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Influence of Hand Weeding and Herbicides on Peanut (*Arachis hypogaea*) Yield and Financial Return in Ghana

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Abstract

Protecting peanut (*Arachis hypogaea* L.) from weed interference is important for optimizing yield in Ghana and other West African countries. Hand removal is the main approach for controlling weeds in this region of the world. Herbicides are an alternative to hand weeding. Information on the balance between herbicides and hand labor required to control weeds is limited. To address this, research was conducted to determine weed biomass, peanut yield, time required to remove weeds by hand and apply herbicides, and financial return when metolachlor was applied immediately after seeding (preemergence), imazethapyr was applied 4 weeks after seeding (postemergence), and both herbicides were applied either with or without hand weeding. Controls without weed management and hand removal of weeds without herbicides were included. Weed biomass was the lowest and peanut yield the highest when herbicides and hand weeding were included and when hand weeding was performed twice without herbicides. Herbicides were only less effective than combinations of herbicides and hand weeding. For weed management approaches that resulted in the greatest financial return, the time required for weeding was reduced from 44.5 workdays/ha for hand weeding twice to 14.1, 17.5, and 16.0 workdays/ha for preemergence herbicide plus hand weeding, postemergence herbicide plus hand weeding, and both herbicide timings plus hand weeding, respectively. These results indicate that the combination of preemergence and postemergence herbicides and the combination of herbicide and hand weeding protect peanut yield as well as hand weeding twice. Although herbicides resulted in less labor allocated for weed management, proper stewardship of herbicide use is needed to protect farm workers and decrease potential negative impact on the environment and reduce risk from herbicide residues in peanut-based foods to consumers.

Keywords: economic return; hand weeding; integrated weed management; weed interference

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1. Introduction

In Ghana, peanut is mainly produced by smallholder farmers with one to four ha of arable lands [1–3]. Manual weeding, often with a metal hoe or cutlass, is the most widely practiced weed control method for crop production [2,4–8]. Approximately 96% of groundnut farmers in Ghana reported that manual weeding only was the dominant weed management approach [2,9]. Labor needed for manual weeding competes with labor needs

for other farm activities due to migration from rural communities to urban centers. Weed control alone constitutes about 40% of total farm labor and about 50 to 70% of total labor for smallholder farmers [4,5,10]. The time needed for weed management in peanut cultivation is a major constraint for other necessary household activities, most notably for women farmers and their children. Alternatives to hand weeding would allow households to address issues other than the need for hand weeding if the risk to food safety and exposure to farm workers does not increase and the environment is not compromised.

Herbicides are effective in suppressing weeds and protecting peanut yield [11–16]. While multiple applications of herbicides are needed within the cropping cycle to achieve adequate suppression during the critical period of weed interference [17–19], herbicides are a cost-effective alternative to hand weeding [4,6,20,21]. However, herbicides can negatively impact the environment and farm workers [22]. The potential impact from herbicides is dependent upon the chemical properties of the herbicide, the site of action of the herbicide, and environmental and edaphic conditions surrounding use of the herbicide [23]. Herbicides can improve the management of vegetation in reduced tillage systems which contribute to gains made in the protection of soil resources [24].

Determining the effectiveness of herbicides in controlling weeds in Ghana, both alone and when supplemented by the hand removal of weeds, would be valuable for farmers and their advisors as they develop comprehensive approaches to weed management. Therefore, research was conducted to determine weed suppression, peanut yield, time required for weed management practices, and financial return when herbicides were applied in conjunction with the hand removal of weeds in Ghana. Results from Ghana have the potential to be extrapolated to other countries in sub-Saharan Africa where herbicides have not been adequately investigated, especially where comparable socioeconomic and agronomic conditions exist.

