but "laribako" was more susceptible to rot than "olodo".

Keywords: yam rots; causes; farmers; herbicides; glyphosate residues

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1. Introduction

Yam (*Dioscorea* spp.), belonging to the genus *Dioscorea,* the order *Liliflorae*, and the family *Dioscoreacae*, is mainly grown in the tropical and sub-tropical countries of the world, including West Africa, the Caribbean, north and central parts of East Asia, and South and Central America [1–4]. It is an important food and income security crop for people in the tropical and subtropical regions [5,6]. It is reported to be an important source of minerals, such as calcium, phosphorus, iron, and carbohydrates and vitamins such as riboflavin, thiamin, vitamin B, and vitamin C [1,7]. Yam has been used in traditional medicine in Africa and among the Chinese and other Asiatic people to treat diseases like diabetes, to increase coronary circulation, and to prevent hypercholesterolemia [1,4,8]. In many yam growing communities in West Africa, yams play an important socio-cultural role, featuring in many traditional festivals. In some cases, a day is even set aside to celebrate the harvest of the new yams [3]. In the Nanumba traditional area of Ghana, and particularly in Wulensi, when it is time for harvesting new yams (the milking stage), most family heads from the royal families do not eat the yam until the formal ceremony, called "Nyuya Dibu" which welcomes the new yam, is organized. The "Nyuya Dibu" ceremony is normally organized on a Friday that coincides with the market day of the town, called "Aluzumma Kofei".

Despite the importance of the yam, the production of the crop faces serious challenges, such as pests and disease rots, both of which lead to yield losses. Weeds are the most economically important pest, with regards to limitations of crop yield [9,10]. Crop losses of yams, both in the field and during storage, remain a critical challenge to farmers and traders. Studies have shown that the biggest losses are caused by rot causing pathogens of fungi, nematodes, and bacteria and the incidence and severity of damage caused by these organisms varies among yam species, varieties, and localities [2–4,11–13]. Conservative estimates put postharvest losses of yams caused by microbial rots between 15% and 40% [2,11]. The "laribako" variety, for instance, though very tasty and the most preferred yam by Ghanaians and Africans both at home and in the diaspora, is prone to soil pathogens and has a very short shelf life, thus compelling farmers to sell their stock as early as possible, even at periods when prices are not good for them [14].

Over the years, yam farmers in Ghana seemed to have found a solution to the weed problem on their farms by using chemical herbicides with glyphosate as the dominant product, but in this solution there lies another problem of tuber rots. Some farmers and yam traders strongly believe that the use of chemical herbicides has aggravated the yam rot problem. Studies on yam rots have clearly established the main causes of the rots, both in the field and in storage, but studies on herbicides/disease interactions have reported mixed results. There are cases of increasing disease incidence and severity, as well as cases of decreasing disease incidence and severity, depending on the crop type, crop variety, soil, and environmental conditions [9,15–19].

This study was, therefore, designed to address the following hypothesis: (1) There is no difference in yam tuber rots between yams cultivated using herbicides and yams cultivated by manual weeding, (2) there is no difference in tuber rots between the "laribako" and the "olodo" yam varieties, and (3) there is no difference in yield between yams produced using herbicides and yams produced by manual weeding. Thus, the main objective of the study was to determine if the use of herbicides contributes to yam tuber rots. The study also sought to determine the influence of herbicides use on the yam yield.

In addition to the abstract, which gives a brief summary of the whole manuscript, this manuscript is made up of 5 sections. Section 1 is the introduction to the manuscript, which provides a brief background literature on yams as a tropical tuber crop, their socioeconomic importance, production challenges, how farmers are dealing with the challenges, and the research hypothesis and objectives. Section 2 is the materials and methods, which describes in detail where the research was conducted and the methodological approach adopted, including the survey, field trial (experimental design, agronomic practices), data collection, and data analysis. Section 3 talks about the results of the study, providing details on the socio-demographic characteristics of the famers, the system of yam farming in the research area, yam storage practices by the famers in the area, answers to the research hypothesis, and the yield and level of yam tuber rots as recorded in the trial. Section 4 is a discussion of the results. It discusses the results of the study in detail, giving insights into why the results appear so. It also discusses the results in relation to other studies, how similar or different it is with the others, and why and what the implications are for future research. Section 5 as the last section of the manuscript and gives the conclusions of the research, bringing out the novelty of the research and the utility of the research findings.

