Evaluation of Agricultural Practices to Increase Yield and Financial Return and Minimize Aflatoxin Contamination in Peanut in Northern Ghana

M. Abudulai[1], G. Mahama[2], I. Dzomeku[3], A. Seidu[1], I. Sugri[1], J.A. Nboyine[2], N. Opoku[3], M.H. Alhassan[1], W. Appaw[4], W.O. Ellis[4], R. Akromah[4], M.B. Mochiah[5], A. Dankyi[5], D.L. Jordan[6], R.L. Brandenburg[7], B.E. Bravo-Ureta[8], J. Jelliffe[8], K. Boote[9], G. MacDonald[9], J. Chen[10], R.D. Phillips[10], K. Mallikarjunan[11], M. Balota[12], D. Hoisington[13], and J. Rhoads[13]

ABSTRACT

Peanut (*Arachis hypogaea* L.) yield and financial returns are often low for smallholder farmers in Ghana. Additionally, aflatoxin concentration in foods derived from peanut can be high enough to adversely affect human health. Eight experiments were conducted in 2016 and 2017 in northern Ghana to compare yield, financial returns, pest reaction, and aflatoxin contamination at harvest with traditional farmer versus improved practices. Relative to the farmer practice, the improved practice consisted of weeding one extra time, applying local potassium-based soaps to suppress arthropods and pathogens, and application of either homogenized oyster shells or a commercial blend of fertilizer containing calcium. Each of these field treatments were followed by either drying peanut on the soil surface and storing in traditional poly bags or drying peanut on tarps and storing in hermetically-sealed bags for 4 months. Peanut yield and financial returns were significantly greater when a commercial blend of fertilizer or oyster shells were applied compared to the farmer practice of not applying any fertilizer. Yield and financial returns were greater when a commercial fertilizer blend was applied compared with oyster shells. Severity of early leaf spot [caused by *Passalora arachidicola* (Hori) U. Braun] and late leaf spot [caused by *Nothopassalora personata* (Berk. & M.A. Curtis) U. Braun, C. Nakash., Videira & Crous], scarring and penetration of pods by arthropods, and the number of arthropods at harvest were higher for the farmer practice than for either fertility treatment; no difference was noted when comparing across fertility treatments. Less aflatoxin was observed for both improved practices in the field compared with the farmer practice. Drying peanut on tarps resulted in less aflatoxin compared to drying peanut on the ground regardless of treatments in the field. Aflatoxin concentration after storage was similar when comparing post-harvest treatments of drying on soil surface and storing in poly bags vs. drying on tarps and storing in hermetically-sealed bags. These results demonstrate that substantial financial gain can be realized when management in the field is increased compared with the traditional farmer practice. While aflatoxin concentrations differed between the farmer practice and the improved practices at harvest and after drying, these differences did not translate into differences after storage.

Key Words: aflatoxin contamination, integrated pest management, mycotoxin, peanut drying, peanut storing, plant health.

Protecting peanut (*Arachis hypogaea* L.) from pest damage and providing adequate nutrition through applied fertilizer can increase yield and financial return (Naab *et al.,* 2009). Access to crop protection products and fertilizers as well as ability to purchase these inputs by smallholder farmers in Ghana are challenges to realizing optimum peanut yield and quality (Idoko and Sabo, 2014). *Aspergillus flavus* and *A. parasiticus* presence in peanut contributes to aflatoxin contamination in food and can negatively affect human health (Gong *et al.*, 2012; Jolly *et al.*, 2006; Kew, 2012; Turner *et al.*, 2003; Williams *et al.*, 2003).