2. Materials and Methods

2.1. Use of Data in the Context of Previous Research in Ghana

A portion of the data used in this paper was published by Arthur et al. [11]. In their paper [11], combinations of weed and disease management treatments were compared. Additional trials beyond those of Arthur et al. [11] that used the weed management treatments in this paper were compared in 2017. We focus on weed management treatments in the absence of fungicides in this paper because most smallholder farmers in Ghana do not apply fungicides for protection from early leaf spot and late leaf spot (caused by *Passalora arachidicola* (syn. *Cercospora arachidicola* [Hori]) and *Nothopassalora personata* (Berk. & M.A. Curtis) U. Braun, C. Nakash., Videira & Crous], respectively) [3,25]. The paper by Arthur et al. [11] includes only one market price for peanut. We expand on the financial comparison by including two additional market prices for peanut. The price used by Arthur et al. [11] reflects a price received in the market during harvest season. Market prices that are 1.5 and 2.0 times higher are often available several months after harvest, when farmers store peanut. The cost of production is estimated to be 25% higher now than the values used in the financial analysis by Arthur et al. [11]. While the paper by Arthur et al. [11] provides evidence for the value of herbicides and fungicides in protecting peanut yield and the contribution of herbicides to reductions in labor requirements for hand weeding, our paper expands information to a third cropping cycle, presents information on a wider range of pricing structures, and include higher estimates of production costs that reflect current peanut production in Ghana.

2.2. Locations and General Procedures

Experiments were conducted at the CSIR-Crops Research Institute (CRI) Kwadaso Research Station during the minor season in 2015 and the major season in 2016. The experiment was also conducted at the Fumesua Research Station in 2016 and 2017 during both the major and minor seasons. The final location was during the major season at Ejura in 2016. The Kwadaso (06°40′42.161″ N 001°40′34.902″ W), and Fumesua (06°43′24.588″ N 001°31′58.164″ W) Research Stations are in the forest agro-ecological zone, whereas the Ejura (07°25′11.381″ N 001°20′12.746″ W) location is in the forest transition agro-ecological zone. These locations experience a bimodal rainfall pattern. The major rainy season begins in April or May and lasts for 6–10 weeks [26]. A second rainy season, referred to as the minor season, begins in September with a duration of 6–8 weeks but is characterized by less rain that can be sporadic.

The cultivar Konkoma was grown during the minor season at Fumesua during both years and at Ejura. The cultivar Yenyawso was grown at Kwadaso and during the major season at Fumesua. The plot size was 4 m × 3 m with a 1 m alley separating plots within a block and a 2 m alley separating blocks. Cultivars were planted at 1 seed per hill at a spacing of 0.5 m × 0.2 m. Konkoma is the traditional cultivar grown in this region [27]. Yenyawso is an improved cultivar with resistance to leaf spot disease but is grown less frequently than Konkoma [27].

2.3. Weed Management Treatments

Weed management treatments consisted of the following: (1) hand weeding at 3 and 6 weeks after planting (WAP); (2) metolachlor applied to the soil surface after planting (preemergence); (3) imazethapyr applied postemergence at 4 WAP; (4) metolachlor applied preemergence followed by imazethapyr applied postemergence; (5) metolachlor applied preemergence followed by hand weeding at 6 WAP; (6) imazethapyr applied postemergence followed by hand weeding at 6 WAP; (7) metolachlor applied preemergence followed by imazethapyr applied postemergence followed by hand weeding at 6 WAP; and (8) no weed control (Supplemental Table S1). Metolachlor (Maestro 960 EC, Shandong Weifang Rainbow Chemical Co., Ltd., Weifang, China) was applied at 1.2 kg ai/ha within 2 days after planting. Imazethapyr (Vezir 240 SL, ADAMA Makhteshim, Kiryat, Israel) was applied at 70 g ai/ha. Nonionic surfactant at 0.25% (v/v) was included with imazethapyr. Herbicides were applied with 15 L Matabi knapsack sprayers calibrated to dispense 200 L/ha. Hand removal of weeds was accomplished with a metal hoe. Imazethapyr and metolachlor are registered for use with peanut in Ghana by the Ghana Environmental Protection Agency [28].