2. Materials and Methods

The research adopted a mixed method approach. It included a survey and a field trial. The purpose of the survey was to elicit farmers' opinion on the causes of yam rots and their yam cultivation practices to set the tone for the field trial. The purpose of the field trial, based on the survey outcome, was to investigate the effect of herbicides (glyphosate) on yam rots.

2.1. Survey

The survey was conducted in two predominant yam growing districts in the northern region of Ghana, i.e., the Nanumba South (8°39′ N–0°01′ W) and Nanumba North (8°5′ N–0°04′ W districts. The communities covered were Lepusi, Dimong, Kpabi, and Bimbilla in the Nanumba North district and

Kukuo, Nakpayili, Wulensi, and Lungni in the Nanumba South district. The survey was executed in three steps, including a structured questionnaire administration, focus group discussions, and community/field visits. The survey was conducted between 12–16 March 2015, shortly before the spraying season of April–May. In total, 100 yam farmers were interviewed and three focus group discussions were organized across the 8 communities in the two districts (Figure 1). The sample size (100) was determined from the total population (235,048) of Nanumba traditional [20], using the formula $n = \frac{1.96^2 * N}{1.96^2 + (2e)\,(N-1)}$, by Charan & Biswas [21], where N is the total population in the area and e is the margin of error (10%). The questionnaire was designed in a manner to extract information about the socio-demographic characteristics of famers, farmers' yam growing practices, and famers' experience and opinions regarding causes of yam rots. The majority of the questions were close ended, with only a few of them being open ended. The questions were pretested with 10 farmers and emerging issues and shortcomings in the questionnaire were addressed before the actual interviews started. The research districts and communities were selected because major yam producers of the country are located in the region. Appendix A presents details of the specific questions posed during the interviews.

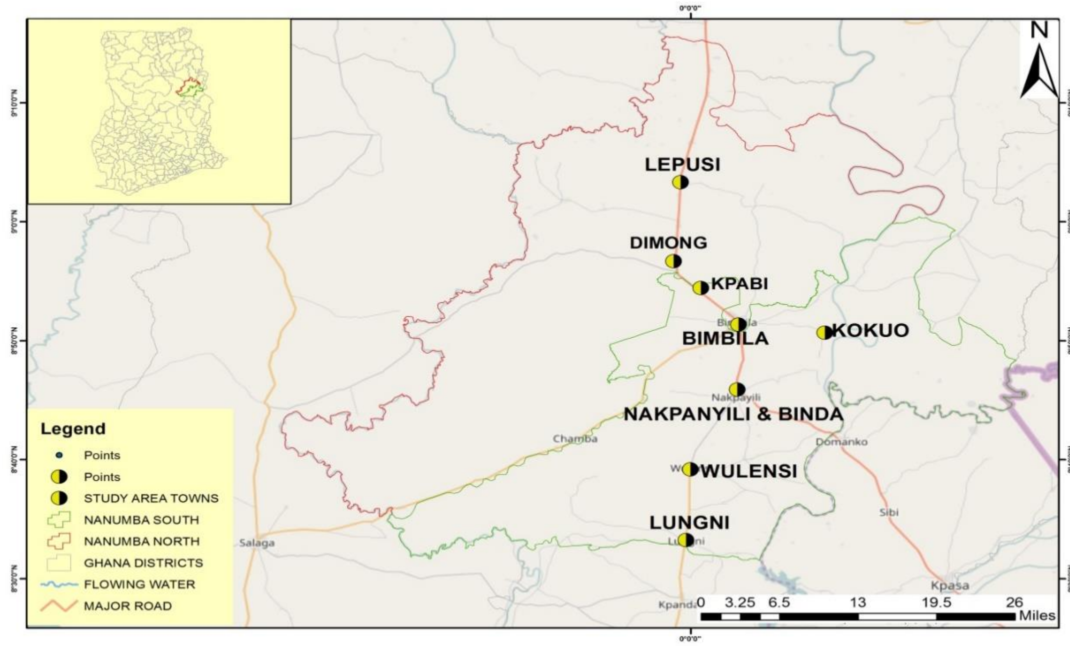

Figure 1. Map of study area.