The majority of smallholder farmers in Ghana do not apply pesticides or fertilizers to minimize

[1]Council for Scientific and Industrial Research-Savanna Agricultural Research Institute, Tamale, Ghana;
[2]Council for Scientific and Industrial Research-Savanna Agricultural Research Institute, Wa, Ghana;
[3]University for Development Studies, Tamale, Ghana;
[4]Kwame Nkrumah University of Science and Technology, Kumasi, Ghana;
[5]Council for Scientific and Industrial Research-Crops Research Institute, Kumasi, Ghana;
[6]Department of Crop and Soil Sciences, North Carolina State University, Raleigh, NC;
[7]Department of Entomology and Plant Pathology, North Carolina State University, Raleigh, NC;
[8]University of Connecticut, Storrs, CT;
[9]Agricultural and Biological Engineering Department, University of Florida, Gainesville, FL;
[10]Department of Food Science and Technology, University of Georgia, Griffin, GA;
[11]Department of Food Science and Nutrition, University of Minnesota, St Paul, MN;
[12]Virginia Polytechnic Institute and State University, Blacksburg, VA; and
[13]Feed the Future Innovation Lab for Peanut, University of Georgia, Athens, GA.
Corresponding author: david_jordan@ncsu.edu

the negative impacts of pests or low soil fertility, respectively, to increase yield in part due to financial constraints (Naab *et al.*, 2009; Osei *et al.*, 2018). Some farmers do apply local potassium-based soaps that have been proven to suppress aphids (*Aphis gossypii* Glover) that transmit peanut rosette virus disease (*Umbravirus*: *Tombusviridae*) (Lamptey *et al.*, 2014). These materials can also suppress leaf spot disease in some instances (Nutsugah *et al.,* 2007). When labor is available, farmers could increase weed management through hand weeding. Preventing weed interference during the first 6 weeks of the growing cycle can prevent yield loss from weed interference (Everman *et al.*, 2008). While commercial fertilizers are often considered too expensive for peanut production by smallholder farmers in Ghana, significant increases in peanut yield have been documented when fertilizers containing nitrogen, phosphorus, potassium, and calcium are applied (Naab *et al.,* 2009). Calcium in the form of homogenized oyster shells is available in some areas of the country. In addition to increasing yield and kernel quality, calcium applied to peanut can reduce aflatoxin (Jordan *et al.*, 2018; White and Broadly, 2003).

In southern Ghana, Appaw *et al.* (2020) reported that a production package that included one extra weeding, application of local soaps for suppression of aphids and peanut rosette virus, and calcium in the form of ground oyster shells at pegging resulted in greater peanut yield and higher financial return compared to the traditional farmer practice without these inputs. However, a comparison of these practices with a commercial fertilizer blend rather than calcium from homogenized oyster shells applied at pegging has not been done in Ghana.

Aflatoxin contamination is affected by practices in the field prior to harvest, during drying, and while in storage (Awuah *et al.*, 2006; Guchi, 2015; Malaker *et al.*, 2008; Villers, 2014; Waliyar *et al.*, 2008 2015). Appaw *et al.* (2020) reported that drying on tarps rather than the ground and storing in hermetically-sealed bags rather than traditional poly bags lowered aflatoxin contamination in peanut. Using at least one improved practice decreased aflatoxin contamination after storage and resulted in greater financial returns than the standard farmer practice (Appaw *et al.*, 2020). However, the study by Appaw *et al.* (2020) was conducted in southern Ghana where peanut production is less dominant than in northern Ghana. Although the bimodal rainfall pattern in southern Ghana allows farmers to potentially grow two peanut crops within the same year, rainfall can affect ability of farmers to harvest and effectively dry peanut prior to storage. In contrast, northern Ghana has a unimodal rainfall pattern and farmers plant as soon as possible after the initial rains so that the growing cycle is complete before the rains end (Abudulai *et al.,* 2012). In some years, rainfall is adequate to produce relatively high yields and minimize aflatoxin contamination in the field (Jordan *et al.,* 2018). However, when rainfall is limited during the final stages of peanut growth, yield can be reduced and aflatoxin contamination can be higher (Craufurd *et al.*, 2006; Jordan *et al.,* 2018).