2.4. Data Collected

Above-ground biomass of all weeds was collected from a randomly selected 0.5 m by 0.5 m section of each plot when peanut was harvested and dried at 75 °C for 24 h. Data were converted to g dry biomass/m^2. Peanut pods were dug at optimum maturity based on pod mesocarp color using the hull scrape method [29]. Pod yield was adjusted to 10% moisture. The amount of time required to apply herbicides and remove weeds by hand was determined for each plot to calculate the number of 6 h workdays.

2.5. Calculation of Financial Return

Financial return was calculated using a base cost of US $180/ha, excluding weed control (e.g., cost of herbicides and their application and hand-weeding cost). The cost of digging pods and removing pods from vines was set at $0.094/kg unshelled peanut based on information provided by local farmers. The cost of shelling peanuts was set at $0.094/kg

shelled peanut based on unpublished surveys from local markets. The cost of metolachlor and imazethapyr was \$13/ha and \$10/ha, respectively, based on quotes from local retailers. The hand-weeding labor cost was set at \$1.25/h. The cost of herbicide application was set at \$3/h.

The cost of weed control was added to the base cost and costs associated with digging peanut, removing pods from vines, and shelling to establish the total cost of production for each weed management treatment (Supplemental Table S2). Three peanut price structures were compared using prices for shelled peanut of \$1.20/kg, \$1.80/kg, and \$2.40/kg. The lowest price represents what price aggregators would offer during the harvest season. Higher prices reflect potential gains in market value of peanut after various periods of storage prior to selling. Gross return was calculated as the product of grain yield, assuming a shell out rate of 65%, and price. Financial return was determined by subtracting the total cost of production from gross return (Supplemental Table S2). Financial returns do not include the cost of land, renting land, or household labor.

2.6. Experimental Design and Statistical Analyses

Data for weed biomass, pod yield, hrs. associated with hand weeding, and financial return at peanut prices of \$1.20/kg, \$1.80/kg, and \$2.40/kg were subjected to ANOVA using the GLMMIX procedure in SAS (SAS version 9.6, Cary, NC, USA) using two approaches. The first analysis considered the trial and weed management treatment as fixed effects to test the interaction of trial × weed management treatment. In a second analysis, the trial was considered a random variable. Replication within a trial was considered a random effect in both analyses. Means for weed management treatments were separated using Tukey's HSD test at $\alpha = 0.05$.

3. Results

3.1. Results of Statistical Analyses

The main effects of the trial and weed management treatment and the interaction of these treatment factors were significant for weed biomass and the 6 h workdays required for hand weeding (Table 1). The interaction between the trial and weed management treatments was not significant for peanut yield and financial returns at any of the three peanut prices, although the main effects were significant for these variables. In the case of weed biomass at harvest and the days required for hand weeding, the F statistics for the weed management treatment were approximately 30 and 74 times larger for these respective measurements than the F statistic for the interaction. Therefore, data were analyzed with the trial considered a random variable, allowing comparisons of weed management treatments pooled across trials.

Table 1. Analysis of variance (F statistic and P > F) for weed biomass at harvest; 6 h workdays required for hand weed; peanut pod yield; and financial return at three market prices for peanut in seven trials in Ghana from 2015–2017.