2.2. Field Trial

The field experiment was conducted in Wulensi in the Nanumba South district in the northern region of Ghana. The study area experiences unimodal rainfall of 1268 mm per annum with most of the rain falling within 6 months, i.e., between May and October with a peak in August and September. Temperatures are usually high, ranging between 29 and 40 °C. Two yam varieties, "laribako", an early maturing variety, and "olodo", a late maturing variety, were used in the experimental set up. These yam varieties are widely grown by farmers of the area, but "laribako" is most preferred. Four treatments in three replicates were evaluated in tandem using the replicated control design. They were grown following good agricultural practices, such as correct site selection, good land preparation, early planting, and good spacing and staking. Three sites, "Bihigubaani" in Wulensi East, "Nayilikurugu" in Wulensi North, and "Sabdaboya" in Wulensi West were purposefully selected for the experiment. At each of the three sites, two treatments (plots treated with herbicides) and two controls (plots manually weeded) were evaluated, thus giving a total of six treatments and six controls. At each of the sites, the design was arranged in such a way that the treatment plots were placed on the down slope of the land while the control plots were placed on the upper slope of the land. This, in essence, was to avoid pesticide contamination of the control plots during runoff. The treatments and controls (experimental design) are presented in Figure 2.

BBN		NKG		SDB	
LC	OC	LC	OC	LC	OC
LS	LS	LS	OS	LS	OS

Figure 2. Experimental design.

BBN = "Bihigubaani" replicate, NKG = "Nayilikurugu" replicate, SDB = "Sabdaboya" replicate, LS = Laribako sprayed, LC = Laribako control, OS = Olodo sprayed, and OC = Olodo control.

2.2.1. Land Preparation

Ploughing was done twice before mounds were raised. The first ploughing was done in the last week of September 2015, after which standing grasses were cleared by the use of a hoe and a cutlass. A period of four weeks was allowed for the soil to get conditioned before the second ploughing was done. Immediately after the second ploughing the raising of yam mounds was done.

2.2.2. Planting

Planting (Figure 3) was done in the month of March 2016, before the start of the rains, at a recommended depth of 10 cm below the soil surface and a spacing of 1.2 × 1.2 m within plots and 2.4 m between plots [14]. Planting was done within a period of three days, taking the weather conditions into consideration to ensure a homogenous planting condition for the three trial sites. There was a day interval between the planting of the first replicate site and the next one. It started from "Bihigubaani", followed by "Nayilikurugu", and ended with "Sabdaboya". Planting was accompanied by capping of the mound with a bundle of grass or leaves as a form of mulch to protect the yam seed from excessive heat of the sun and desiccation.

Figure 3. Planting of seed yam at the "Bihigubaani" (BBN) trial site.

2.2.3. Weeding

One month after planting and before germination, the first weeding was carried out. A total of three weeding operations were done between April and August. The first weeding operation took place in April after the first rains. The second weeding was done in June and the third weeding was done in August. For the first weeding, the treatment plots on all the replicate sites were sprayed with glyphosate at a recommended rate of 2 kg/ha [22], while the control plots were manually weeded. In the subsequent weeding operations, both the treatment plots and the control plots were manually weeded in conformity with the common practice of the farmers, where the majority of them spray only once, i.e., during the first weeding. Spraying of the herbicide was done in the early hours of the day, when the temperatures were still low, with sufficient moisture in the soil. The timing of the spraying was done in such a way that it did not coincide with any rain event, either immediately before or after treatment.

2.2.4. Staking

Staking, which is proven to have enhancing effects on yam yields, especially seed yam [23,24], was sparingly done due to the palpable difficulties in accessing stakes in the area, like other yam growing areas, as a result of the ongoing massive deforestation [25].

2.2.5. Harvesting and Storage

The ware yam was harvested towards the end of January and stored in traditional storage barn until the end of May. The harvesting was done with the use of a hoe and a cutlass and care was taken not to cause unnecessary bruises to the yam tubers, as this could enhance rots during storage [26]. The number of rotten tubers per plot, the number of market quality tubers per plot, and the total weight of market quality tubers per plot were counted as quality assessment parameters. The quality of a tuber was thereafter judged by its size and wholesomeness, i.e., no symptoms of rots, deep cuts, gals, and termite holes. In the storage facility, the yam tubers were placed according to the treatments and controls, with the appropriate labels attached to them (Figure 4). During storage, monthly inspections were done to check the level of rots. During these inspections, rotten tubers in each treatment were removed and counted. At the end of the storage period, counting and weighing were done again to determine the number of rotten tubers and the loss of weight after storage, respectively.

Figure 4. Yam tubers in storage with their labels.

2.3. Data Collection

The following data were taken: The number of rotten tubers at harvesting, the number of market quality tubers at harvesting, the weight of market quality tubers at harvesting, the number of tubers two months into storage, the number of tubers at the end of four month storage period, the percentage of rotten tubers after two months in storage, and the percentage of rotten tubers at the end of four months storage period.

