Haiti Peanut Research Report

Efforts to improve peanut production in Haiti by investigating management options for foliar diseases, low soil fertility, and other yield-limiting agronomic issues

University of Georgia Extension

Feed the Future Innovation Lab for Collaborative Research on Peanut Productivity and Mycotoxin Control (Peanut & Mycotoxin Innovation Lab)

Haiti Peanut Research Report

Summary Report of 2015 to 2017 Data

Edited by Abraham Fulmer

Developed by

Haiti Peanut Value Chain Intervention

Project C1. Production to Consumption:

Technologies to Improve Peanut Production, Processing and Utilization in Haiti

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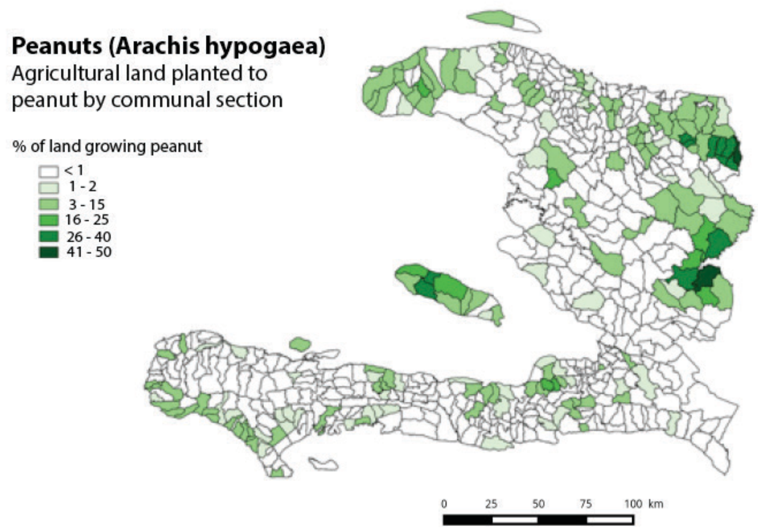
Chapter 1.1 Peanut Production in Haiti

Introduction: Peanut has been cultivated in Haiti for at least 500 years and most likely dates back to prehistoric times. According to Bartolomé de las Casas, a priest who accompanied Christopher Columbus on his expedition to the New World and who is accredited with the first written description of the peanut, the native Amerindians cultivated peanut as a food crop on the island of Hispaniola prior to the arrival of the Europeans (Hammons, 1982).

Peanut production in Haiti has continued up to the present day, and it is a popular crop because it brings a high market price and is an important and enjoyable food source for many Haitians. Dried peanuts can be found year-round in most open-air markets, and locally made peanut products such as peanut butter (including sweet, spicy, and unflavored forms) are commonly sold in shops and supermarkets (Nelson *et al.,* 2003).



Although peanuts are grown throughout the country, there are regions with more concentrated production (Figure 1.1.a). The heaviest centers of production occur in the Northeast near Ouanaminthe, Haiti, and in the Central Plateau region (from Mirebalais eastward to the Dominican border). It is estimated that, on average from 2012 to 2014, peanuts were planted on 45,590 ha, representing roughly 3% of the land area devoted to agricultural production in Haiti (FAOSTAT, 2016).

There are two primary peanut market-types grown in Haiti – the local Haitian runner and the local Haitian Valencia. Interestingly, farmers in the North traditionally sow only the runner variety, whereas the local Valencia is confined to the Central Plateau. To the best of our knowledge, there is no information available concerning the origin of these peanut varieties, and our assumption is that they are landraces that were introduced into Haiti at some point in the past and have continued to be cultivated to the present day. Farmers generally save their own seed or purchase their seed from the market. Similar to other varieties within these market types, the local Valencia and the local runner reach full maturity on average from 80 to 90 days and 120 to 130 days, respectively.