				Financial Return		
Source of Variation	**Weed Biomass at Harvest (g/m^2)**	**Workdays for Hand Weeding and Herbicide Application**	**Peanut Pod Yield**	**Peanut Price at \$1.20/kg Shelled**	**Peanut Price at \$1.80/kg Shelled**	**Peanut Price at \$2.40/kg Shelled**
Trial considered a fixed effect in the analysis						
Trial	9.6 (<0.0001)	36.8 (<0.0001)	4.2 (<0.0001)	7.3 (<0.0001)	7.0 (<0.0001)	6.9 (<0.0001)
Weed management treatment [a]	56.8 (<0.0001)	609.9 (<0.0001)	36.2 (<0.0001)	26.9 (<0.0001)	30.3 (<0.0001)	32.0 (<0.0001)
Trial × Weed Management treatment	1.9 (<0.0014)	8.3 (<0.0001)	1.1 (0.3230)	1.1 (0.3035)	1.1 (0.3035)	1.1 (0.3008)

Table 1. *Cont.*

Source of Variation	Weed Biomass at Harvest (g/m^2)	Workdays for Hand Weeding and Herbicide Application	Peanut Pod Yield	Financial Return		
				Peanut Price at $1.20/kg Shelled	Peanut Price at $1.80/kg Shelled	Peanut Price at $2.40/kg Shelled
	Trial considered a random effect in the analysis					
Weed management treatment	47.6 (<0.0001)	245.7 (<0.0001)	35.4 (<0.0001)	24.8 (<0.0001)	24.3 (<0.0001)	26.1 (<0.0001)
Coefficient of variation (%)	77.5	51.4	41.8	67.6	56.3	52.4

[a] Weed management consisted of the following: (1) hand weeding at 3 and 6 weeks after planting (WAP); (2) metolachlor applied to the soil surface after planting (preemergence); (3) imazethapyr applied postemergence at 4 WAP; (4) metolachlor applied preemergence followed by imazethapyr applied postemergence; (5) metolachlor applied preemergence followed by hand weeding at 6 WAP; (6) imazethapyr applied postemergence followed by hand weeding at 6 WAP; (7) metolachlor applied preemergence followed by imazethapyr applied postemergence followed by hand weeding at 6 WAP; and (8) no weed control.

3.2. Influence of Weed Management on Weed Biomass at Harvest

The primary weed species across years and locations are presented in Table 2. These weeds are often present in peanut fields across these ecological zones in Ghana [2].

Table 2. Weed species across seven trials in Ghana at Fumesua, Ejura, and Kwadoso, 2015–2017.

Fumesua	Ejura	Kwadoso
Ageratum conyzoides L.	*Brachiaria lata* (Schumach) C.E. Hubbard	*Centrosema pubescens* Benth.
Brachiaria lata (Schumach) C.E. Hubbard	*Commelina benghalensis* L.	*Commelina benghalensis* L.
Centrosema pubescens Benth.	*Cyperus* spp.	*Cyperus* spp.
Commelina benghalensis L.	*Euphorbia heterophylla* L.	*Digitaria ciliaris* (Retz.) Koeler
Cyperus spp.	*Spigelia anthelmia* L.	*Euphorbia heterophylla* L.
Euphorbia heterophylla L.	*Tridax procumbence* L.	*Panicum maximum* Jacq.
Panicum maximum Jacq.		
Spigelia anthelmia L.		

Herbicides, hand weeding twice, and the combination of herbicides and hand removal of weeds resulted in less weed biomass compared with the no-weed management control (Table 3). The lowest weed biomass was observed when a single herbicide (e.g., metolachlor or imazethapyr) was applied in conjunction with hand weeding or hand weeding twice at 3 and 6 WAP. The highest weed biomass, excluding the no-weed management control, was noted when metolachlor was applied without hand weeding. While imazethapyr without hand weeding was more effective than metolachlor without hand weeding, this treatment was less effective than when both herbicides were used in the absence of hand weeding.

Table 3. Influence of weed management treatment on weed biomass at harvest, number of 6 h. workdays required for weed management, and peanut pod yield in seven trials in Ghana, 2015–2017 *.