2.4. Data Analysis

The data were analyzed using SPSS version 23 (IBM, Armonk, NY, USA) and MS Excel 2016 (Microsoft Corp., Redmond, WA, USA). A statistical test of a one sample *t*-test was conducted to determine whether there were any significant differences in yam tuber rots between the glyphosate treated plots and the control plots tubers, whether there was any difference in tuber rots between the "laribako" and the "olodo" varieties, and whether there was any difference in yield between glyphosate treated plots and manually weeded plots.

3. Results

3.1. Socio-Demographic Characteristics of Respondents

The socio-demographic characteristics of the farmers is presented in Table 1. The majority of the farmers (99%) were male. In terms of age, the majority of them were within the active age group, between 31 and 50 years. All the farmers grow yams as their major crop and about 50% of them grow maize as a secondary crop, with an overwhelming majority (58%) of them lacking formal education. With regards to land holding, the majority of the farmers cultivate between 0.5 ha and 4 ha.

Table 1. Socio-Demographic Characteristics of Respondents.

Category	Variable	*n*	%
Gender	Male	99	
	Female	1	
Age category	21–30 years	15	
	31–40 years	34	
	41–50 years	31	
	51–60 years	11	
	Above 60 years	9	
Level of Education	Primary	7	
	JHS	7	
	Middle School	6	
	SHS	8	
	Tertiary	14	
	Non formal	3	
	No education	55	
Major Crop	Yam	100	
Total acreage	0.5–1.6 ha	33	
	1.7–2.8 ha	47	
	2.9–4.0 ha	10	
	4.1–5.2 ha	7	
	5.3–6.4 ha	1	
	Above 10 ha	2	
Other Crops	Cassava	42	21.8
	Maize	96	49.7
	Guinea Corn	10	5.2
	Millet	15	7.8
	Soybean	12	6.2
	Groundnuts	3	1.6
	Rice	8	4.1
	Okro	1	0.5
	Cashew	1	0.5
	Cowpea	4	2.1
	Water melon	1	0.5

3.2. System of Yam Farming

Table 2 presents the system by which yam farming is done in the study area. The majority (89%) of the farmers indicated that they grow yam in a mixed cropping system, while 55% of them indicated they practice crop rotation with the type of rotation being as follows: Yam-maize (53%), yam-groundnuts (1%), and yam-millet (1%). The majority (93%) of the farmers said they observe bush fallowing in yam production with the length of fallowing for the majority (83%) of them varying between 1 and 4 years. All the farmers indicated that the common pesticides they apply on their farms are herbicides, with the majority (89%) of them applying herbicides on their farms only once in a year. It was revealed that those farmers who apply herbicides only once in a year use only glyphosate, while those who apply herbicides two times use glyphosate for the first application and atrazine for the second application.

Table 2. System of yam farming.

Category	Variable	*n*
Do you grow yam in mono cropping or mixed cropping system?	Mono cropping	11
	Mixed cropping	89
Do you practice crop rotation in your yam farming?	Yes	55
	No	45
What type of rotation do you practice?	Yam-maize	53
	Yam-groundnuts	1
	Yam-millet	1
	Not applicable	45
Do you observe following in your yam farming?	Yes	93
	No	7
If yes, how long is the length of fallowing?	1–2 years	34
	3–4 years	49
	5 years	7
	Above 5 years	3
	Not applicable	7
If no, why don’t you observe fallowing?	Limited access to land	7
	Not applicable	93
How many times do you apply pesticides on your yam farm in a year	Once	89
	Twice	11
What type of pesticide do you usually apply?	Herbicides	100

3.3. *Yam Storage by Farmers*

The majority (63%) of the yam farmers store their yams in a traditional yam barn after harvesting, while 29% store yam under trees and cover them with grass, and 8% bury the yams in the soil after harvest (Table 3). With regards to treatment of yams for storage, the majority (97%) of the farmers said they do not offer any treatment. For the few farmers who said they treat yam for storage, they indicated that they use insecticides (1%), powdered pepper (1%), and baits (1%) against rodents.

Table 3. Method of yam storage by farmers.