Generally speaking, cropping practices are similar throughout Haiti, and are primarily characterized as low-input agro-ecosystems under rain-fed conditions. For instance, peanuts are often manually planted and harvested by groups of neighboring farmers in rural communities on gardens/farms 1 hectare or less in size. Corn, sorghum or sugarcane are often rotated between peanut crops. Such production systems require farmers to use hoes or ox-drawn plows to prepare the land for seeding, and do not involve fertilizer or pesticides. Additionally, peanuts are typically planted during late spring/early summer (i.e., to align with the rainy season), and depending on the zone, a late summer/fall/winter crop may be planted, such as in the northern part of the country where fall/winter rainfall is generally more abundant.

Yield-Limiting Factors: In comparison to high-input systems in the United States, peanut yield in Haiti is very low. For example, in the U.S. state of Georgia, the average peanut yield in 2016 was 4,416 kg/ha (USDA-NASS, 2016), but in Haiti, average yields were estimated to range from 448 to 897 kg/ha (FAOSTAT, 2016; Nelson *et al.,* 2003), and field experience has shown farmers consistently see even lower yields. As will be seen in the results of this research, both of the local Haitian varieties are capable of achieving yields greater than 4,000 kg/ha in Haiti. This highlights the major gap between actual and potential peanut yield in Haiti.

A number of obvious factors for low-yielding peanuts in Haiti can be explained with Figure 1.1.b. This picture is representative of many fields in Haiti and illustrates the following:

i. Brown leaves and defoliated plants. Foliar diseases (see section below for details) are major yield limiting factors in Haiti. In this case, this field was planted with a highly susceptible local variety and not treated with fungicide, which resulted in premature defoliation, and, ultimately, fewer mature pods.

ii. Decreased plant growth. Stunted plants indicate poor soil fertility and moisture deficiencies throughout the growing season.

iii. Low plant density. Large gaps between plants decreases the potential yield per unit of land area and increases the likelihood of weed pressure. In this case, low plant density was mostly due to improper seeding rate, but was most likely also affected by poor seed quality, lack of seed treatment and/or lack of moisture after planting.

Many growers are not aware that their peanut yields are actually considered extremely low. Rather, the fields look natural, the same as they always have looked. Therefore, it is often the case that growers express great surprise (and delight) at the discovery of the actual yield potential of peanut in Haiti.

Figure 1.1.b. A typical example of the condition of the local Haitian runner in a grower field nearing the time of harvest close to Ouanaminthe, Haiti.

Quality Reducing Factors: In addition to low yields, peanuts grown and sold in Haiti are often contaminated with dangerous, health-damaging levels of aflatoxins. Aflatoxins are carcinogenic mycotoxins caused by the fungus *Aspergillus flavus*, and chronic exposure even to low doses can lead to severe health problems, including increased incidence of liver cancer and childhood stunting, and in acute high doses, aflatoxicosis and death. In a recent study, samples taken from locally produced Haitian peanut butter, aflatoxin levels ranged from 7.9 to 799.8 micrograms/kg aflatoxin, and 16 out of 18 samples had more than 20 ng/kg, the U.S. Food and Drug Administration (FDA) regulatory limit (Schwartzbord and Brown, 2015).

Foliar Diseases of Peanut in Haiti: As previously mentioned, foliar diseases of peanut are major factors responsible for the gap between actual and potential pod yield in Haiti, and have therefore been a major focus of this project. These diseases include early leaf spot caused by *Cercospora arachidicola*, late leaf spot caused by *Cercosporidium personatum,* and peanut rust caused by *Puccinia arachidis* (see Fig 1.1.c and d). While all three of these fungal pathogens are capable of infecting peanuts in Haiti, our studies demonstrate that those causing peanut rust, followed by late leaf spot, are the most important. These diseases occur on leaves, petioles, and stems, and thrive in conditions of prolonged moisture (>12 h), such as prolonged rainfall, extended dew interval or extreme relative humidity (>90%) (Shokes and Culbreath, 1997; Subrahmanyam, 1997). In Haiti, these diseases often lead to 100% defoliation prior to the plants reaching full maturity (e.g., as depicted in Figure 1.1.e). Yield loss results because fewer leaves are capable of photosynthesis and harvest must come before many of the pods reach full maturity.

