agronomy

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Evaluation of Production and Pest Management Practices in Peanut (*Arachis hypogaea*) in Ghana

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Abstract: The economic return for peanut (*Arachis hypogaea* L.) in Ghana is often low due to limitations in the availability of inputs or their adoption, which are needed to optimize yield. Six experiments were conducted in Ghana in 2020 and 2021 to determine the impact of planting date, cultivar, fertilization, pest management practices, and harvest date on peanut yield, financial return, and pest reaction. A wide range of interactions among these treatment factors were often observed for infestations of aphids (*Aphis gossypii* Glover); groundnut rosette disease (*Umbravirus*: *Tombusviridae*); millipedes (*Peridontopyge* spp.); white grubs (*Schyzonicha* spp.); wireworms (*Conoderus* spp.); termites (*Microtermes* and *Odontotermes* spp.); canopy defoliation as a result of early leaf spot disease caused by *Passalora arachidicola* (Hori) and late leaf spot caused by *Nothopassalora personata* (Berk. and M. A. Curtis); and the scarification and boring of pods caused by arthropod feeding. Pod yield and economic return increased for the cultivar Chitaochi and Sarinut 2 when fertilizer was applied and when fertilizer was applied at early, mid-, and late planting dates. Pod yield and economic return increased when a combination of locally derived potassium soaps was used for aphid suppression and one additional hand weeding was used in the improved pest management practice compared with the traditional practice without these inputs. Pearson correlations for yield and economic return were negatively correlated for all pests and damage caused by pests. The results from these experiments can be used by farmers and their advisors to develop production packages for peanut production in Ghana.

Citation: Seidu, A.; Abudulai, M.; Dzomeku, I.K.; Mahama, G.Y.; Nboyine, J.A.; Appaw, W.; Akromah, R.; Arthur, S.; Bolfrey-Arku, G.; Mochiah, M.B.; et al. Evaluation of Production and Pest Management Practices in Peanut (*Arachis hypogaea*) in Ghana. *Agronomy* **2024**, *14*, 972. https://doi.org/10.3390/agronomy14050972

Academic Editor: Christos Athanassiou

Received: 22 March 2024
Revised: 30 April 2024
Accepted: 30 April 2024
Published: 6 May 2024

Keywords: cultural practices; fertilizer; groundnut; harvest date; integrated pest management; planting date; variety resistance

1. Introduction

Peanut (*Arachis hypogaea* L.) is an important crop worldwide that contributes to local economies and food security [1,2]. The protection of peanut crops against pest damage is important in optimizing peanut yield [3,4]. The deployment of improved cultivars and adoption of cultural practices, including fertilizers, can also increase yield [5]. However, these inputs can be expensive or unavailable in some areas of peanut production [3]. Where these inputs are available, it is important to determine not only yield response to pests but also the economic return from inputs.

In Ghana, a wide range of pests are present in peanut production, and in many cases these pests are present in fields at levels that reduce yield significantly. Canopy defoliation caused by early leaf spot [caused by *Passalora arachidicola* (Hori) and late leaf spot [caused by *Nothopassalora personata* (Berk. and M. A. Curtis) can cause significant yield loss in peanut [4,6]. Groundnut rosette virus (*Umbravirus*: *Tombusviridae*) transmitted by aphids (*Aphis gossypii* Glover), causing groundnut rosette disease (GRD) [7], also affects yield [7]. Millipedes (*Peridontopyge* spp.), white grubs (*Schyzonicha* spp.), wireworms (*Conoderus* spp.), and termites (*Microtermes* and *Odontotermes* spp.) can injure and consume vegetative and reproductive structures at levels that can reduce peanut yield [8]. Weed interference also impacts yield [9], and the presence of aflatoxin (caused by *Aspergillus flavus* and *A. parasiticus*) can reduce peanut quality and negatively affect food safety and access to markets [3]. The majority of farmers in Ghana are considered smallholder farmers, with limited access to capital to purchase inputs that could be used to improve plant nutrition and suppress pests in order to minimize their damage [10–12]. Additionally, inputs that can be used for pest management are often not available in local markets.

Research in Ghana has demonstrated the value of applying various fertilizer blends and sources of calcium on peanut yield and quality [3]. Improved plant nutrition can enhance plant health and the ability of plants to withstand damage from pests [4]. For example, Abudulai et al. [3] demonstrated in northern Ghana that the application of homogenized oyster shells or a commercial blend of fertilizer containing calcium minimized arthropod pod damage and increased peanut yield. Naab et al. [4] reported improved plant growth and high yields when fertilizers containing nitrogen, phosphorus, potassium, and calcium were applied to peanut. In addition to increasing yield and kernel quality, fertilizer containing calcium, when applied to peanut crops, can minimize aflatoxin contamination through strengthening the pod walls to increase resistance to soil arthropods' damage and penetration by aflatoxin causing fungi, *Aspergillus flavus* and *A. parasiticus* [3,12].

Aphid populations, GRD severity, and the incidence and severity of leaf spot disease can be lower when locally derived botanicals and soaps are applied to peanut foliage [3]. Abudulai et al. [3] reported lower aphid populations and GRD when locally derived potassium soap was applied to peanut in northern Ghana. Also, leaf spot severity was lower when the soap was applied to peanut [6].

Preventing weed interference early in the cropping cycle can lead to greater peanut yields and economic return [9]. Dzomeku et al. [13] reported that the removal of weeds early in the season increased peanut haulm and pod in yield in northern Ghana. Peanut is susceptible to early-season weed interference due to its relatively slow initial growth and morphological characteristics, which do not allow it to grow above weeds [14,15]. In northern Ghana, Abudulai et al. [3] reported that a production package that included one extra weeding and the application of calcium fertilizer, and the use of locally derived potassium soap to manage pests and diseases, resulted in greater peanut yield and financial returns. Cultivars with greater yield potential through pest resistance, particularly leaf spot disease and GRD, are available but are not widely adopted because of limitations in seed systems [16–19]. For example, the peanut cultivar Sarinut 2 has a higher yield and is more resistant to disease than the local variety, Chitaochi [20]. While a considerable amount of research has been conducted to compare the yield of Sarinut 2 with other cultivars [20], research is limited when it comes to defining the interactions of this cultivar with fertility and pest management inputs. The response of this cultivar compared with the traditional cultivar Chitaochi when using a range of fertilizer and pest management practices has not been determined at different planting and harvest dates in Ghana. Abudulai et al. [3] compared cultural practices designed to minimize pest damage and aflatoxin contamination for the cultivar Chitaochi when planted at the start of the rainy season in northern Ghana. The results from this study [3] demonstrated the value of practices that were subsequently used to develop recommendations for northern Ghana relative to increasing peanut yield and reducing aflatoxin contamination. The primary sources of information from empirical studies did not include the interactions of cultivars planted at different planting and harvest dates when fertilizer was applied. The defining interactions of cultivars with cultural and pest management practices are important when making recommendations to farmers regarding their adoption. Therefore, this research was conducted in Ghana in 2020 and 2021 to define the interactions between planting date, cultivar, fertilizer, pest management practices, and harvest date and their effects on pest reaction, peanut yield, and economic return.

2. Materials and Methods

The experiments were conducted in 2020 and 2021 at Fumesua (6°42′53.1″ N 1°31′52.4″ W 259 m altitude) in southern Ghana and at Nyankpala (9°42′ N, 0°92′ W, 184 m altitude) and Tanina (10°3′ N, 2°50′ W, 323 m altitude) in northern Ghana. Weekly rainfall amounts after planting at Nyankpala and Tanina are presented in Supplementary Table S1. Rainfall data were not available at Fumesua. Fields were tilled with a disc harrow and peanut cultivars were planted in rows spaced 0.5 m apart and were 0.20 m apart within rows. Plot size was 6 rows by 5 m long with 1 m of unplanted alleys between plots and 2 m between blocks and replications. Final plant population was approximately 100,000 plants/ha.