Category	Variable	*n*	%
How do you store yam after harvesting?	Burying	8	8
	In a barn	67	63
	Under a tree covered with grass	31	29
Do you treat yam before or during storage?	Yes	3	
	No	97	
How you treat yam for storage?	Use of baits against rodents	1	
	Use of powdered pepper against rodents	1	
	Use of insecticides	1	
	Not applicable	97	

3.4. *Yam Rots and Farmers Opinion on the Causes*

The majority (92%) of them produce a harvest between 100 and 10,000 tubers of yam in the farming season, while 3% of them produce a harvest between 10,000 and 25,000 tubers (Table 4). Out of the previous year's harvests, the majority (62%) of the farmers recorded between 1% and 8% tuber loss due to rotting, while 27% of them record between 10% and 40% tuber loss, with only 11% of them recording 0% tuber loss due to rotting. With regards to the causes of the rotting, the majority (28.3%) of the farmers respectively mentioned pesticides and excessive heat as the causes. The other causes of importance, as mentioned by the farmers, were poor handling at harvesting (18.4%), bad storage (11%), poor soils (10%), long storage time (7%), and damage by rodents (5%). This result represents the generally held view, by a section of the public, that the use of herbicides makes the yam tuber rot easily.

Table 4. Yam rots and farmers opinion on the causes.

Category	Variable	*n*	%
How many tubers of yam did you harvest last season?	100–1000	29	
	1001–5000	63	
	5001–10,000	5	
	10,001–15,000	1	
	15,001–20,000	1	
	20,001–25,000	1	
How percentage of your last season harvest got rotten?	0%	11	
	1%	3	
	2%	39	
	3%	1	
	4%	6	
	6%	6	
	8%	7	
	10%	20	
	20%	6	
	40%	1	
What is the cause of the rampant yam rotting?	Use of herbicides	43	28.3
	Excessive heat	43	28.3
	Poor handling at harvesting	28	18.4
	Early harvesting	2	1.3
	Long storage	7	4.6
	Rodent damage	5	3.3
	Don't know	3	2.0
	Poor soils	10	6.6
	Bad storage	11	7.2

3.5. Hypothesis Tests

A statistical analysis using a one sample *t*-test was conducted to test the difference in rotting between herbicides treated and manually weeded yams, the differences in rotting between the "laribako" and the "olodo" yam varieties, the difference in yield between herbicides treated and manually weeded yams, and the difference in yield between the "laribako" and the "olodo" yam varieties (Table 5).

Table 5. Hypothesis tests.

Test	Observed *t*	Degrees of Freedom	*p* Value	Decision
There is no difference in rots between herbicides treated manually weeded yam	−1.387	5	0.224	Accept H_0: Herbicides do not have influences yam tuber rots
There is no difference in rots between "Laribako" and "Olodo" yam varieties	−3.371	5	0.02	Reject H_0: Yam variety has significant influence rots/shelf life

There is no difference in yield between herbicides treated yam and manually weeded yam	−1.732	5	0.144	Accept H_0: Herbicides do not have influence on the yield of yam

3.6. Yield and Levels of Tuber Loss Due to Rots

Table 6 presents information on yield across the trial fields and the levels of tuber rots in the field and during storage. With regards to yield, the “laribako” field treated with glyphosate recorded a higher yield than “laribako” field not treated at all the trial sites, while “olodo” field treated with glyphosate recorded a lower yield than “olodo” field not treated at two of the trial sites (BBN and NKG) and a higher yield than the untreated at SDB. In terms of tuber rots in the field, “laribako” treated recorded fewer rots than “laribako” not treated at BBN and SDB, but recorded more rots than the untreated at NKG. Similarly, treated “olodo” recorded fewer rots in the field than “olodo” not treated at BBN and SDB, but more rots than the untreated at NKG. With regards to tuber rots during storage, the results show that, at the end of the four-month storage period, treated “laribako” recorded lesser tuber rots than “laribako” not treated at BBN and NKG and more rots than the nontreated at SDB. On the other hand, treated “olodo” and “olodo” not treated recorded the same level of rots at BBN, but with lesser rots for the treated at SDB and higher rots at NKG. Indeed, “olodo” not treated with glyphosate at the NKG site recorded zero rotting throughout the storage period.

Table 6. Levels of rotting and yield.