Herbicide Treatment [a]	Hand Weeding Timings	Weed Biomass at Harvest	Workdays for Hand Weeding and Herbicide Application [b]	Peanut Pod Yield
	Weeks after planting	g/m^2	Days/ha	kg/ha
-	3 and 6	14.2 e (3.9)	44.5 a (2.32)	2000 a (134)
Metolachlor	-	78.7 b (6.0)	0.5 d (0.03)	540 d (59)
Imazethapyr	-	56.7 c (6.2)	0.6 d (0.03)	1350 c (99)
Metolachlor and imazethapyr	-	40.7 d (7.8)	1.2 d (0.06)	1640 bc (126)
Metolachlor	6	17.2 e (3.8)	14.1 c (1.29)	1960 a (168)
Imazethapyr	6	14.2 e (4.5)	17.5 b (1.32)	1870 ab (117)

Table 3. *Cont.*

Herbicide Treatment [a]	Hand Weeding Timings	Weed Biomass at Harvest	Workdays for Hand Weeding and Herbicide Application [b]	Peanut Pod Yield
Metolachlor and imazethapyr	6	4.6 e (1.5)	16.0 bc (1.29)	1770 ab (98)
-	-	118.5 a (11.3)	-	380 d (50)

* Means followed by the same letter within a column are significantly different based on Tukey's HSD test at $\alpha = 0.05$. The number in parentheses is the standard error of the mean. [a] Metolachlor applied at 1.2 kg/ha to the soil surface within 3 d after planting. Imazethapyr applied at 70 g/ha to emerged weeds 4 wks after planting. [b] Calculated based on a 6 h workday.

3.3. Influence of Herbicides on Days Required for Hand Weeding

The fewest number of 6 h workdays required for weed management (0.5 to 1.2 workdays) was noted when herbicides were the sole approach to weed management (Table 3). The number of days required for hand weeding twice was 44.5 days compared with 14.1 to 17.5 days when herbicides and hand weeding were included for weed management.

3.4. Influence of Weed Management on Peanut Yield

Hand weeding twice or applying herbicides in conjunction with hand weeding resulted in similar yields (Table 3). Applying both metolachlor and imazethapyr in the absence of weeding by hand was less effective in protecting yield from weed interference than hand weeding twice or hand weeding following metolachlor. Peanut yield was similar when metolachlor and imazethapyr were applied sequentially, either with or without hand weeding. Hand weeding after both metolachlor or imazethapyr resulted in higher yield than when herbicides were not followed by hand weeding. In the absence of hand weeding, peanut yield was higher when imazethapyr was applied compared with metolachlor.

3.5. Financial Return Based on Peanut Market Price

Few differences in the ranking of approaches to weed management were noted when compared across pricing structures (Table 4). The financial return was similar when hand weeding twice, when herbicides were applied twice (e.g., metolachlor followed by imazethapyr) in the absence of hand weeding, and when hand weeding was used in combination with a single application of herbicide or the sequential application of herbicide. A single application of metolachlor was no more cost effective than the non-treated control. The financial return following sequential application of imazethapyr or metolachlor and imazethapyr without and with hand weeding was similar.

Table 4. Financial return from eight approaches to weed management at three market peanut prices across seven trials in Ghana, 2015–2017 *.

		Financial Return [b]		
Herbicide Treatment [a]	Hand Weeding Timings	Peanut Price at $1.20/kg Shelled	Peanut Price at $1.80/kg Shelled	Peanut Price at $2.40/kg Shelled
	Weeks after planting		US $/ha	
-	3 and 6	727 bc (95)	1502 a (149)	2278 a (203)
Metolachlor	-	113 d (37)	311 c (60)	508 c (82)
Imazethapyr	-	634 c (64)	1158 b (103)	1682 b (141)
Metolachlor and imazethapyr	-	791 abc (84)	1426 ab (135)	2060 ab (186)
Metolachlor	6	941 a (122)	1721 a (195)	2497 a (268)
Imazethapyr	6	853 ab (82)	1598 a (132)	2333 a (181)