Figure 1.1.c. Leaves of the local Haitian Valencia peanut market type with late leaf spot and peanut rust.

Figure 1.1.d. Leaves of the local Haitian runner with early leaf spot (light brown lesions), late leaf spot (dark brown lesions) and peanut rust (light/dark orange pustules).

Options for managing foliar peanut diseases in the tropics include planting resistant varieties, rotating crops, destroying volunteer peanuts and infested plant residue, and using fungicide judiciously (MacDonald *et al.,* 1985; Subrahmanyam *et al.,* 1985). Currently, there are no high-yielding disease-resistant varieties identified for use in Haiti, and the local Haitian runner and Valencia are extremely susceptible to both diseases. However, previous studies conducted in Haiti confirmed that resistant varieties can significantly reduce disease intensity and increase yield (Fulmer *et al.,* 2012). The data from these studies can be referenced in Appendix IV of this report. Similar to other tropical areas where peanut is cultivated (MacDonald *et al.,* 1985), crop rotation and destruction of crop residue likely has only a limited impact on reducing the overall inoculum level since there are almost always abandoned/fallow fields with volunteer peanuts. Furthermore, since there are almost always peanuts grown in every month in Haiti at some locale, and because the spores of the causal fungi are aerially dispersed by wind and insects, it is probable that there is a constant source of spores, making it difficult for the peanut plants to evade contact with the pathogens. However, as there is little research on this topic, this tactic should still be encouraged as part of an integrated disease management program. Fungicides are relied upon in many developed and developing countries for managing the foliar diseases in question. In other tropical countries, three to four applications have been shown to significantly increase yield (Naab *et al.,* 2009; Waliyar *et al.,* 2000), and preliminary results in Haiti indicates that two applications significantly reduce disease severity and increase yield (J. Rhoads, unpublished data). However, the best timings and number of these applications has not been well understood. Recently, our research in Haiti has confirmed that low-input fungicide regimes are extremely effective for reducing disease and increasing yield; results have been used to develop more specific use recommendations (Chapter 1.3, and Chapter 2.1).

In addition to the fungal diseases of peanut just mentioned, our studies have identified the presence of a tospovirus that can occur on peanut in Haiti (Adegbola *et al.,* 2016). Symptoms of this disease are described in Appendix VI of this report. However, after three years of monitoring peanuts for this disease in Haiti, we have found that incidence is rather low (<5%) and sporadic and that the disease is mainly confined to the northern regions. Overall, our results indicate that while it could be a yield-limiting factor in some instances, such as in plots planted with low plant density (See Chapter 4.1), we believe that there is generally very little (if any) yield loss that results from this disease in Haiti.

Figure 1.1.e. Local Haitian runner with >95% defoliation caused by late leaf spot and peanut rust. Plots to the left were untreated; plots to the right were treated with four applications of fungicide.

Soil Fertility: Soils in Haiti are generally considered infertile due to years of intense erosion caused by unmitigated deforestation and near continuous cropping, as well as a natural fragility resulting from the underlying bedrock formations and soil types (Bargout and Raizada, 2013). Overall, most of the soil in Haiti is highly alkaline and high in calcium (Bargout and Raizada, 2013). In a previous study conducted at the University of Florida that evaluated 1,500 soil samples from locations throughout Haiti, most were low in nitrogen and 62% were reported to be deficient in phosphorus; in 96% of the cases, potassium was not a limiting factor (Hylkema, 2011).