Comprehensive approaches to managing aflatoxin at all steps in the supply chain are relatively untested in Ghana. While research by Appaw *et al.* (2020) addressed this need in southern Ghana, the majority of peanut is grown in the northern part of the country (Anonymous, 2011). Therefore, research was conducted to determine the impact of improved crop management during the growing cycle and improved practices for drying and storing. The first objective was to compare peanut yield, financial return, pest reaction, and aflatoxin contamination when two sources of calcium-containing fertilizer were applied and additional suppression of weeds and aphids was included compared to the traditional farmer practices that did not include these inputs. The second objective was to determine if aflatoxin contamination differed when peanut was dried on a tarp compared to drying on the soil surface following the different practices used during the growing cycle. The final objective was to determine if aflatoxin levels differed after 4 months of storage when peanut was dried on the soil surface and stored in traditional poly bags compared with drying on tarps and then storing in hermetically-sealed bags.

Materials and Methods

The experiments were conducted on sandy loam soils common in northern Ghana during 2015 and 2016 seasons in farmer fields near Kpalbe (9° 06′ N, 0° 33′ W) in the Salaga North District, near Zankali (9° 50′ N, 0° 41′ W) in the Karaga District of the Northern Region, and Tanina near Wa (10° 3′ N, 2° 50′ W) in the Upper West Region. The cultivar Chinese, the most commonly grown cultivar in northern Ghana, was used in all experiments (Abudulai *et al.,* 2018; Anonymous, 2014).

Improved field practices used in this research were similar to those compared by Appaw *et al.* (2020) in southern Ghana. The improved practices consisted of one additional hand weeding at 6 weeks after planting (WAP), application of a locally-derived potassium soap at 3 WAP (initiation of flowering), and application of either a commercial blend fertilizer (0% N, 18% P_2O_5, 13% K_2O, 29% CaO) (Yara Legume Fertilizer, Accra, Ghana) at 370 kg/ha or homogenized oyster shells applied at the base of plants at 180 kg/ha at 4 WAP. Although farmer cooperators were the same for each year, the experimental fields were placed in separate areas by each farmer during the two years. The farmer practice did not include fertilizer or soap sprays and had only one hand weeding at 3 WAP. The improved practice for drying included peanut drying on a polyethylene tarp (Kotap America LTD, Lawrence, NY) compared with the farmer practice of drying on the soil surface. The comparison of drying treatments was included within each of the management practice treatments compared during the growing cycle in the field. Peanut pods dried on the soil surface were placed in poly bags while those dried on tarps were placed in hermetically-sealed bags (GrainPro, Inc., Boston, MA) and stored for 4 months. These drying and storage treatments represent the least and most effective approaches to maintaining kernel quality and minimizing aflatoxin (Appaw *et al.*, 2020) and are referred to as the post-harvest farmer practices. Within each experiment, farmers served as replications with 10 to 12 farmers randomly selected by local Ministry of Food and Agriculture staff. Peanut rows were spaced 50 cm apart, with an intra row plant spacing of 20 cm. Plot size was 20 rows with a length of 20 m. A plot with the farmer practice and a plot with each of the improved practices were included in each farmer's field. The experimental design was a randomized complete black with 10-12 farmers serving as replications for each experiment. All treatments in the field, during drying, and in storage were compared by each farmer.

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. Termite (*Microtermes* spp. and *Odontotermes* spp.) (Isoptera: Termidae), millipede (Myriapoda: Odontopygidae), white grub (Coleoptera: Scarabaeidae), and wireworm (Coleoptera: Elateridae) populations were determined at harvest from 10 plants randomly selected by removing 60 cm^3 of soil within the upper 15 cm of the soil profile. 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. Sample collection for aflatoxin included selection of five plants at random from each of five sections within the 12 bordered inner rows of each plot (total of 25 plants) at harvest (Mahuku *et al.,* 2010). Twenty kilograms of unshelled pods were placed on tarps and on the soil surface for drying to 10% or less moisture prior to placing in poly bags or sealed bags for storage for 4 months. At each step of aflatoxin determination, approximately 2 kg of unshelled pods were aggregated from 12 randomly collected sub-samples for each treatment (150 g per sub-sample). Haulm yield was determined after the plants harvested for aflatoxin analysis were dried. Final weight was adjusted based on the number of plants collected and converted to kg/ha. Pod yield (kg/ha) was determined from the 12 inner rows of the plot and adjusted to 10% moisture. One hundred pods were collected from each plot and sorted into mature kernels and immature kernels. The percentage of mature kernels was determined by dividing the number of mature kernels by the number of total kernels in the sample.