Table 4. *Cont.*

Herbicide Treatment [a]	Hand Weeding Timings	Financial Return [b]		
		Peanut Price at $1.20/kg Shelled	Peanut Price at $1.80/kg Shelled	Peanut Price at $2.40/kg Shelled
Metolachlor and imazethapyr	6	745 abc (63)	1433 ab (103)	2114 ab (144)
-	-	1 d (26)	117 c (41)	233 c (59)

* Means followed by the same letter within a column are significantly different based on Tukey's HSD test at $\alpha = 0.05$. Number in parentheses is the standard error of the mean. [a] Metolachlor applied at 1.2 kg/ha to the soil surface within 3 d after planting. Imazethapyr applied at 70 g/ha to emerged weeds 4 wks after planting. [b] Estimated economic return calculated by subtracting total cost (e.g., sum of base cost, harvest and shelling costs, and hand weeding and herbicide costs) from gross economic return [Supplemental Table S2].

4. Discussion

4.1. Interpretation of Results and Application

When applied without hand weeding, imazethapyr was more effective than metolachlor in controlling the weeds in these fields and protecting peanut yield from weed interference. Previous research [30] indicates that metolachlor seldom provides season-long weed control in peanut cultivation and that imazethapyr is considered more effective than this herbicide [30–33]. Efficacy of herbicides can be influenced by rainfall for activation and the weed complex [23,30]. While imazethapyr does not control weeds completely in many fields, control of weeds that have emerged with postemergence applications may be a more effective option than applying metolachlor at planting, with no guarantee that rainfall will be adequate for activation of a preemergence herbicide.

Hand weeding twice resulted in the same suppression of weed biomass and peanut yield as weed management with herbicides alone or when herbicides and hand removal of weeds were used in combination. Bhale et al. [34], Gunri et al. [35], and Jhala et al. [36] reported similar yields when herbicides and manual weeding were integrated for weed control in peanut. Manual weeding in peanut encourages aeration, water infiltration, easy penetration of peanut pegs, and pod development [37,38]. The loosening of the soil also makes digging pods easier. Since peanut growth is slow in the early stages and cannot compete with weeds, the use of herbicides reduced the weeds' competition with the crop in the early stages of growth, and their synergistic effect with the follow-up manual weeding ensured the protection of yields. These findings are particularly significant in Ghana and many other West African production zones where labor shortages are increasing due to rural–urban migration and competition for labor during the peak farming period [4,5,10]. Weed management is widely recognized as one of the most labor-intensive activities in smallholder agriculture, with women and children providing some share of weeding labor [4,5]. Decisions on labor allocation need to be considered in this context [39].

Weed control is one of the top five crop production constraints of farmers in Sub-Saharan Africa [5,34,35,38]. The weed control labor time requirements observed in this study corroborate those of Ishaya et al. [40] and Moyo et al. [41], who reported that manual weeding required 54, 52, and 33 to 48 workdays/ha to control weeds in sorghum, maize, and cassava systems, respectively. Moyo et al. [41] and Benson [42] reported that herbicide-based weed management mostly required less than 2 workdays/ha, representing labor savings exceeding 90%. The integration of herbicides and manual weeding similarly required 7.8 to 27 workdays/ha, which represented a 44 to 76% reduction in manual weeding labor time. In the present study, herbicide-only treatments required less than 1.2 workdays/ha, while integrating herbicides with one hand weeding reduced labor time by more than 60% compared with hand weeding twice. Akobundu [43,44] reported that the cost of weed control exceeds the cost of controlling other agricultural pests.

Gianessi and Williams [6] suggest that herbicides can make important contributions to crop productivity in Sub-Saharan Africa. Auld and Menz [4] highlighted that the adoption of improved weed management technologies can generate economic benefits through reduced labor needs. Oerke [7] also noted that weeds remain one of the most important causes of crop yield losses globally, underscoring the value of effective weed suppression strategies. However, herbicides and other pesticides used in agricultural systems are not without considerable risk. Potential negative impacts from exposure to imazethapyr and metolachlor [45–48] have been reported. While the benefits of pesticides have been documented [49] and the scientific process used to define risk has been established [50,51], efforts to develop alternatives to pesticides, in this case herbicides, need to be developed and implemented, especially in Sub-Saharan Africa, where labor constraints are high. Weed management needs to be considered in the larger context of integrated pest management to enable farmers to protect crops from pest damage and to limit negative impacts on human health and the environment [52–57].