From soil samples taken at our research sites in Haiti, our results corroborate Hylkema (2011) in that they consistently had a high pH and high levels of calcium. However, phosphorus was mainly only below average in fields located in the Central Plateau (see Appendix II of this report). It should be noted, however, that the fields sampled in the Central Plateau did not have a history of fertilizer inputs, whereas, the other fields sampled at MFK had a prior history of fertilizer inputs. In addition to our observations, results from our soil samples also indicate that many of the soils in Haiti have a heavy clay content (see Appendix II of this report), although there are some areas with extremely sandy soils (J. Rhoads, personal communication).

Peanuts generally require a well-drained, sandy soil (e.g., loamy sand, sandy loam, or sandy clay loam) (Henning *et al.,* 1982). This soil type not only promotes growth of the plant, it also facilitates the harvesting process by making it easier to dig the pods from the ground and leaving less soil clinging to the pods (Stalker, 1997). High-pH soils (such as in Haiti) are challenging environments for peanut production as this can lead to other nutrient deficiencies (e.g., by binding up nutrient availability) and can also result in iron chlorosis and zinc toxicity (Stalker, 1997). Peanuts also require soils with high calcium content, which is a positive aspect of the soils in Haiti (Stalker, 1997). Boron is an important micronutrient for proper seed development (Cox *et al.,* 1982) and samples have shown the soils to be deficient. As with other legumes, peanut growth is generally not thought to be limited by low nitrogen soils, since they can receive nitrogen from the symbiotic relationship with Rhizobium root nodulating, nitrogen-fixing bacteria that convert atmospheric nitrogen to available nitrogen used in plant growth. There are a number of instances where peanut yields have been increased due to applications of nitrogen, but it was presumed that these results were due to lack of Rhizobium strains in the soil (Cox *et al.,* 1982).

In short, growing peanuts in Haitian soils is challenging primarily due to heavy clay content, complications from high soil pH, and uncertainty in regards to the capacity of peanut plants to utilize native Rhizobium strains. In order to help close the actual yield vs. potential yield gap, more research is needed to better understand how to manage the fertility of the soils in Haiti.

Planting Method: Proper seed spacing between rows and within rows is a cultural practice that directly relates to yield per unit of area (Henning *et al.,* 1982). As a result, much research has been conducted on determining the most appropriate planting density, which ultimately depends on seed quality, seed size, row spacing and variety (Henning *et al.,* 1982). In previous studies where cultivation methods would have been most relative to those in Haiti, "the highest yields of Spanish varieties were realized from plantings 45-60 cm (18-24 in) between rows with plants 15-20 cm (6-8 in) within the row. Cultivars of the runner and Virginia types yielded highest when planted with row spacings of 75-90 cm (30-36 in) and with plant spacings of 15-20 cm (6-8 in) in the row" (Henning *et al.,* 1982). In short, bunch type varieties (Spanish and Valencia market types) generally benefit from higher plant density per unit of land, whereas prostrate-growth types (Virginia and runner market types) do not benefit from as high a plant density per unit of land.

In Haiti, planting method is one of the few things growers have a very strong opinion about and a sense of control over. While nearly all peanuts are sown by hand, the exact planting method often differs by region or farmer, but generally consists of scatter planting or single-furrow planting. The first method involves using a hoe to make a divot in the ground, dropping seed into the hole/divot and covering it with the feet. Depending on the farmer, these divots may be spaced approximately 30 cm to 45 cm (12 in to 18 in) and may include one or two seed per divot/hole. In the second method, a farmer uses an ox-drawn plow to make a single furrow in the ground, while walking in a circular pattern around the field; another person comes behind dropping one to two seed at 30 cm to 60 cm (12 in to 24 in) spacing within the row. Furrows are generally spaced 45 to 60 cm apart and as the new furrow is made, the soil is pushed in the direction of the previously seeded furrow and is generally enough to bury the seed in the adjacent row.