Analysis of Aflatoxin Contamination. The entire sample of shelled peanut was used in the aflatoxin extraction based on the USDA-GIPSA 2013-041 protocol (USDA-GIPSA, 2015) using RevealQ$^+$ aflatoxin lateral flow strips (Neogen Corp., Lansing, MI) for quantitative test with Mobile Diagnostic Reader (mReader™) (Mobile Assay Inc., Boulder, CO). Shelled peanut kernels (2 kg) were milled using a blender (Preethi Mixer-Blender, Sholinganallur, Chennai, India). Ten grams of milled product were placed in 50 ml extraction tube and 30 ml of 65% ethanol was added and vortexed for 3 min. The mixture was filtered through a 0.45 μm filter paper. One hundred μl of sample extract was added to 500 μl of Reveal Q$^+$ sample diluent. The test strip was removed after 6 min and the level of toxin quantified using the Mobile Detection Reader. Aflatoxin levels greater than 50 μg/kg (threshold determination level for the lateral flow strips) were diluted and reanalyzed. Aflatoxin concentration was also determined using the High Performance Liquid Chromatography (HPLC) based on the AOAC (Association of Official Agricultural Chemists Method 2005.08) (AOAC International, 2006) with minimal detection level of 0.5 μg/kg.

Financial Analysis. Base cost of production was set at \$140/ha including land preparation, seed, planting, and one weeding. Cost of the additional hand weeding was \$50/ha. Cost of calcium applied as oyster shells and commercial fertilizer was \$6/ha and \$148/ha, respectively. Cost of the improved practice during the growing cycle prior to harvest included the local soap for aphid and rosette suppression, one additional hand weeding, and either oyster shells or commercial fertilizer for a combined total of \$52/ha or \$150/ha, respectively. Cost of removing pods from vines was set at \$0.075/kg farmer stock. Shelling cost was set at \$0.075/kg shelled peanut.

Peanut price was set at \$1.20/kg assuming an estimated shell out rate of 65% of unshelled pods. Estimated financial returns were determined for each combination of the improved and farmer practices during the growing cycle from the gross return (product of unshelled yield in the field with a 65% shell out rate) and the price of \$1.20/kg minus the costs of each combination of practices. Unlike results reported by Appaw *et al.* (2020), kernel quality after 4 months of storage was not documented. This prevents determining the impact of post-harvest practices on financial return.

Statistical Analysis. To address Objective 1, data for pod yield, haulm, kernel maturity, financial returns, canopy defoliation caused by leaf spot disease, percentage of pods expressing visible scaring and puncturing from arthropod feeding, populations of arthropods, and aflatoxin concentration at harvest were subjected to ANOVA using the GLIMMIX Procedure in SAS (SAS Software Version 9.4, Cary, NC) to compare the three treatments administered in the field during the growing cycle. To address Objective 2, data for aflatoxin concentration after drying but before storage were subjected to ANOVA using the GLIMMIX Procedure in SAS considering the 3 (field treatments) by 2 (drying treatments) factorial arrangement of treatments. To address the final objective, data for aflatoxin concentration after 4 months of storage were subjected to ANOVA for a 3 (field treatment) by 2 (post-harvest treatment of drying and storage) factorial treatment arrangement using the GLIMMIX Procedure in SAS. In each analysis, data are pooled over experiments. Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $\alpha = 0.05$. Data for aflatoxin concentration was transformed to natural logs prior to statistical analysis. Pearson correlation coefficients were determined for pod yield, kernel maturity, financial return, canopy defoliation caused by leaf spot disease, percentages of pods expressing pod scaring and penetration from arthropod feeding, and populations of arthropods at $p < 0.05$. The data used in the correlation analysis were based on values per individual farmer, thus local effects of disease and insect effects on yield were evaluated. This allowed a more thorough attribution of yield response to arthropod pests that were not controlled by the management practices employed.