Treatment factors included three levels of planting date (referred to as early, mid, and late; Supplementary Table S2), two levels of cultivar (Chitaochi vs. Sarinut 2), two levels of fertilizer (no fertilizer vs. fertilizer), two levels of pest management (referred to as traditional vs. improved), and two levels of harvest date (optimum maturity vs. one week after optimum maturity). Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO, Yara Legume Fertilizer, Accra, Ghana) at 375 kg/ha was applied 4 weeks after planting (WAP). Improved pest management consisted of applying locally derived potassium soap at 3 WAP at flower initiation and one additional hand weeding at 6 WAP. The traditional pest management practice included one weeding at 3 WAP and no other inputs for pest control.

Visual estimates of canopy defoliation caused by leaf spot disease were determined at harvest using a scale of 0 to 100% where 0 = no canopy defoliation and 100 = all leaves had fallen from the plant [21,22]. Termite (*Microtermes* and *Odontotermes* spp., Isoptera:Termitidae), millipede (*Peridontopyge* spp., Myriapoda: Odontopygidae), white grub (*Schyzonycha* spp. and *Lachnosterna* spp., Coleoptera: Scarabaeidae), and wireworm (*Conoderus* spp., Coleoptera: Elateridae) populations were determined at harvest from 10 randomly selected plants including foliage and roots. Plants were gently lifted from soil using a hoe. Arthropod density was recorded in situ. Scarring and penetration of pods caused by soil arthropods were determined at harvest by collecting 100 pods at random from each plot. In this study, we focused on the pests (e.g., arthropods and disease) that most likely contributed to peanut yield. We did not determine if populations of predator arthropods would have been affected by treatment factors or the possible impacts of plant-parasitic nematodes. The infestation of aphids on peanut plants was determined using an ordinal scale of 0 to 9 where 0 = no aphids present; 1 = early instar nymphs present/few individual aphids (1–100); 3 = early and late instar nymphs and adults spread on most stems/few isolated colonies (101–300); 5 = aphids spread on all stems and new trifoliate leaves/several small colonies (301–600); 7 = high density of aphids on all stems and 50–80% trifoliate leaves covered with aphids/large isolated colonies (601–1000); and 9 = plants overwhelmed by aphids with >80% covered/large contentious colonies (>1000) [7]. Groundnut rosette disease was determined using an ordinal scale of 1 to 9 where 1 = resistant, with no symptoms; 2 = very slight leaf symptoms; 3 = slight leaf symptoms but still negligible; 4 = 50% symptoms on leaves; 5 = all leaves show symptoms of chlorosis; 6 = 25% stunting; 7 = 50% stunting, 8 => 50% stunting with few pods; and 9 => 50% stunting and no pods [23–25].

The base cost of production was set at USD 145/ha and included land preparation, seed, planting, and the cost of one hand weeding (Supplementary Table S3). Fertilizer cost was USD 148/ha. The cost of the improved practice during the growing cycle prior to harvest included the local soap for aphid and rosette suppression (USD 15/ha), and one additional hand weeding (USD 50/ha). These costs were fixed across the treatment structure. The cost of removing pods from vines and shelling was based on the yield of peanut for each treatment and replication. The cost of removing pods was set at USD 0.075/kg farmer stock. The cost of shelling was set at USD 0.075/kg shelled peanut.

Peanut price was set at USD 1.2/kg assuming an estimated shelling rate of 65% of unshelled pods. Estimated economic returns were determined for each combination of the fertilizer and pest management practices during the growing cycle by subtracting the costs of each combination of practices from the gross return (product of unshelled yield in the field with a 65% shelled rate) (Supplementary Table S3).

The experimental design was a split plot, with planting date serving as the whole plot unit and combinations of cultivar, fertilizer, and pest management serving as subplots. The experimental unit consisted of combinations of planting date, cultivar, fertilizer, pest management, and harvest date, replicated 4 times. Data for pod yield; economic return; populations of aphids, millipedes, white grubs, wireworms, and termites at harvest; canopy defoliation caused by early and late leaf spot disease; GRD severity; and the scarring and boring of pods caused by arthropod pests in soil were subjected to ANOVA using the GLIMMIX Procedure in SAS (SAS Version 9.4, Cary, NC, USA). Year, location, and replication within site–year combinations were considered random effects. Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $\alpha = 0.05$. Pearson correlation coefficients were determined for pod yield and economic return versus populations of arthropods, pod damage caused by arthropods, GRD, and canopy defoliation caused by leaf spot disease at $p \leq 0.05$.

3. Results and Discussion

3.1. Peanut Yield and Estimated Economic Return

The interactions of cultivar × fertilizer treatment and planting date × fertilizer treatment were significant for peanut yield and economic return (Supplementary Table S4). The main effect of pest management practice was also significant for peanut yield and economic return. The main effect of harvest date and all other interactions between variables were not significant. Peanut yield and economic return for both the traditional cultivar, Chitaochi, and the improved cultivar, Sarinut 2, were greater when fertilizer was applied (Table 1). The yield of Sarinut 2 was greater than the yield of Chitaochi regardless of the fertilizer treatment. The combination of the cultivar Chitaochi and fertilizer yielded less and had a lower economic return than Sarinut 2 in the absence of fertilizer. These data indicate that the combination of Sarinut 2 and fertilizer deliver the greatest economic return. In circumstances where fertilizer is not available or financial constraints prevent the purchase of fertilizer, growing Sarinut 2 in the absence of fertilizer will result in the greatest economic return. Alternatively, if the improved cultivar Sarinut 2 is unavailable, applying fertilizer to the traditional cultivar Chitaochi will increase yield adequately to compensate for the higher cost of production due to fertilizer costs. Regardless of fertilizer treatment, peanut yield and economic return were greatest when peanut was planted in early June compared with later plantings (Table 1). Planting in July resulted in the lowest yield and economic return. Regardless of planting date, peanut yield and economic return were greater when peanut was fertilized. Increasing pest management (e.g., applying local soaps for aphid suppression, including one additional weeding, and drying peanut on a tarpaulin) resulted in greater yield and economic return than the traditional farmer practices (Table 2). These findings are relevant to production systems outside of Ghana where the availability of inputs such as fertilizer or improved cultivars is limited or their cost exceeds what farmers can afford.

Table 1. Peanut pod yield and estimated economic return as influenced by the interactions of cultivar × fertilizer and planting date × fertilizer.

Treatment Factor	Peanut Pod Yield		Estimated Economic Return	
	No Fertilizer	Fertilizer [c]	No Fertilizer	Fertilizer
	kg/ha		USD/ha	
Cultivar [a]				
Chitaochi	1330 d	1950 c	651 d	1031 c
Sarinut 2	2440 b	3770 a	1370 b	2213 a
Planting date [b]				
Date 1	2370 x	3390 z	1327 x	1973 z
Date 2	1950 w	3090 y	1056 w	1777 y
Date 3	1330 v	2080 w	648 v	1115 w

[a] Means for pod yield and estimated economic return followed by the same letter are not significantly different at $\alpha = 0.05$ when comparing response the interactions between cultivar and fertilizer treatment. Data are pooled over site–year combinations, planting dates, pest management practices, and harvest dates. [b] Means for pod yield and estimated economic return followed by the same letter are not significantly different at $\alpha = 0.05$ when comparing the interaction between planting date and fertilizer treatment. Data are pooled over site–year combinations, cultivars, pest management practices, and harvest dates. [c] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting.

Table 2. Influence of pest management practice on peanut pod yield and estimated economic return.

Pest Management Practice	Peanut Pod Yield	Estimated Economic Return
	kg/ha	USD/ha
Traditional	2100	1149
Improved [a]	2650	1475
P > F	*	*

* Indicates significance when comparing means within yield and estimated economic return at $p < 0.05$. Data are pooled over site–year combinations, planting dates, cultivars, fertilizer treatment, and harvest dates. [a] Improved pest management practice included the application of local soaps for aphid suppression and one additional hand weeding compared with the traditional approach.

The results indicate that applying fertilizer to both traditional and improved cultivars (e.g., Chitaochi and Sarinut 2, respectively) and planting early will increase yield and economic return. Increasing pest management increased yield and economic return, irrespective of planting date, cultivar, fertilizer treatment, and harvest date. The main effects and interactions of treatment factors will be more prevalent for pest populations and the damage pests caused than those noted for yield and economic return. These measurements were affected primarily by the main effects, with the exception of harvest date, and the interaction between planting date and cultivar with fertilizer treatment.