It is generally understood that planting in rows is more beneficial than scatter planting. This makes sense where tractor operated mechanical planters can create a much more efficient, uniform and precise placing of seed. However, in Haiti, where there is little to no mechanical implementation beyond soil preparation, it is uncertain whether the additional labor required for planting in rows would benefit growers. From a practical standpoint and without considering the economic implications, planting in rows appears to be more beneficial for a number of reasons. First, it is a more precise way of utilizing and estimating seed for planting. Secondly, it facilitates practices aimed at the maintenance of the crop, such as easier weeding and harvesting with a hoe, and makes the uniform application of fungicide by backpack sprayer much easier. Not only would this likely lead to better spray coverage, it would also decrease the probability of damaging the main stem (and pegs around the main stem) by stepping on the plant.

Increased Demand of Peanut in Haiti: Since 2007, Meds & Foods for Kids (MFK) has been making a peanut-based Ready-to-Use Therapeutic Food (RUTF), locally known as Medika Mamba and commonly known as Plumpy'nut (MFK, 2017). This product is the gold standard for the treatment of severe acute malnutrition in children both globally (WHO, 2017) and in Haiti (Iannotti *et al.,* 2015). Childhood malnutrition continues to be a major issue in Haiti due to the high levels of poverty and food insecurity (PMIL, 2017). MFK produces and distributes RUTF and other similar peanut-based supplementary products through partnerships with UNICEF, the World Food Programme and many other local and international humanitarian organizations.

As a Non-Governmental Organization (NGO), MFK's approach is to facilitate treatment of malnutrition, but also to address the root of the problem by developing the economic sector through employment at their factory and driving demand for locally sourced agricultural products. As such, MFK's desire has been to purchase 100% of the peanuts for the factory from local Haitian farmers. However, this remains difficult due to a number of reasons, including low quality, aflatoxin contamination, and inconsistent and uncompetitive high market prices due to low productivity. By increasing the production of high-quality peanuts, MFK would be able to accomplish this goal of 100% local sourcing. The strategy to achieve this has been to lower the overall cost by increasing yields. The end-result theoretically would be a win-win situation for growers and consumers alike. Growers would benefit from yield increases, despite lower market prices, as long as net profitability remained high through cost controls. A lower market price and supply of aflatoxin-free peanuts would benefit the average consumer both from a financial standpoint and from a health standpoint and facilitate the in-country purchase of value-added products such as Medika Mamba.

Additionally, Acceso Peanut Enterprise, a for-profit peanut value-chain business, has been operating in Haiti since 2015 with the aim of increasing farmer productivity and easing difficulties of aggregation to meet this demand for high-quality peanuts. The Acceso model directs technology exchange by establishing a system of depots in small, rural communities. Depot managers trained on best production practices are able to extend this information to local growers. From these depots, local farmers in the Acceso program are able to obtain yield increasing inputs such as high quality seed, fertilizers and fungicide on credit. Following harvest, these same farmers are able to sell their peanuts back to Acceso at a fixed, competitive price. Once Acceso sorts and tests the peanuts for aflatoxin and kernel moisture content, they are then able to deliver a high quality product to local businesses with whom they have previously established a purchasing contract.

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Chapter 1.2 PMIL Project

Objectives and Role of the PMIL Project: The Peanut and Mycotoxin Innovation Lab (PMIL) is part of the U.S. government's Feed the Future initiative administered by the U.S. Agency for International Development (USAID) and is intended to improve livelihoods and health in developing countries through advances in peanut research in production, processing, and markets. The Haiti Value Chain project is multidisciplinary collaboration and involves specialists from the University of Florida, the University of Georgia and Cornell University. Key to this project is the collaboration of in-country partners–MFK, Acceso, and Premiere Steppe Ferme. In addition, PMIL also has a global peanut breeding program, including a relatively new initiative in Haiti led by Barry Tillman at the University of Florida in collaboration with Raphael Colbert at Quisqueya University in Haiti.

From 2007 to 2012, PMIL's predecessor program, the Peanut Collaborative Research Support Program (PCRSP) worked directly with MFK to improve local production. During this phase of the project, efforts were primarily focused on working directly with local farmers to provide support from a local agronomist employed with MFK. Local production was linked to providing peanuts for the MFK factory but also to local markets.