Results and Discussion

Applying local soaps to suppress aphids and rosette virus, applying either calcium in the form of ground oyster shells or a commercially blended fertilizer, and weeding one additional time resulted in higher values for pod yield, kernel maturity, and financial return when compared to the farmer practice (Table 1). Haulm yield was similar when comparing the farmer practice to the improved practice when either fertilizer was applied while haulm yield following commercial fertilizer exceeded yield following application of oyster shells. Pod yield, kernel maturity, and financial return were greater when commercial fertilizer was applied compared with oyster shell only.

Scarring and penetration of pods caused by arthropods, canopy defoliation caused by early and late leaf spot disease, and termite number were similar for both improved practices, and lower than the farmer practice (Table 1). These results were not unexpected. Additional weeding most likely reduced weed interference and protected yield for the improved practices compared with the farmer practice of a single weeding. In addition to suppression of aphids, local soaps can play a significant role in suppressing leaf spot disease (Nutsugah *et al.,* 2007). While calcium is important for overall plant growth and pod and kernel nutrition, applying a commercial fertilizer that contains N, P_2O_5, and K_2O as well as calcium likely improved plant health and contributed to both an ability to withstand biotic stresses and increased plant nutrition, resulting in an increase in yield (Jordan *et al.,* 2018). However, the mechanism causing less pod damage was not determined in these experiments. Based on financial returns, the increase in yield more than compensated the farmer for the additional costs associated with fertilizer, local soaps, and the additional hand weeding.

Less aflatoxin was observed at harvest when the improved practices were used compared with the farmer practice (Table 1). However, this difference was small and the biological significance unknown. The number of experiments and replications within experiments contributed to greater power in comparing these treatments (96 observations for each treatment in the field). The interaction between the field treatments and drying treatments was not significant for aflatoxin concentration after drying ($p = 0.8697$ and $p = 0.4862$, respectively). However, drying peanut on a tarp rather than the soil surface resulted in less aflatoxin (Table 2). No difference in aflatoxin concentration was observed after 4 months of storage when comparing peanut dried on the soil surface and then stored in poly

Table 1. Peanut yield, pest reaction, and financial returns using improved practices in the field that included additional hand weeding, and application of local soaps for arthropod suppression.[a]

Measured variable	Treatments in the field during the growing cycle[b]			P > F
	Farmer practice	Improved practice with commercial fertilizer blend	Improved practice with ground oyster shells	
Pod yield (kg/ha)	1,020 c	2,820 a	2,170 b	<0.0001
Haulm yield (kg/ha)	4,820 ab	5,410 a	4,250 b	0.0011
Kernel maturity (%)	73 c	89 a	84 b	<0.0001
Financial return ($/ha)	451 c	1,291 a	1,057 b	<0.0001
Pods with scarring (%)	5 a	0 b	0 b	<0.0001
Pods penetrated by arthropods (%)	3 a	0 b	0 b	<0.0001
Defoliation caused by leaf spot disease (%)	65 a	40 c	43 b	<0.0001
Termite density (No./60 cm^3 soil)	12 a	0 b	6 ab	0.0092
Millipede density (No./60 cm^3 soil)	1.0 a	0.4 b	0.4 b	0.0008
White grub density (No./60 cm^3 soil)	0.5 a	0.3 b	0.2 b	0.0056
Wireworm density (No./60 cm^3 soil)	0.3 a	0.1 b	0. 1 b	<0.0001
Aflatoxin prior to drying (μg/kg)	0.7 a	0.5 b	0.5 b	0.0004

[a]Means within a row for each measured variable followed by the same letter are not statistically significant based on Fisher's Protects LSD test at $\alpha = 0.05$. Data are pooled over 8 experiments with 10-12 farmers in each experiment.