The results for yield and economic return were not unexpected. Planting peanut when rainfall begins during the rainy season in Ghana increases the likelihood that rain will occur during a longer period of the cropping cycle [3,4]. The cultivar Sarinut 2 has been shown to have a higher yield than the traditional cultivar Chitaochi [20]. Applying fertilizer and pest management has also been shown to increase yield and economic return [3]. A lack of yield and economic return due to a delay in harvest was not expected in this research. Previous research has shown that delays in harvest can result in decreased yield [26]. However, harvest was delayed by only one week relative to optimum maturity in our study.

3.2. Arthropod Populations on Plants

Millipede and termite populations on plants at harvest were affected by the interaction between cultivar, fertilizer, and pest management practice (Supplementary Table S4). When pooled over planting date and harvest date, the highest number of millipedes and termites were observed when using the farmers' approach to pest management (e.g., cultivar Chitaochi, no fertilizer, and no additional weeding or local soaps for aphid control) (Table 3). Regardless of fertilizer treatment, a decrease in the number of millipedes was noted when improved pest management was employed. When comparing cultivars undergoing different pest management practices for millipedes, the farmers' practice had the greatest number of millipedes when Chitaochi was grown in the absence of fertilizer, with a decrease in the population when Sarinut 2 was grown without or with fertilizer or when Chitaochi was grown with fertilizer. Millipede population was similar when Sarinut 2 was grown without fertilizer or when Chitaochi was grown with fertilizer. Termite population decreased when improved pest management was used for the cultivar Chitaochi regardless of fertilizer treatment or when Sarinut 2 was grown without fertilizer. No difference in termite population was observed due to pest management practices when Sarinut 2 was grown with fertilizer. When comparing within a pest management practice, termite population was lower when Sarinut 2 was grown with or without fertilizer or when Chitaochi was grown with fertilizer. Unlike the response of millipedes, when improved pest management was employed, no difference in termite population was observed, regardless of cultivar or fertilizer treatment.

Table 3. Number of millipedes and termites on peanut plants at harvest, as influenced by the interaction between cultivar, fertilizer, and pest management practice.

		Millipedes [a]		Termites [b]	
		Pest Management Practice [d]		Pest Management Practice	
Cultivar	Fertilizer [c]	Traditional	Improved	Traditional	Improved
		No./plant			
Chitaochi	No	7.1 a	2.8 c	290 z	26 x
Chitaochi	Yes	3.6 b	1.6 d	29 x	1 x
Sarinut 2	No	3.4 b	1.2 d	106 y	6 x
Sarinut 2	Yes	1.7 d	0.4 e	13 x	0 x

[a] Means for millipede population on peanut for the interaction between cultivar, fertilizer treatment, and pest management practice followed by the same letter are not significantly different at α = 0.05. Data are pooled over site–year combinations, planting dates, and harvest dates. [b] Means for termite population on peanut for the interaction between cultivar, fertilizer treatment, and pest management practice followed by the same letter are not significantly different at α = 0.05. Data are pooled over site–year combinations, planting dates, and harvest dates. [c] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [d] Improved pest management consisted of applying local soaps for aphid control and one additional hand weeding compared with the traditional approach.

Wireworm populations were affected by the interaction between cultivar and fertilizer treatment and cultivar and pest management practice (Supplementary Table S4). Fewer wireworms were observed when fertilizer was applied to the cultivar Chitaochi but not Sarinut 2 (Table 4). Sarinut 2 had fewer wireworms compared with Chitaochi in the absence of fertilizer but not when fertilizer was applied. Similar to the response without fertilizer treatment, a higher number of wireworms was present when Chitaochi was grown using traditional farmer practices for pest management. Sarinut 2 had fewer wireworms than Chitaochi.

White grubs were affected by the interaction between fertilizer and pest management practice (Supplementary Table S4). A greater number of white grubs was present when peanut was not fertilized and the traditional pest management practice was used compared with the improved pest management for both fertilizer treatments (Table 5). Applying fertilizer resulted in fewer white grubs when the traditional pest management approach was used. The white grub population was similar when peanut was fertilized and traditional pest management used compared to improved pest management in the absence of fertilizer. The lowest number of white grubs was observed when peanut was fertilized and the improved approach to pest management was used. The mechanism behind the reduced numbers of white grubs due to the interaction between these practices is not known. Cultivar affected response to planting date, fertilizer, and pest management practice (Supplementary Table S4). The highest number of white grubs was noted when Chitaochi was planted late compared with early or mid-plantings (Table 6). However, white grub populations were not affected by planting date when the Sarinut 2 cultivar was selected. When fertilizer was not applied or when traditional pest management was used, white grub populations were the highest. Fertilizing Chitaochi reduced white grubs compared with the no-fertilizer control for Chitaochi. White grub populations were lower when Sarinut 2 was planted compared with Chitaochi, regardless of fertilizer treatment. The lowest number of white grubs was noted when Sarinut 2 was fertilized. Calcium-based fertilizer most likely improved plant growth in a manner that allowed plants to withstand injury from pests or outgrow injury in a rapid manner [3,5]. Calcium strengthens cell walls in peanut and potentially prevents cell damage caused by arthropod pests [27]. White grub populations were lower when Sarinut 2 was planted compared with Chitaochi for both pest management practices. For both cultivars, the improved pest management approach had fewer white grubs.

Table 4. Number of wireworms on peanut plants at harvest, as influenced by the interaction between cultivar × fertilizer and cultivar × pest management practice.

	Wireworm Population on Peanut			
	Fertilizer Treatment [a]		Pest Management Practice [b]	
Cultivar	No Fertilizer	Fertilizer [c]	Traditional	Improved [d]
	No./plant			
Chitaochi	0.6 a	0.3 b	0.6 z	0.2 x
Sarinut 2	0.3 b	0.2 b	0.4 y	0.2 x

[a] Means followed by the same letter for the interaction between cultivar and fertilizer treatment are not significantly different at $\alpha = 0.05$. Data are pooled over the levels of planting date, pest management practice, and harvest date. [b] Means followed by the same letter for the interaction between cultivar and pest management practice are not significantly different at $\alpha = 0.05$. Data are pooled over levels of planting date, fertilizer treatment, and harvest date. [c] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [d] Improved pest management consisted of applying local soaps for aphid control and one additional hand weeding compared with the traditional approach.

Table 5. Number of white grubs as influenced by the interaction between cultivar and fertilizer and the interaction between cultivar and pest management practice [a].

Fertilizer [b]	White Grub Number on Peanut	
	Pest Management Practice	
	Traditional	Improved [c]
	No./plant	
No	2.8 a	1.0 b
Yes	1.2 b	0.3 c

[a] Means for the interaction between fertilizer treatment and pest management followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations, planting dates, cultivars, and harvest dates. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [c] Improved pest management practices consisted of applying local soaps to suppress aphids and one additional hand weeding compared with the traditional approach.

Table 6. Number of white grubs as influenced by the interaction between cultivar × planting date, cultivar × fertilizer, and cultivar × pest management practices.

Treatment Factor	White Grub Number on Peanut	
	Cultivar	
	Chitaochi	Sarinut 2
	No./plant	
Planting date [a]		
Early		
Mid	1.8 b	0.6 c
Late	2.0 b	0.6 c
	2.5 a	0.6 c
Fertilizer [b,c]		
No	3.0 z	0.8 x
Yes	1.1 y	0.3 w
Pest management practice [d]		
Traditional	2.9 A	1.0 B
Improved	1.2 B	0.1 C

[a] Means for the interaction between planting date and cultivar followed by the same lowercase letter are not significant at α = 0.05. Data are pooled over site–year combinations, fertilizer treatment, pest management practices, and harvest dates. [b] Means for the interaction between fertilizer treatment and cultivar followed by the same lowercase letter are not significant at α = 0.05. Data are pooled over site–year combinations, planting dates, pest management practices, and harvest dates. [c] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [d] Means for the interaction between pest management practice and cultivar followed by the same uppercase letter are not significant at α = 0.05. Data are pooled over site–year combinations, planting dates, fertilizer treatment, pest management practices, and harvest dates.