In 2013, the project linked with TechnoServe, a global NGO known for agribusiness development that was providing technical support to the Partners in Health/Zanmi Lasante RUTF factory in the Central Plateau. During this time, Acceso was formed and took over that role and adopted a small business model approach. As previously noted, their model provides technical inputs to improve production, such as tillage services, improved varieties, fertilizer and fungicide.

From 2013 to 2017, PMIL, in collaboration with MFK and Acceso, focused on applied research to support outreach programs and technical inputs for small holder farmers. This involved working with Acceso agronomists and depot managers. Applied research was conducted through MFK in collaboration with Acceso and allowed for more formal training of students and local agronomists. Throughout this time, information generated from the research program and the technical guidance of the PMIL specialists continued to provide input for extension related materials.

Toward the latter phase of the project, the focus of PMIL shifted from extension-based programs (trainings and materials directed to growers) to applied production research and the training of agronomists, Acceso depot managers (train the trainer), and agronomy students from local universities. The latter resulted in training 34 undergraduate students in applied research through a rigorous and competitive internship/undergraduate research project program offered at MFK.

From the applied research relating to enhancing yield, specific objectives were to:

1. Evaluate and screen multiple varieties in order to identify a high-yielding, disease-resistant variety suitable to the environment in Haiti;
2. Determine the optimum number and timing of fungicide applications for runner and Valencia market types grown in Haiti;
3. Test the effect of different treatments aimed at boosting soil fertility; and
4. Determine the most appropriate method for planting runner and Valencia peanut market types.

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Chapter 1.3 Recommended Best Practices for Peanut Production in Haiti

Purpose:

To provide agronomists and grower advisors in Haiti with the best possible recommendations based on our research regarding variety, planting, fertility, and fungicide in order to aid in the development of a more complete technology package for Haitian peanut farmers. These recommendations are based on the results of our research and experience in Haiti and in the Southeast U.S.

Variety Selection:

Valencia. Currently, our research efforts have failed to identify a high yielding, disease-resistant variety that consistently outperforms the local Valencia. The New Mexico Valencia A was extensively screened in the fungicide timing trials (Chapter 2.1), but did not offer any advantage over the local Valencia in terms of disease severity or yield (Figure 2.1.b).

The Top 6 Valencia trials (Chapter 2.2) demonstrated that 309 Tan, a Valencia variety from the New Mexico State University (NMSU) breeding program, had excellent resistance to foliar diseases in Haiti, but did not yield as high as the local Valencia in plots with and without fungicide (Figure 2.2.b). Similarly, while other varieties from the NMSU breeding program did have a higher numerical yield compared to the local Valencia, the increase does not appear to be significant enough to justify the introduction of any of these varieties into Haiti at present.

Current recommendation: Farmers who desire to plant a Valencia market type should continue to use the local Haitian Valencia.

Runner. Georgia-06G consistently out-yielded the local Haitian runner in the fungicide timing trials (Figure 2.1.b). From a physiological standpoint, the Georgia-06G variety generally exhibits stunted growth in Haiti and, compared to its growth in the southeastern U.S., does not appear to thrive in most Haitian soils. However, upon digging, the pod load is still consistently higher than the local runner. Also, it should be noted that Georgia-06G is extremely susceptible to peanut rust while the converse is true for the local runner for late leaf spot (Figure 2.1.a).

Current recommendation: Although the Georgia-06G variety is not the perfect ideal for Haiti, it could be a good option for growers until a better option is identified.

It should be noted that the local Haitian varieties have several positive traits that appear to have been selected for over years of cultivation in Haiti. Both varieties have excellent seed vigor; they are almost always the first to germinate and both seem to grow well in Haitian soils. This may also include greater resistance to native soil-borne diseases. This suggests that a local breeding program to improve upon these local adaptations may be a feasible strategy in the future.