[b]The farmer practice included one hand weeding 3 WAP (weeks after planting) and no application of local soaps or fertilizer. The improved practice with a commercial blend of fertilizer included hand weeding at 3 and 6 WAP, local soaps applied 3 WAP, and commercial fertilizer applied 4 WAP. The improved practice with ground oyster shells included hand weeding at 3 and 6 WAP, local soaps applied 3 WAP, and ground oyster shells applied 4 WAP.

bags vs. drying peanut on tarps and then storing in sealed bags (Table 2). This could be due to very low aflatoxin in peanut after harvest. Similar results were observed for field storage studies by Darko *et al*. (2018). They found, when the concentration of aflatoxin is low, the type of packaging did not influence the increase in aflatoxin content during storage. However, if the initial aflatoxin content is higher, use of hermetically-sealed packages provided more effective control of aflatoxin levels during storage. A major objective of this research was to determine the impact of practices in the field during the growing cycle and at the drying and storing stages on aflatoxin contamination in peanut just prior to consumption or marketing. Generally, aflatoxin contamination in peanut across northern

Table 2. Aflatoxin concentration in peanut after drying on the soil surface vs. drying on tarps and after drying on the soil surface and storing in poly bags vs. drying on tarps and storing in sealed bags.

Post-harvest treatments		Aflatoxin concentration[a]	
Drying	Storage	After drying but prior to storage	After both drying and 4 months of storage
		μg/kg	
Soil surface	Poly bag	6.2	10.3
Tarp	Sealed bag	2.7	6.7
P>F		0.0081	0.6470

[a]Data are pooled over experiments and practices administered during the growing cycle.

Ghana and in particular at these experimental locations was relatively low in 2015 and 2016 (Sugri *et al*., 2017). This limited the ability to make adequate comparisons across treatments at each step in the supply chain relative to aflatoxin contamination.

Pearson correlation coefficients are presented for pod yield, haulm yield, kernel maturity, and financial returns vs. data for individual response to pests or their damage (Table 3). While these correlations are informative, they are challenging to interpret because in this research, peanut response to an improved production package was compared to the traditional farmer practice. This approach limits ability to establish cause and effect when considering individual responses for a particular pest. Additionally, the biological significance of reaction by some pests, especially arthropods, may have been limited in these experiments.

Results from these experiments document the positive contribution of production management packages in the field (increased suppression of weeds and insects, and improved plant and kernel nutrition) during the growing cycle to pod yield, pest reaction, financial returns, and aflatoxin reduction. Appaw *et al*. (2020) also demonstrated increased yield and financial returns when one extra weeding was performed, and local soaps and calcium were applied compared with the traditional farmer practice in research conducted in southern Ghana. Similar to other research (Appaw *et al*.,

Table 3. Pearson correlation coefficients[a] for pod yield, haulm yield, percentage of mature kernels, and financial returns versus percentages of pods with scaring and penetration from arthropod feeding, canopy defoliation caused by leaf spot disease, and arthropod populations in soil.

Pest or pest damage	Pod yield (kg/ha)	Haulm yield (kg/ha)	Maturity of kernels (%)	Financial return ($/ha)
Pods with scarring (%)	-0.38***[b]	-0.19***	-0.40***	-0.34***
Pods penetrated by arthropods (%)	-0.40***	0.07	-0.54***	-0.36***
Defoliation due to leaf spot disease (%)	-0.61***	0.05	-0.55***	-0.61***
Termite density (No./60 cm^3 soil)	-0.25***	0.27***	-0.25	-0.57**
Millipede density (No./60 cm^3 soil)	-0.33***	0.48***	-0.15	-0.32***
White grub density (No./60 cm^3 soil)	-0.15	0.20*	-0.19*	-0.15
Wireworm density (No./60 cm^3 soil)	-0.26*	0.35***	-0.14	-0.24***
Aflatoxin prior to drying (μg/kg)	-0.31***	0.21**	-0.10	0.32***

[a]Data are pooled over experiments.
[b]Significance at $p = 0.01$ to 0.05, $p < 0.01$ to 0.001, and $p < 0.001$ denoted by *, **, and ***, respectively.

2020; Jordan *et al.*, 2018), our results document the benefit of drying peanut on a tarp vs. on soil to reduce aflatoxin contamination. However, availability of labor and inputs and ability to access adequate financial credit to purchase inputs remain major challenges for smallholder farmers in northern Ghana (Quartey *et al.,* 2012). None-the-less, results from this research provide information on solutions that could address poor pest control and low yields of peanut in Ghana.

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