Treatment	No of Rotten Tubers at Harvest	No of Tubers/ha at Harvest	Weight (kg/ha) at Harvest	No of Tuber/ha 2 Months in Storage	No of Tubers/ha at 4 of Storage	% Tuber Loss at 2 Months in Storage	% Tuber Loss at 4 Months of Storage
BBN LS	525	2275	8278	2100	1995	8	12
BBN LNS	1120	1820	6885	1540	1400	15	23
BBN OS	15	840	3241	770	735	8	13
BBN ONS	105	1120	3913	1015	980	9	13
SDB LS	70	2275	7476	1925	1295	15	43
SDB LNS	805	1575	5716	1400	1190	11	24
SDB OS	175	2625	10,724	2555	2450	3	7
SDB ONS	210	1050	3238	1015	910	3	13
NKG LS	385	3080	14,046	2555	2380	17	23
NKG LNS	175	2975	12,793	2345	1610	21	46
NKG OS	175	1295	4452	1225	1155	5	11
NKG ONS	35	1890	7707	1890	1890	0	0

BBN: Bihigubaani; SDB: Sabdaboya; NKG: Nayilikurugu; L: Laribako; O: Olodo; S: Sprayed; NS: Not spray; LS: Laribako sprayed; LNS: Laribako not sprayed; OS: Olodo sprayed; ONS: Olodo not sprayed.

4. Discussion

The present study investigated the effect of herbicide (glyphosate) use on the yield and shelf life of yams. It started with a survey of farmers to understand their yam farming practices and to elicit their opinions and understanding about yam rot and the causes. From the survey, a field trial was conducted. Generally, information on herbicide effects on disease rots of roots and tuber crops is limited. Therefore, findings of this study are important to contribute to knowledge in this field. Similar to other studies [27,28], the majority of the yam farmers in this study were males. This is a reflection of the fact that yam farming, which is a highly labour intensive occupation, is dominated by men. The majority of the farmers as reported are illiterates. The lack of formal education and low level of education of the farmers naturally will have some implications for their adoption of good agricultural practices, such as the proper handling and use of pesticides, among others [29,30]. The majority of the yam farmers have land holdings of between 0.5 ha and 4 ha, an indication that yam farming is still done on a wider scale by small holder farmers, as earlier observed [28].

As can be seen in Table 2, the yam farmers cultivate yam in a mixed cropping system. They also rotate yam with other crops and observe generally short fallow periods. It is reported that yam grown under a sole cropping system does better in terms of productivity than under a mixed cropping system, but farmers prefer the mixed cropping due to the insurance it gives them against heavy loss of capital and labour input on the farm in case of failure of the yam crop [31]. For the few farmers who did not observe fallowing, they said it was because of their limited access to land. It is observed that fallowing, as currently practiced by the farmers, is shortened. The farmers themselves indicated that in the past the shortest fallowing period was 10 years. To compensate for the depletion in soil nutrients as a result of the shortened fallow periods, yam-legume rotation is recommended [32,33]. These shortened fallow periods could possibly explain why the farmers generally complain of poor soils and weed invasion on their farms. Yam, as a heavy feeder, prefers rich and loose-textured soils, hence fallowing is normally observed to allow enough time for the soil to recover the lost nutrients and to restore its fertility. The longer the fallowing the richer the soil becomes, with less weed problems [32].

Farmers in the Nanumba traditionally store yam in the traditional way, as reported in Table 3. The farmers indicated that each of the methods is a good method for storing yam, but the efficiency of each method depends on how it is done. For instance, if you are to bury yam at the time you still expect some rains, it is better not to bury it on the downslope of the farm. If you bury it on the downslope the pit will receive too much water during run off and this will cause rotting due to moisture condensation and mold growth as result of poor ventilation and high temperatures [34,35]. The yam farmers, at the moment, generally do not offer preharvest or postharvest chemical treatment to yam for the purpose of preserving, although this is done in other jurisdictions, such as Nigeria, and is reported to have suppressing effects on fungal rots in yam [36,37].

On the incidents of yam rot, the farmers reported rot percentages up to 40% and they attributed the rot to factors including the use of pesticides, excessive heat, poor handling, bad storage, poor soils, and damage by rodents. This result conforms with previous studies [2,11], in which tuber loss of between 15% and 40% as a result of microbial rots was reported. Most of the assertions of the farmers are not farfetched, as studies have linked poor handling during harvesting and post harvesting, poor conditions in storage, high temperature, and pest damage to yam rots [34,35,38].