Fertility:

Thus far, we have failed to see a significant yield increase from any of the fertility treatments that we have evaluated in Haiti (Chapters 3.1, 3.2, and 3.3). However, we must emphasize that many of the fertility studies were conducted in fields that likely had a good residual level from previous peanut crops that were fertilized. More studies need to be conducted in fields with known fertility deficiencies before a definitive recommendation can be made. It should be noted, however, that we did see a *numerical* trend in the most recent fertility studies (Chapter 3.2) that suggests that a significant yield response would be obtained in nutrient-deficient soils.

As noted in the research on fulvic acid and foliar applications, the high-pH soil greatly contributes to the challenge of determining highly responsive fertilizer recommendations, in spite of the known deficiencies in most soils.

It appears that the use of an inoculant (to increase root nodulation by Rhizobia species) is not necessary in Haiti. We did not see a positive yield increase in either of the inoculant trials we conducted (Chapter 3.1) in 2015, and we have consistently found good nodulation on the roots of plants in noninoculated fields. It should be also noted that inoculants require cool storage conditions (which make implementing this practice very difficult) and are not readily available in Haiti. Furthermore, evidence from alkaline soils in Texas suggests that liquid inoculum greatly outperformed granular forms and that seed coated inoculant was not found to be effective at all.

Current recommendation: Given that soil tests are not very practical in Haiti and the general infertility of most soils, we still suggest that growers apply 40-60 kg/ha of 20-20-10 or DAP at planting or as a side-dress application two to three weeks after planting. However, we do not suggest using an inoculant at this time.

Planting:

Seed/row spacing trials (Chapter 4.1) have consistently demonstrated that the ideal planting density is not the same for the local runner and the local Valencia.

Valencia. Overall, regardless of between-row spacing or within-row spacing, the Valencia variety yield consistently increases with increasing planting density (Table 4.1.c and Figure 4.1.c). However, there is generally less of a yield gap between 12- and 18-inch row spacing than 24- and 18-inch row spacing, and three and six seed/ft than between one and three seed/ft (Figure 4.1.d). In the absence of a formal cost-benefit analysis, this suggests that 18-inch rows planted at three seed/ft may be the best option for growers in Haiti. However, it should be noted that these studies were conducted with high-quality seed with excellent germination. This is often not the case in Haiti–therefore, if the seed germination is questionable, we would advise using 12-inch row spacing with three seed/ft spacing within the row, or 18-inch row spacing with six seed/ft spacing within the row.

The positive correlation between planting density and yield for the local Valencia was corroborated with the row vs. scatter planting method trials (Chapter 4.2). In these studies, we found that the traditional scatter planting method did not result in a yield loss when compared to the same amount of seed sown in rows. As mentioned elsewhere, while we believe that there are number of advantages for planting in rows (better plant density control, ease of crop protection and harvest, etc.) and will continue to advocate that practice, these data suggest that the traditional method can provide equivalently high yields at higher densities.

Runner. We did not find the same consistency in the response to seed/row spacing treatments for the runner variety (Table 4.1.c and Figure 4.1.c). However, yield in plots with three and six seed/ft within-row spacing were more often higher than plots with the 1 seed/ft spacing (Figure 4.1.d). Row spacing did not have an effect on yield when planted at three or six seed/ft (Table 4.1.c), suggesting that the within-row spacing is more important for the runner variety.

Results from the row vs. scatter planting method trials (Chapter 4.2) corroborate that an increase in the planting density of the local runner variety does not necessarily result in a significant increase in yield (Figure 4.2.c). Also, similar to the results for the Valencia market type, the results from these trials suggest that planting in rows does not necessarily signify an increase in yield compared to the traditional scatter method. As long as the planting density is similar, similar yields can be obtained from both methods.