White grub and wireworm populations were affected by the interaction between pest management practice and harvest date (Supplementary Table S4). When pooled over site–years, cultivars, and fertilizer treatments, the highest number of both insect pests was observed when the farmers' pest management approach was used and harvest was delayed compared with all other combinations of pest management practices and harvest dates (Table 7). When comparing harvest dates within pest management practices, an increase in white grubs was noted when harvest was delayed for both approaches to pest management. This observation indicates that an appropriate time of harvest is critical for optimizing both the yield and quality of peanut [28].

Table 7. Number of white grubs and wireworms on peanut plants at harvest as influenced by the interaction between pest management practice × harvest date.

Pest Management Practice [c]	White Grubs [a]		Wireworms [b]	
	Harvest Date		Harvest Date	
	Optimum Pod Maturity	Optimum Pod Maturity Plus 7 Days	Optimum Pod Maturity	Optimum Pod Maturity Plus 7 Days
	No./plant			
Traditional	1.5 b	2.5 a	0.3 y	0.7 z
Improved	0.5 d	0.8 c	0.1 x	0.3 y

[a] Means for white grub population on plants for the interaction between pest management practice and harvest date followed by the same letter are not significantly different at α = 0.05. Data are pooled over site–year combinations, planting dates, cultivars, and fertilizer treatment. [b] Means for millipede population on plants for the interaction between pest management practice and harvest date followed by the same letter are not significantly different at α = 0.05. Data are pooled over site–year combinations, planting dates, cultivars, and fertilizer treatment. [c] Improved pest management practice consisted of the application of local soaps for aphid suppression and one additional hand weeding relative to the traditional practice.

Wireworm population was affected by the interaction between fertilizer treatment and pest management practice (Supplementary Table S4). The greatest number of wireworms was observed when pest management practices were similar to those used by farmers (Table 8). Within this pest management approach, the use of fertilizer resulted in fewer wireworms at harvest compared with no fertilizer. In contrast, when improved pest management was used, no difference in wireworm populations was noted.

Table 8. Number of wireworms on peanut plants at harvest as influenced by the interaction between fertilizer and pest management practice [a].

Fertilizer Treatments [b]	Wireworm Number on Peanut	
	Pest Management Practice [c]	
	Traditional	Improved
	No./plant	
No	0.7 a	0.2 bc
Yes	0.4 b	0.1 c

[a] Means for the interaction between fertilizer treatment and pest management practice followed by the same letter are not significant at α = 0.05. Data are pooled over site–year combinations, planting dates, cultivars, and harvest date. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [c] Improved pest management practices consisted of the application of local soaps for aphid suppression and one additional hand weeding compared with the traditional approach.

Termite population was affected by the interaction between cultivar, fertilizer, and harvest date (Supplementary Table S4). Delaying harvest for the cultivar Chitaochi in the absence of fertilizer resulted in the highest number of termites (Table 9). The delay in harvest resulted in an increase in termites for the cultivar Chitaochi regardless of fertilizer treatment. In contrast, no difference in termite numbers was observed for Sarinut 2 regardless of harvest date. When comparing within harvest dates, no difference in termite population was noted among combinations of cultivars and fertilizer treatments. However, when harvest was delayed, Chitaochi without fertilizer had the highest number of termites while Chitaochi with fertilizer had a lower population. Significant increases in arthropod populations and a lower yield and quality have been observed when harvest is delayed past the optimum timing [29]. Fekede at al. [30] reported that delays in harvesting peanut until peanut was past its optimum maturity resulted in poor quality of seed (e.g., germination and seedling vigor) due to damage caused by arthropods and infection by pathogens. Sarinut 2 had lower numbers of arthropods than Chitaochi at this harvest date regardless of fertilizer treatment.

Table 9. Number of termites on peanut plants at harvest as influenced by the interaction between cultivar, fertilizer, and harvest date [a].

Cultivar	Fertilizer [b]	Termite Number on Peanut	
		Harvest Date	
		Optimum Maturity	Optimum Maturity Plus 7 Days
		No./plant	
Chitaochi	No	54 c	264 a
Sarinut 2	Yes	9 c	21 c
Chitaochi	No	16 c	96 b
Sarinut 2	Yes	3 c	10 c

[a] Means for the interaction between cultivar, fertilizer treatment, and harvest date followed by the same letter are not significant at α = 0.05. Data are pooled over site–year combinations, planting dates, and pest management practices. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting.

Millipedes and white grubs were affected by the main effect of planting date (Supplementary Table S4). Millipede number was lower for the first planting date compared with the second and third planting dates (Table 10). No difference in the infestation of this pest was observed when comparing the second and third planting dates. The white grub population was lower for the first planting date compared with the last planting date: population at the second planting date was intermediate. Millipede population was greater when harvest was delayed regardless of planting date, cultivar, fertilizer treatment, or pest management practice (Table 10). Umeh et al. [8] also observed increased populations of white grub and millipede and greater crop injury during years of higher precipitation.

Table 10. Influence of planting date and harvest date on the number of millipedes and white grubs at peanut harvest.

Treatment Factor	Millipedes	White Grubs
	No./plant	
Planting date [a]		
Early	2.4 b	1.1 y
Mid	2.9 a	1.3 yz
Last	2.9 a	1.5 z
Harvest date [b]		
Optimum maturity	2.3	1.0
Optimum maturity plus 7 days	3.1	1.6
P > F	*	*

[a,b] Means for planting dates for millipedes and white grubs followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations, cultivars, fertilizer treatment, pest management practices, and harvest dates. * indicates significance for harvest dates for millipedes and white grubs at $p \leq 0.05$. Data are pooled over site–year combinations, cultivars, fertilizer treatment, pest management practices, and planting dates.

Of particular interest is the response of arthropods to fertilizer treatment and cultivar. While we did not set up the experiment and make appropriate observations to establish a causal relationship between these factors, several possibilities are found in the literature. Nitrogen status in plants can affect the relationships between herbivore and predatory insects [31–34] and plant defense mechanisms [35–37]. Potassium deficiency has been shown to increase plant injury from insects [38]. Wetzel et al. [39] reported that nutrient balance in plants can affect insect herbivore activity. Additional research in Ghana is needed to determine why arthropod populations were often lower when peanut nutrition was improved. The cultivar Sarinut 2 has not been established in the literature as resistant to arthropods. Our results suggest that additional research is needed to determine if this improved cultivar can be defined as resistant to certain insects that are of economic importance to peanut.

3.3. Aphids and Groundnut Rosette Disease

The number of aphids on plants at harvest was affected by the interaction between planting date, fertilizer treatment, and pest management practice (Supplementary Table S4). Regardless of planting date or fertilizer treatment, fewer aphids were observed when the additional weeding was included and local soaps were used (Table 11). When comparing combinations of planting dates and fertilizer treatments, fewer aphids were observed when fertilizer was applied compared with no fertilizer, regardless of planting date, when the farmer approach to pest management was used. As discussed earlier, relative to the response of other arthropods to plant nutrition, aphid populations may have been affected by the differential status of nutrients in foliage and the presence of predators on aphid populations. In the current work, we did not monitor predator populations.

The highest number of aphids was observed when peanut was planted on the third date, followed by the first planting date and then the middle planting date, for the farmer pest management practice. No difference in aphid population was observed across planting dates when fertilizer was applied when using this approach to pest management. In contrast, no difference in aphid numbers was observed when the improved pest management approach was used. A component of the improved pest management regime was the application of potassium-based soap. Abudulai et al. [3] reported fewer aphids and less GRD on peanut treated with locally derived potassium soaps.

The aphid population was lower on Sarinut 2 compared with Chitaochi when farmer practices were used (Table 12). Although not substantiated, this difference may be associated with the differential concentrations of tannins in leaves for these cultivars. Kimmins et al. [40] reported that aphid populations were affected by tannin concentration in peanut leaves. Improved pest management resulted in fewer aphids for both cultivars compared to farmer practices. No difference in aphid numbers was observed for cultivars when comparing within the improved pest management practice.