On the effect of herbicide use on yam rots, the result is in sharp contrast with the generally held view by farmers and the public that the use of herbicides causes yam tuber rots, since there was no significant difference ($p < 0.05$) in yam tuber rots between herbicide treated yams and manually weeded yams (Table 5). The results agree with the hypothesis that there is no difference in tuber rots between herbicide treated yams and manually weeded yams. As already elaborated, in this study, there were instances when the use of the herbicide (glyphosate) seemed to have a suppressing effect on tuber rots and, in a few instances, it seemed to have an enhancing effect on tuber rots. The result conforms with previous studies on pesticide–disease interactions, in which mixed results of both enhancing and suppressing effects were recorded [9,39]. Since it is established in this study that the herbicides cannot be responsible for the yam tuber rots, both in the field and during storage, the rots could be attributed to rot causing pathogens, enhanced by physical/mechanical factors, as have been widely published in literature [2–4,11,12], in which yam samples with rots were collected from a yam barn and from selected markets in Accra (Ghana). A total 10 spoilage micro-organisms, including 9 fungal species (*Aspergillus flavus, Aspergillus niger, Botryodiplodia theobromae, Fusarium culmorum, Fusarium oxysporium, Fusarium* sp., *Penicillium brevi-compactum, Penicillium* sp., *Rhizopus stolonifera*) and one bacterium species (*Erwinia carotovora*) were identified. In another study (Kwoseh et al. [40]), two nematode species (*Scutellonema bradys* and *Meloidogyne incognita*) were identified to be associated with dry rots and galling of yams, respectively, in Ghana.

Previously, Cornelius [41] had also identified *Aspergillus flavus*, *A. niger*, *A. oryzae*, *Botryodiplodia theobromae*, *Fusarium culmorum*, *F. moniliforme*, *F. oxysporum*, *Penicillium brevi-compactum*, *Penicillium* sp., *Rhizopus stolonifer*, and *Erwinia* sp. as the causes of spoilage rots in white yam (*Dioscorea rotundata* Poir) in Ghana. In a study in Nigeria [3], fungal species were identified to be the cause of storage rots of yams. Indeed, the damage caused by these micro-organisms can be enhanced by mechanical factors, such as bruising and crushing, insect infestation by boring and chewing at the tubers, and rodent/bird attacks [35]. As can be seen in Table 5, the only factor in this study that had effect on yam tuber rots was the type of yam variety, since there was a significant difference ($p < 0.05$) in rots between the two yam varieties. The "olodo" variety recorded a fewer number of rotten tubers than the "laribako" variety, in terms of the level of rots, hence the hypothesis that there is no difference in yam tuber rots between the two yam varieties was rejected. This result conforms with Demuyakor et al. [38] and Kusi et al. [14], in which the laribako variety was observed to be a short storage variety compared to the "olodo" variety.

With regards to the effect of herbicide use on yield, the results (Table 5) showed that there was no significant difference ($p > 0.05$) in the yield across the fields, hence the hypothesis, that there is no difference in yield between yam plots treated with glyphosate and plots manually weeded, was accepted. This means that, contrary to the farmers thinking that the use of herbicides on their farms leads to increases in yield, the herbicides by themselves do not influence the yield. Instead, how clean the farm is kept, irrespective of the method used, is what influences the yield. Indeed, weeds are one of the most important factors causing economic losses in crop production and that is why, over the years, the sales of herbicides are globally outstripping those of insecticides and fungicides [10,18,40]. The result also conforms with the study of Unamma & Melifonwu [42], in which the pre-emergence application of fluometuron, chloramben, diuron/paraquat, simazine, and atrazine/metolachlor at the rates of 1.4, 2.7, 1.6, 5.7, and 3.8 kg/ha, respectively, effectively controlled weeds and gave tuber yields that compared favorably with the recommended practice of three hand weedings at 3, 8, and 12 weeks after planting.

In terms of percentage tuber loss due to rots, the results from the field trial showed tuber loss up to 46% at the end of the four-month storage period and up to 21% at two months during storage. This conforms with the farmers assertion, during the interviews, that long periods of storage also contribute to the tuber rots. Farmers are usually not comfortable with selling very early, unless they are compelled, because the longer they keep their yams into the lean season the better the prices they will attract [14]. The levels of rots recorded are similar to what has been reported in the survey and in previous studies [13,14].

Despite the significant benefits that accrue with the use of pesticides, the noncompliance with safety rules by farmers is a source of concern throughout the world [43,44]. Famers in developing countries, in particular, usually have inadequate knowledge on the proper handling of pesticides and, therefore, do not normally handle the products according to agricultural best practices, leading to their exposure to the products [45–47]. With regards to the yam farmers handling of the herbicide (glyphosate) on their farms and their exposure to it, Wumbei et al. [48] found that the yam farmers do not handle the products according to safety rules and are, therefore, exposed to high levels of glyphosate, above the acceptable operator exposure limit (AOEL). Apart from occupational exposure to pesticides, another source of human exposure to pesticides is through food consumption. When pesticides are used correctly, they clearly produce tangible benefits to increase in crop yields and incomes [49]. However, their misuse can possibly lead to the presence of residues in food products, which could trigger negative effects on human health [50,51]. On the food safety impacts of pesticide use in yam production, studies have shown that the yam tuber is contaminated with multiple pesticides residues, including glyphosate, at levels below the EU MRL (maximum residue limit) of the pesticides and generally with no food safety risk [52,53].