Developing new technologies that help farmers target herbicide applications or allow them to use cultural and mechanical practices for weed management would decrease the likelihood of negative environmental impact. A systematic review of non-chemical approaches to weed management in peanut worldwide, as in Daramola et al. [58], would be informative. Integrating machine learning and precision application of herbicides into weed management strategies shows promise but needs validation [59]. In the short term, a challenge will be providing these alternatives to both hand weeding and broadcast applications of herbicides, where equipment delivering these technologies is likely unavailable, expense is high, and maintenance is challenging.

4.2. Limitations and Risk Considerations

The present study did not include the determination of pesticide residue in peanut and peanut products, the environmental fate of herbicides, occupational assessments for farm workers, or biodiversity and ecotoxicological evaluations. These considerations are important in determining whether herbicides are a feasible alternative to hand removal of weeds in peanut or a complement to hand removal in an integrated weed management strategy. Sensitivity analyses that would address fluctuations in labor costs, herbicide prices, or implementation costs associated with stewardship measures, including personal protection equipment and training, were also not conducted in this study. These conceptual concerns are not only important for herbicides but also for other pesticides that suppress pests in peanut.

Results from this study can be used to inform farmers and their advisors in the context of sustainable intensification. Pretty [60] suggests that sustainable production systems should maintain food production, enhance environmental outcomes, limit cultivation of more land at the expense of unfarmed habitats, and ensure no net environmental costs. In this design, pesticides, including herbicides, are considered reasonable technologies to suppress pests, but only when considered in the context of enhancing ecological services and avoiding degradation of the environment while maintaining yield. Adoption of precision agriculture technologies that more precisely target herbicide application on weeds is needed in the framework of sustainable intensification. This approach, when coupled with the use of herbicides in a manner enhancing stewardship in the context of protecting human health and the environment, is essential in protecting from unintended consequences caused by herbicides.

5. Conclusions

Results from this research demonstrate that adequate suppression of weeds, protection of yield from weed interference, and improved financial gain by farmers can be obtained when manual weeding is achieved within the critical period of weed interference. When labor is available to remove weeds in a timely manner, this approach would eliminate the risk of herbicides to farm workers and the environment and the risk of herbicide residues in peanut-based foods. However, when herbicides are integrated with manual removal of weeds, substantially fewer workdays are required.

Given the increasing limits and cost of agricultural labor in Ghana, especially during peak crop production periods, the incorporation of herbicides into peanut weed management can reduce labor requirements for smallholder households. However, incorporation of pesticides, in this case herbicides, into peanut production systems requires not only understanding the value of herbicides to the system in terms of pest suppression and protection of peanut yield but also the ramifications of their use on the environment, the potential impact on consumers of peanut and peanut-derived products if pesticide residues are present in foods, the risk to farm workers from preparing and applying pesticides, and preventing access to storage of pesticides on farms. The balance between the benefits of pesticides and the risks posed by their use is important to establish. Adoption should be supported by effective stewardship, farmer training, and safe-use practices to minimize risk to the environment and humans. Our findings are designed to assist farmers, practitioners advising farmers, and policymakers on the impact of herbicides on labor requirements for peanut production in Ghana. These results should be transferable to other production systems in Africa characterized by comparable socioeconomic and agronomic conditions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agrochemicals5020029/s1, Table S1: Weed management practices; Table S2: Example calculation of economic return associated with harvest, shelling, and production costs at a price of $1.2/kg shelled peanut.

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