Table 11. Influence of planting date, fertilizer treatment, and pest management practice on aphid population on peanut plants at harvest [a].

		Number of Aphids	
		Pest Management Practices	
Planting Date	Fertilizer [b]	Traditional	Improved [c]
		No./plant	
Early	No	439 b	0 e
Early	Yes	115 d	11 e
Mid	No	340 c	32 e
Mid	Yes	162 d	0 e
Late	No	508 a	39 e
Late	Yes	129 d	1 e

[a] Means for the interaction between planting date, fertilizer treatment, and pest management practice followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations, cultivars, and harvest dates. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [c] Improved pest management consisted of applying local soaps for aphid suppression and one additional hand weeding compared with the traditional practice.

Table 12. Number of aphids as influenced by the interaction between cultivar and pest management practices [a].

	Number of Aphids	
	Pest Management Practices	
Cultivar	Traditional	Improved [b]
	No./plant	
Chitaochi	423 a	26 c
Sarinut 2	141 b	2 c

[a] Means for the interaction between cultivar and pest management practice followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations, planting dates, and harvest dates. [b] Improved pest management practices consisted of applying local soaps for aphid suppression and one additional hand weeding compared with the traditional practice.

Groundnut rosette disease was affected by the interaction between planting date, cultivar, fertilizer treatment, and pest management practice (Supplementary Table S4). The highest level of GRD was observed when the cultivar Chitaochi was planted either at the mid- or late planting date in the absence of fertilizer (Table 13). Less rosette was noted for Sarinut 2 when peanut was planted at the mid- and late timings when fertilizer was not applied for both approaches to pest management. The resistance or field tolerance of Sarinut 2 compared with Chitaochi has not been demonstrated in the peer-reviewed literature. Our results suggest that Sarinut 2 may express resistance to GRD, at least when compared with the traditional cultivar, Chitaochi. Although Sarinut 2 was not included in research by Appiah et al. [41], several cultivars express resistance to GRD when compared with Chitaochi in Ghana.

Table 13. Groundnut rosette disease at harvest due to arthropods as influenced by the interaction between planting date, cultivar, fertilizer treatment, and pest management practices [a].

		Groundnut Rosette Disease			
		No Fertilizer		**Fertilizer [b]**	
		Pest Management Practices [c]		**Pest Management Practices**	
Planting date	**Cultivar**	**Traditional**	**Improved**	**Traditional**	**Improved**
		%			
Early	Chitaochi	4.0 b	0.3 kl	1.2 fg	0.1 l
Early	Sarinut 2	1.3 f	0.2 l	0.6 jkl	0 l
Mid	Chitaochi	4.6 a	0.8 hij	1.8 e	0.3 kl
Mid	Sarinut 2	2.2 d	0.2 l	0.9 fgh	0 l
Late	Chitaochi	4.4 a	1.1 fgh	2.1 de	0 l
Late	Sarinut 2	2.7 c	0.4 jkl	1.3 fg	0 l

[a] Means for the interaction between planting date, cultivar, fertilizer treatment, and pest management practice followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations and harvest dates. [b] Fertilizer applied at 375 kg/ha. [c] Improved pest management practices consisted of the application of local soaps for aphid suppression and one additional hand weeding.

3.4. Canopy Defoliation Caused by Leaf Spot Disease

The interaction between cultivar, fertilizer treatment, pest management practice, and harvest date was significant for peanut canopy defoliation caused by leaf spot disease (Supplementary Table S4). Delaying harvest by 7 days resulted in greater defoliation regardless of cultivar, fertilizer treatment, and production package (Table 14). In all but two combinations of cultivar, pest management practice, and harvest date, less defoliation was noted when fertilizer was applied compared with the no-fertilizer treatment. The cultivar Sarinut 2 was less defoliated by leaf spot disease than the cultivar Chitaochi, regardless of fertilizer treatment, pest management practice, and harvest date. This suggests that the improved cultivar Sarinut 2 is tolerant or moderately resistant to leaf spot disease. Gaikpa et al. [42] reported that most of the moderately resistant cultivars were found among genotypes with low levels of defoliation. They stated that leaf-spot-resistant genotypes had more leaves on the plant than their susceptible counterparts. Improved plant nutrition may also contribute to prolonged vegetative growth, which could contribute to yield.

Table 14. Influence of planting date, cultivar, fertilizer treatment, pest management practice, and harvest date on peanut canopy defoliation caused by early and late leaf spot disease [a].

			Peanut Canopy Defoliation			
			Pest Management Practice [c]			
			Traditional		**Improved**	
			Harvest Date		**Harvest Date**	
Planting Date	**Cultivar**	**Fertilizer [b]**	**Optimum Timing**	**Optimum Timing Plus 7 Days**	**Optimum Timing**	**Optimum Timing Plus 7 Days**
			%			
Early	Chitaochi	No	53 f	72 bc	42 k	57 e
Early	Chitaochi	Yes	41 k	56 e	30 n	40 k
Early	Sarinut 2	No	35 l	44 j	24 o	30 n
Early	Sarinut 2	Yes	30 n	40 k	21 p	31 n
Mid	Chitaochi	No	62 d	82 a	47 hij	62 d
Mid	Chitaochi	Yes	46 ij	61 d	35 l	45 ij
Mid	Sarinut 2	No	40 k	50 fg	25 o	32 mn
Mid	Sarinut 2	Yes	34 lm	44 j	20 p	31 n
Late	Chitaochi	No	74 b	82 a	57 e	72 bc
Late	Chitaochi	Yes	56 e	71 c	40 k	50 fg
Late	Sarinut 2	No	47 hi	57 e	30 n	36 l
Late	Sarinut 2	Yes	40 k	49 gh	20 9	31 n

[a] Means for the interaction between planting date, cultivar, fertilizer treatment, pest management practice, and harvest date followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [c] Improved pest management consisted of applying local soap for the suppression of aphids and one additional hand weeding compared with the traditional practice.

3.5. Scarring and Penetration of Peanut Pods Caused by Arthropods

Pod scarring was affected by the interactions between planting date, fertilizer treatment, and cultivar, the interaction between planting date, fertilizer treatment, and pest management practice, and the interaction between cultivar, fertilizer treatment, pest management practice, and harvest date (Supplementary Table S4). Pod scarring was lower when fertilizer was applied for both Chitaochi and Sarinut 2 for all combinations of planting date and fertilizer treatment (Table 15). In the absence of fertilizer, pods for Sarinut 2 had less scarring than Chitaochi. However, when fertilizer was applied, no difference in pod scarring was noted when comparing cultivars. Oni and Lawal [43] reported a variable response of cultivars to planting date.

Table 15. Scarring of pods at harvest due to arthropods as influenced by the interaction between planting date, fertilizer treatment, and cultivar and the interaction between planting date, fertilizer treatment, and pest management practices.

		Pod Scarring			
		Cultivar [a]		Pest Management Practices [b]	
Planting Date	**Fertilizer [c]**	**Chitaochi**	**Sarinut 2**	**Traditional**	**Improved [d]**
		%			
Early	No	2.9 b	0.9 d	3.7 y	0.2 uv
Early	Yes	0.6 def	0.1 f	0.7 wx	0 t
Mid	No	3.3 b	0.8 de	3.9 y	0.3 uvw
Mid	Yes	0.3 f	0.2 f	0.5 vwx	0.1 uv
Late	No	5.4 a	1.6 c	6.1 z	0.9 x
Late	Yes	0.5 def	0.3 f	0.7 wx	0.1 uv

[a] Means for the interaction between planting date, fertilizer treatment, and cultivar followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations, production practices, and harvest dates. [b] Means for the interaction between planting date, fertilizer treatment, and pest management practice followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations, cultivars, and harvest dates. [c] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [d] Improved pest management consisted of the application of local soaps for aphid suppression and one additional hand weeding.