As a case study, this study has its weaknesses as well as strengths. In general, cases studies have been criticized by some authors for their lack of scientific rigor and the fact that they do not address generalizability [54]. Although the study was a one-year study and, therefore, definitive conclusions could not be made, the study, through its multiple sources of evidence gathering, presents a holistic view of herbicide use in yam production and yam tuber rots, which reflects the strength of the study.

5. Conclusions

Yam farming is the main economic activity for the people of the Nanumba traditional area. As a known yam producing area in the country, yam production in the area faces a number of challenges, including weed pressure, inadequate labour, and yam rots. In their quest to address the weed pressures on their farms, coupled with the inadequacy of manual labour, farmers have resorted to the use of herbicides. The use of the herbicides is perceived by the farmers to be associated with an increase in yam tuber rots. Although the concern of herbicide use causing an increase in yam tuber rots has persisted for some time in the area, and other yam growing areas in Ghana, no study has reported on the effect of herbicides on yam rots. Therefore, this study was the first to investigate the possibility of herbicide (glyphosate) use leading to an increase in yam rots, the findings of which will contribute to knowledge production in this field.

The study revealed that yam farming in the Nanumba traditional region of Ghana is done in mixed cropping, crop rotation, and bush fallowing systems, even though the length of fallowing has been reduced drastically over the years. The farmers use herbicides (glyphosate) as a substitute for manual labour.

Although storage rots of yam are a serious problem for the yam farmers in the area, it was found that there was no difference in tuber rots between yam plots treated with glyphosate and yam plots manually weeded. However, there was significant difference in tuber rots between the "laribako" and the "olodo" yam varieties with the "laribako" variety recording more rots than the "olodo" variety. Since the study was just a one-year trial, it can be concluded that the findings are indicative that the increase in yam tuber rots cannot be attributed to the use of herbicides in yam production. Hence, while recommending further research to firm up this conclusion, research efforts should be directed at other causes of yam rots in order to find a lasting and sustainable solution for the yam rot problem.

Weeds are an important factor affecting the production and, for that matter, the yield of yam. For this reason, yam farmers are searching for every possible means they can adopt to keep their farms free of weeds, with special preference for herbicides with the thinking that herbicides have yield enhancing effects. This study found that there was no difference in yield between herbicide treated plots and manually weeded plots. This is indicative of the fact that farmers will always be sure to obtain optimum yields if their farms are kept free of weeds at the critical periods in the production cycle. Therefore, if possible, farmers should be encouraged to use manual weeding in order to safeguard human health and the environment from the negative pressures of herbicides.

Author Contributions: A.W. is the corresponding author of the paper. He conceived the project idea and worked through it from the proposal stage through the survey, field trial, and production of the manuscript to the final submission. J.K.A.B. and M.A.A. were part of the proposal development and submission to Wienco Research Fund to access funding for the field trial. They took part in the research and implementation in Ghana. While J.K.A.B. monitored the trial sites and collected relevant data from the project inception to completion, Mahamudu provided the supervisory oversight and direction. They have both contributed in shaping the manuscript for submission. P.S., as a PhD supervisor to the corresponding author, provided the overall direction and guidance for the project, from project inception to completion.

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Conflicts of Interest: The authors jointly wish to state that none of them has any competing interest as far as this submission is concerned.

Appendix A: Specific interview questions

Questions
Socio-Demographic Characteristics
What is your gender?
What is your age?
What is your level of education?
What is the major crop you cultivate?
What the total acreage you cultivate?
What other crops do you cultivate?
What type of pesticides do you apply on your yam farm?
How many times do you apply herbicides on your yam farm in a year?
Yam Production
Do you grow yam as a mono crop or as a mixed crop?
Do you practice crop rotation in your yam production?
What type of crop rotation do you practice?
Do you observe fallowing in your yam production?
What is the length of fallowing?
Why do you not practice fallowing?
How many times do you apply herbicides on your yam farm in a year?
How do you store your yam?
Do you treat yam before storage?
How do you treat yam before storage?
How much yam did you harvest the previous season?
How much of your yam got rotten during storage?
What in your opinion is the cause of the rampant rotting of yam?

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