Pod scarring for Chitaochi and Sarinut 2 was greater when harvest was delayed in the absence of fertilizer treatment when farmer pest management was used (Table 16). No difference in scarring due to harvest date was noted for both cultivars for this approach to pest management when fertilizer was applied. Less scarring was observed when improved pest management was used for the cultivar Chitaochi in the absence of fertilizer but not when fertilizer was applied when peanut was harvested at optimum maturity compared with delayed harvest. When fertilizer was applied to Chitaochi and Sarinut 2 with farmer pest management, or when fertilizer was applied with farmer pest management, there was no difference in pod scarring due to harvest date. Additionally, no difference in pod scarring was noted when peanut was harvested later when improved pest management was used, regardless of fertilizer treatment. When comparing within harvest dates, the greatest pod scarring was noted for Chitaochi in the absence of fertilizer and when farmer pest management practices were used. When harvested at the optimum timing, pod scarring was similar for Chitaochi when fertilizer was applied and for Sarinut 2 without fertilizer when farmer pest management was used. No differences in pod scarring were observed for other combinations of cultivar, fertilizer treatment, and pest management practice. When comparing within cultivars when harvest was delayed, applying fertilizer when the farmer practice was used resulted in more pod scarring than when fertilizer was applied in this approach to pest management or when fertilizer was applied when improved pest management was used.

Table 16. Influence of cultivar, fertilizer treatment, pest management practice, and harvest date on scarring of pods caused by arthropods [a].

Cultivar	Fertilizer [b]	Pest Management Practice [c]	Pod Scarring	
			Harvest Date	
			Optimum Timing	Optimum Timing Plus 7 Days
			%	
Chitaochi	No	Traditional	5.0 b	9.1 a
Chitaochi	Yes	Traditional	0.7 def	0.0 de
Chitaochi	No	Improved	0.4 fg	1.0 de
Chitaochi	Yes	Improved	0 g	0.1 g
Sarinut 2	No	Traditional	1.2 d	3.0 c
Sarinut 2	Yes	Traditional	0.3 fg	0.5 efg
Sarinut 2	No	Improved	0.1 g	0.2 fg
Sarinut 2	Yes	Improved	0 g	0 g

[a] Means for the interaction between cultivar, fertilizer treatment, pest management practice, and harvest date followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [c] Improved pest management practice consisted of the application of local soaps for aphid suppression and one additional hand weeding compared with the traditional practice.

The penetration of pods by arthropods was affected by the interaction between cultivar, fertilizer treatment, and harvest date, and the interaction between fertilizer treatment, pest management practice, and harvest date (Supplementary Table S4). The greatest level of penetration of pods was observed when the cultivar Chitaochi was planted without fertilizer when comparing cultivar and fertilizer treatments within harvest dates (Table 17). Fertilizing Chitaochi or planting Sarinut 2 with or without fertilizer led to the similar penetration of pods. For both harvest dates, the lowest amount of pod penetration was observed for Sarinut 2 with fertilizer. When comparing pod penetration regarding the interaction between fertilizer treatment, pest management practices, and harvest date, growing the cultivar Chitaochi with the farmer pest management approach led to the greatest penetration when comparing within harvest dates (Table 18). For both harvest dates, fertilizer and the farmer pest management and the improved approach to pest management without fertilizer resulted in a similar penetration of pods. The lowest amount of pod penetration was noted when fertilizer and improved pest management were used. With the exception of using both fertilizer and improved pest management, pod boring increased when harvest was delayed. Poor seed quality is associated with damage caused by insect boring [28]. The penetration of peanut pods caused by insects provides an entry point for soil, which contains *Aspergillus flavus*, the organism that contains aflatoxin [44,45].

Table 17. Influence of cultivar, fertilizer treatment, and harvest date on the boring of pods caused by arthropods [a].

Cultivar	Fertilizer [b]	Pod Boring	
		Harvest Date	
		Optimum Timing	Optimum Timing Plus 7 Days
		%	
Chitaochi	No	1.6 b	2.8 a
Chitaochi	Yes	0.4 d	0.6 c
Sarinut 2	No	0.4 d	0.8 c
Sarinut 2	Yes	01 e	0.2 de

[a] Means for the interaction between cultivar, fertilizer treatment, and harvest date followed by the same letter are not significant at $\alpha = 0.05$. Data are pooled over site–year combinations and pest management practices. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting.

Table 18. Influence of fertilizer treatment, pest management practice, and harvest date on the boring of pods caused by arthropods [a].

Fertilizer [b]	Pest Management Practices [c]	Pod Boring	
		Harvest Date	
		Optimum Timing	Optimum Timing Plus 7 Days
		%	
No	Traditional	1.6 b	2.8 a
Yes	Traditional	0.4 d	0.7 c
No	Improved	0.4 d	0.8 c
Yes	Improved	0 e	0.1 e

[a] Means for the interaction between fertilizer treatment, pest management practice, and harvest date followed by the same letter are not significant at α = 0.05. Data are pooled over site–year combinations and cultivars. [b] Fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) was applied at 375 kg/ha at 4 weeks after planting. [c] Improved pest management practice consisted of the application of local soaps for aphid suppression and one additional hand weeding.

A wide range of factors can affect peanut yield, including pest reaction. Peanut is a resilient crop with the ability to compensate for a wide range of biotic and abiotic stresses. Defining the most important factor that impacts peanut yield can be challenging, especially when trying to determine the precise mechanism associated with reactions among factors. A primary goal of this research was to determine if interactions between treatment factors (e.g., planting date, cultivar, fertility, pest management practice, and harvest date) exist, and if so, to define the magnitude of those interactions. While numerous interactions were noted for pests and the damage they cause to peanut [46], yield was affected primarily by the main effects and the interaction between cultivar × fertility and planting date × fertility. Pearson correlation coefficients indicated that all measures of pest population and damage from pests negatively impacted yield ($p \leq 0.0003$, Table 19). Although the causative nature of the effects of pests and pest management was identified to a degree in mean separation tests for various main effects and interactions, negative correlation coefficients was highest for leaf spot disease (R = −0.63), followed by GRD (R = −0.63), for peanut yield. Aphid, millipede, and white grub populations, and the scarring and penetration of pods caused by arthropods, had R values between −0.28 and −0.38 with respect to yield. Although significant, the R values for wireworms and termites were relatively low, at −0.12 and −0.11, respectively.

Table 19. Pearson correlation coefficients for pod yield and economic return versus population of aphids on plants; groundnut rosette disease; population of millipedes, white grubs, wireworms, and termites on plants; canopy defoliation caused by leaf spot disease; and percentages of pods with scarring and penetration from arthropod feeding [a].

Pest or Pest Damage	Pod Yield (kg/ha)	Economic Return ($/ha)
Aphid population (No./plant)	≤0.0001, R = −0.32	≤0.0001, R = −0.31
Groundnut rosette disease (Scale 1–9)	≤0.0001, R = −0.44	≤0.0001, R = −0.43
Millipede density (No./plant)	≤0.0001, R = −0.28	≤0.0001, R = −0.27
White grub density (No./plant)	≤0.0001, R = −0.34	≤0.0001, R = −0.33
Wireworm density (No./plant)	≤0.0001, R = −0.12	≤0.0001, R = −0.12
Termite density (No./plant)	0.0001, R = −0.11	0.0003, R = −0.11
Canopy defoliation due to leaf spot disease (%)	≤0.0001, R = −0.63	≤0.0001, R = −0.62
Scarred pods (%)	≤0.0001, R = −0.38	≤0.0001, R = −0.37
Penetrated pods (%)	≤0.0001, R = −0.37	≤0.0001, R = −0.36

[a] Data are pooled over site–years.

4. Conclusions

These experiments were designed to provide information to practitioners to assist in developing effective production and pest management packages for peanut production systems. While a considerable number of interactions among treatment factors (e.g., planting dates, cultivars, fertilizer treatments, pest management practices, harvest dates) were documented for pest reaction, yield and financial returns were most often affected independently by these factors. These results suggest that farmers in Ghana can select from the available inputs and increase yield and financial return with minimal concern regarding the interactions between the technologies they may invest in. One question is how translatable the findings of the current work are to other regions of Africa or other continents where peanut is grown. The improvements in pest management through cultural practices (e.g., cultivar selection, planting date, and fertilizer) are important and translatable to peanut production systems regardless of geography or the complexity of the resources available for these systems. While the specifics of cultivars will vary based on pest complexes, genetic resources, and the seed systems that deliver varieties to farmers, themes including the use of an improved variety and enhanced fertility are basic principles that can be translated to other regions. While response to planting date may be translatable to other areas of production in West Africa, this response may be not be as applicable to other countries or regions because of the specificities associated with local weather and climate. The value of timely weeding and removing weeds at multiple times during the cropping cycle are directly applicable to peanut production systems around the world. The importance of ensuring peanut is free of weed interference early in the season, during the critical period of interference, is almost universal. Additional research is needed to determine the most essential element of the improved pest management practice on yield and economic considerations (e.g., locally derived potassium soaps vs. one additional hand weeding vs. drying pods on tarpaulins). The results showing fewer arthropods on plants with more optimum nutrient status should be investigated in more detail to define the causative factor.

The results from this experiment can inform peanut farmers and their advisors in Ghana on the economic value of cultural practices for peanut. The information derived from these experiments will be used to assist farmers and practitioners in modifying their practices to avoid or minimize risk.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14050972/s1, Table S1: Weekly rainfall at two locations in northern Ghana during 2020 and 2021. Table S2: Planting dates at three locations in northern Ghana during 2020 and 2021. Table S3: Planting dates at three locations in northern Ghana during 2020 and 2021. Table S4: Planting dates at three locations in northern Ghana during 2020 and 2021.

Author Contributions: Conceptualization, A.S., M.A., I.K.D., J.A.N. and D.L.J.; methodology, A.S., M.A., D.L.J., M.A., I.K.D. and M.B.M.; statistical analysis, D.L.J.; investigation, A.S. and S.A.; resources, D.L.J., D.H. and J.R.; data curation, A.S. and D.L.J.; writing—original draft preparation, A.S. and D.L.J.; writing—review and editing, A.S., M.A., I.K.D., J.A.N., D.L.J., G.Y.M., W.A., R.A., S.A., G.B.-A., M.B.M., R.L.B., G.M., M.B., D.H. and J.R.; project administration, M.A. and J.A.N.; funding acquisition, M.A., J.A.N., D.L.J., D.H. and J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the North Carolina Agricultural Foundation and the Office of Agriculture, Research and Policy, Bureau of Food Security, U.S. Agency for International Development, under the terms of Award No. AID-ECG-A-00-07-0001 to The University of Georgia as management entity for U.S. Feed the Future Innovation Lab for Peanut. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development.

Data Availability Statement: Contact the corresponding author with questions concerning data availability.

Acknowledgments: Appreciation is expressed to the staff at the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute, Tamale and Wa, Ghana, the University for Development Studies, Tamale, Ghana, and the Council for Scientific and Industrial Research-Crops Research Institute, Kumasi, Ghana for their assistance with this research.

Conflicts of Interest: D.H. and J.R. are the Director and Associate Director of the U.S. Feed the Future Innovation Lab for Peanut, respectively. This is the funding source for the research presented in this paper. These individuals were involved in the planning stages of the project based on directives from U.S. Feed the Future. They also reviewed the manuscript prior to submission and provided technical feedback. All other authors declare no conflicts of interest.

References

1. Fletcher, S.M.; Shi, Z. An overview of world peanut markets. In *Peanuts: Genetics, Processing, and Utilization*; Stalker, H.T., Wilson, R.F., Eds.; AOCS Press Monograph on Oil Seeds; Elsevier: Amsterdam, The Netherlands, 2016; pp. 267–288.
2. Valentine, H. The role of peanuts in global food security. In *Peanuts: Genetics, Processing, and Utilization*; Stalker, H.T., Wilson, R.F., Eds.; AOCS Press Monograph on Oil Seeds; Elsevier: Amsterdam, The Netherlands, 2016; pp. 447–461.
3. Abudulai, M.; Mahama, G.; Dzomeku, I.; Seidu, A.; Nboyine, J.A.; Opoku, N.; Alhassan, M.H.; Appaw, W.O.; Ellis, W.O.; Akromah, R.; et al. Evaluation of agricultural practices to increase yield and financial return and minimize aflatoxin contamination in peanut in northern Ghana. *Peanut Sci.* **2020**, *47*, 156–162. [CrossRef]
4. Naab, J.B.; Seidu, S.S.; Gyasi, K.O.; Mahama, G.Y.; Prasad, P.V.V.; Boote, K.J.; Jones, J.W. Groundnut yield response and economic benefits of fungicide and phosphorus application in farmer-managed trials in Northern Ghana. *Exp. Agric.* **2009**, *45*, 385–399. [CrossRef]
5. Abady, S.; Shimelis, H.; Pasupuleti, J.; Mashilo, J. Groundnut (*Arachis hypogaea* L.) in sub-Saharan Africa: A review. *Acta Agric. Scand. Sect. B–Soil Plant Sci.* **2019**, *69*, 528–548.
6. Nutsugah, S.K.; Abudulai, M.; Oti-Boateng, C.; Brandenburg, R.L.; Jordan, D. Management of leaf spot diseases of peanut with fungicides and local detergents in Ghana. *Plant Pathol.* **2007**, *6*, 248–253.
7. Waliyar, E.; Kumar, P.L.; Ntare, B.R.; Monyo, E.; Nigam, S.N.; Reddy, A.S.; Osiru, M.; Diallo, A.T. *A Century of Research on Groundnut Rosette Disease and Its Management*; Information Bulletin No. 75; International Crops Research Institute for the Semi-Arid Tropics: Andhra Pradesh, India, 2002; 40p, ISBN 978-92-9066-501-4.
8. Umeh, V.C.; Youm, O.; Waliyar, F. Soil pests of peanut in sub-Saharan Africa–A review. *Int. J. Trop. Insect Sci.* **2002**, *21*, 23–32. [CrossRef]
9. Everman, W.J.; Clewis, S.B.; Thomas, W.E.; Burke, I.C.; Wilcut, J.W. Critical period of weed interference in peanut. *Weed Technol.* **2008**, *22*, 63–67. [CrossRef]
10. Idoko, M.D.; Sabo, E. Challenges in groundnut production and adoption of groundnut production technology information packages among women farmers. *J. Agric. Environ. Sci.* **2014**, *3*, 107–117.
11. Osei, O.; Abaidoo, R.C.; Ahiabor, B.D.K.; Boddey, R.M.; Rouws, L.F.M. Bacterial related to *Bradyrhizobium yuanmingense* from Ghana are effective groundnut micro-symbionts. *Appl. Soil Ecol.* **2018**, *127*, 41–50. [CrossRef]
12. White, P.J.; Broadly, M.R. Calcium in plants. *Ann. Bot.* **2003**, *92*, 487–511. [CrossRef]
13. Dzomeku, I.K.; Baba, S.; Abudulai, M.; Mohammed, A.M.; Abdulai, A.L. Groundnut (*Arachis hypogaea* L.) response to phosphorus and weed management in the Guinea Savannah Zone of Ghana. *Tropicultura* **2019**, *37*. [CrossRef]
14. Akobundu, I.O. Weed control in other food crops. In *Weed Science in the Tropics: Principles and Practices*; John and Wiley and Sons: Hoboken, NJ, USA, 1987; 522p.
15. Subrahmaniyan, K.; Kalaiselvan, P.; Arulmozih, N. Weed control in groundnut (*Arachis hypogaea* L.) with polyethylene film mulching. *Int. J. Pest Manag.* **2002**, *48*, 261–264. [CrossRef]
16. Anonymous. Growing Africa agriculture: Planting the seeds of a green revolution in Africa. Alliance for a Green Revolution in Africa. 2014. Available online: https://reliefweb.int/report/world/planting-seeds-green-revolution-africa (accessed on 29 April 2024).
17. Anonymous. *National Seed Plan. Plan for the Implementation of the National Seed Policy*; Ministry of Food and Agriculture: Accra, Ghana, 2015.
18. Tasila Konja, D.; Mabe, F.N.; Oteng-Frimpong, R. Profitability and profit efficiency of certified groundnut seed and conventional groundnut production in Northern Ghana: A comparative analysis. *Cogent Econ. Financ.* **2019**, *7*, 1631525. [CrossRef]
19. Anonymous. Groundnuts. In *Catalogue of Crop Varieties Released and Registered in Ghana*; National Variety Release and Registration Committee Directorate of Crop Services, Ministry of Food and Agriculture: Accra, Ghana, 2019; pp. 48–52.
20. Oteng-Frimpong, R.; Konlan, S.P.; Denwar, N.N. Evaluation of selected groundnut (*Arachis hypogaea* L.) lines for yield and haulm nutritive quality traits. *Int. J. Agron.* **2017**, *2017*, 7479309. [CrossRef]
21. Backman, P.A.; Crawford, M.A. Relationship between yield loss and severity or early and late leafspot disease of peanut. *Plant Dis.* **1984**, *74*, 1101–1103. [CrossRef]
22. Nutter, F.R., Jr.; Littrell, R.H. Relationship between defoliation, canopy reflectance, and pod yield in the peanut-late season pathosystem. *Crop Prot.* **1996**, *15*, 135–142. [CrossRef]
23. Okello, D.K.; Akello, L.; Tukamuhabwa, P.; Odong, T.; Ochwo-Ssemakula, M.; Adriko, J.; Deom, C.M. Groundnut rosette disease symptoms types distribution and management of the disease in Uganda. *Afr. J. Plant Sci.* **2014**, *8*, 153–163.
24. Khalid, E.M.; Afutu, E.; Odong, T.L.; Okello, D.K.; Nuwamanya, E.; Olupot, G.; Rubaihayo, P.R.; Okori, P. Assessment of groundnut (*Arachis hypogaea* L.) genotypes for yield and resistance to late leaf spot and rosette diseases. *J. Exp. Agric. Int.* **2018**, *21*, 1–13. [CrossRef]

25. Kumakech, A.; Otim, G.A.; Opio, T.; Komakech, A.; Turyagyenda, L.F. Yield and disease responses of improved groundnut genotypes under natural disease infection in Northern Uganda: Implication for groundnut disease management. *J. Agric. Sci.* **2022**, *14*, 70–77. [CrossRef]
26. Williams, E.J.; Drexler, J.S. A non-destructive method for determining peanut pod maturity. *Peanut Sci.* **1981**, *8*, 134–141. [CrossRef]
27. Alireza, H.G.; Vishekaei, M.N.S.; Hosseinzadeh, M.H. Effect of potassium and calcium application on yield components and qualitative characteristics of peanut (*Arachis hypogaea* L.) in Guilan province, Iran. *World Appl. Sci. J.* **2012**, *16*, 540–546.
28. Zuza, E.J.; Muitia, A.; Amane, M.I.V.; Brandenburg, R.L.; Mondjana, A.M. Effect of harvesting time on groundnut yield and yield components in Northern Mozambique. *J. Postharvest Technol.* **2017**, *5*, 55–63.
29. Singh, F.; Oswalt, D.L. *Groundnut Production Practices*; ICRISAT Skill Development Series No. 3; ICRISAT Training Program; International Crops Research Institute for the Semi-Arid Tropics: Andhra Pradesh, India, 1995; Available online: http://gis4agricgh.net/POLICIES/Groundnut%20Production.pdf (accessed on 29 April 2024).
30. Fekede, T.A. Evaluation of Harvesting Time on Seed Quality of Groundnut (*Arachis hypogaea* L.) in Assosa District, Western Ethiopia. *Int. J. Agric. Environ. Sci.* **2019**, *6*, 37–45.
31. Bala, K.; Sood, A.K.; Pathania, V.S.; Thakur, S. Effect of plant nutrition in insect management: A review. *J. Pharmacol. Phytochem.* **2018**, *7*, 2737–2742.
32. Coqueret, V.; Le Bot, J.; Larbat, R.; Desneux, N.; Robin, C.; Adamowicz, S. Nitrogen nutrition of tomato plant alters leafminer dietary intake dynamics. *J. Insect Physiol.* **2017**, *99*, 130–138. [CrossRef]
33. Han, P.; Becker, C.; Le Bot, J.; Larbat, R.; Lavior, A.V.; Desneux, N. Plant nutrient supply alters the magnitude of indirect interactions between insect herbivores: From foliar chemistry to community dynamics. *J. Ecol.* **2020**, *108*, 1497–1510. [CrossRef]
34. Lou, Y.; Baldwin, I.T. Nitrogen supply influences herbivore-induced direct and indirect defenses and transcriptional responses in Nicotiana attenuata. *Plant Physiol.* **2004**, *135*, 496–506. [CrossRef] [PubMed]
35. Poelman, E.H.; Dicke, M. Chapter 9—Plant-mediated interactions among insects within a community ecological perspective. In *Annual Plant Reviews Insect Plant Interactions*; Poelman, E.H., Dicke, M., Eds.; Wiley: New York, NY, USA, 2014.
36. Larbat, R.; Paris, C.; Le Bot, J.; Adamowicz, S.; Robin, C. Phenolic characterization and variability in leaves, stems and roots of Micro-Tom and patio tomatoes, in response to nitrogen limitation. *Plant Sci.* **2014**, *224*, 62–73. [CrossRef]
37. Tan, C.W.; Chiang, S.Y.; Ravuiwasa, K.T.; Yadav, J.; Hwang, S.Y. Jasmonate-induced defenses in tomato against *Helicoverpa armigera* depend in part on nutrient availability, but artificial induction via methyl jasmonate does not. *Arthropod-Plant Interact.* **2012**, *6*, 531–541. [CrossRef]
38. Amtmann, A.; Troufflard, S.; Armengaud, P. The effect of potassium nutrition on pest and disease resistance in plants. *Physiol. Plant.* **2008**, *133*, 682–691. [CrossRef]
39. Wetzel, W.C.; Kharouba, H.M.; Robinson, M.; Holyoak, M.; Karban, R. Variability in plant nutrients reduces insect herbivore performance. *Nature* **2016**, *539*, 425–427. [CrossRef]
40. Kimmins, F.M.; Padgham, D.E.; Harborne, J.B.; Rao, D.V.R. Condensed tannin levels and resistance of groundnuts (*Arachis hypogaea*) against aphids (*Aphis cracczvora*). *Photochemistry* **1992**, *31*, 3795–3800.
41. Appiah, A.S.; Offei, S.K.; Tegg, R.S.; Wilson, C.R. Varietal response to groundnut rosette disease and the first report of groundnut ringspot virus in Ghana. *Plant Dis.* **2016**, *100*, 946–952. [CrossRef] [PubMed]
42. Gaikpa, D.S.; Akromah, R.; Asibuo, J.Y.; Nyadanu, D. Molecular and phenotypic resistance of groundnut varieties to leaf spots disease in Ghana. *J. Microb. Biotech Food Sci.* **2017**, *6*, 1043–1048. [CrossRef]
43. Oni, F.G.O.; Lawal, B.A. Effects of sowing date on yield and yield parameters of some groundnut (*Arachis hypogaea* L.) cultivar under rainfed condition in Ogbomoso, Nigeria. *J. Nat. Sci. Res.* **2019**, *9*, 43–46.
44. Danso, J.K.; Mbata, G.N.; Holton, R.L. Preharvest insect pests of peanuts and associated aflatoxin contaminants in Georgia, USA. *J. Econ. Entomol.* **2024**, toae074. [CrossRef] [PubMed]
45. Umeh, V.C.; Waliyar, F.; Traore, A. *Aspergillus* species colonization of termite-damages peanuts in parts of West Africa and its control prospects. *Peanut Sci.* **2000**, *27*, 1–6. [CrossRef]
46. Tanzubil, P.B. Incidence of arthropod pests and diseases of groundnut (*Arachis hypogaea* L.) in northern Ghana. *J. Entomol. Zool. Stud.* **2016**, *4*, 29–32.