Current recommendation: For the Valencia, we suggest planting 18-inch rows with three seed/ft or 24-inch rows with six seed/ft. For runner, we suggest planting 24-inch rows at six seed/ft. Both of these suggestions assume a relative low seed germination of 50-70%, which is often the case in Haiti.

Fungicide Applications:

Results from multiple studies conducted from 2015 to 2017 on runner and Valencia market types emphasize the importance of managing foliar diseases in Haiti (Chapter 2.1). However, yield loss for runner varieties is higher than Valencia varieties, likely due to the phenomenon of disease escape. Runner varieties require ~40 more days to reach maturity than Valencia varieties and are therefore exposed to the threat and impact of foliar diseases for a longer period of time.

Overall, for both Valencia and runner varieties, we report an inverse relationship between disease severity and fungicide applications, namely, disease increases with decreasing fungicide applications (Figure 2.1.a). Similarly, pod yield tended to increase with increasing fungicide applications (Figure 2.1.a).

As a result, a straightforward recommendation cannot be made simply based on the differences between treatments alone. Practical, biological and economic factors must also be considered in the decision process.

For example, most growers in Haiti do not have access to fungicide spray equipment and the appropriate products are not widely available. Therefore, most farmers must purchase the application service from a contract service provider (such as Acceso). In this scenario, three to four applications would likely be the maximum number of applications that could be made during the season.

From a biological standpoint, fungicide resistance is something that must be considered when attempting to make a fungicide recommendation. The current fungicide available for growers in the Acceso program is a mixture of tebuconazole and chlorothalonil (Muscle® ADV). Tebuconazole resistance has been detected in populations of both leaf spot pathogens in the United States, and the rust pathogen could also have a similar risk. A key principle of avoiding resistance is to make applications when the pathogen population is low. In Haiti, we have found that this is generally between 30 and 60 days after planting (DAP), depending on which pathogen is in question. A second factor that aids this key principle is to use more frequent applications, thereby ensuring that the pathogen population is still low when the second/third/fourth application of fungicide is made. Ideally, therefore, in Haiti, applications should start around 45 DAP and continue every 14 days in order to decrease the risk of fungicide resistance.

A more formal cost/benefit analysis will be needed to help determine the most appropriate recommendation. Just because there are more peanuts in the plots treated with the greatest number of fungicide applications doesn't mean that it will translate into the most profitable return on investment. For this reason, a more in-depth analysis is currently being conducted by the economist in order to help guide the decision-making process.

Current recommendation: Without considering an economic analysis–strictly from a disease-management perspective–the data and the aforementioned practical and biological considerations suggest that three applications at either of the timings evaluated would be the best practice for Valencia varieties grown in Haiti. For runner varieties, we suggest that four applications made at either of the timings evaluated would be advisable for growers in Haiti, particularly during the rainy season.

Chapter 1.4 Lessons Learned

Purpose: The objective of this chapter is to reconsider critical steps that have led to success and failure in this research project undertaking to evaluate potential technologies aimed at improving peanut productivity in Haiti. The other chapters review completed projects with relatively comprehensive data collection; however, many other trials were attempted during this period that were deemed inadequately definitive for inclusion or were not completed for various reasons. Undertaking field research in Haiti has proven challenging in often unanticipated ways, and there are numerous lessons to be learned for future research endeavors in Haiti or in similar environments with limited research infrastructure or technical experience.

Site Selection: Without a proper research station with historic field data, weather data collection, equipment for field preparation, planting, irrigating, harvesting, or sample processing, trained experienced staff or security from livestock or inclement weather, conducting rigorous repeatable research is a real challenge. Initial efforts to work on collaborating farmers' fields, leased land or university land, led to mixed results. Examples:

- Two unfenced trials were lost to livestock invasion.
- One trial was lost at a university for failure to anticipate student vacation.
- At least two trials were lost to inclement weather, including flooding and drought, before irrigation and extensive drainage systems were established.
- Soil variability (texture and fertility) is quite high and resulted in data exclusion in some trials. Soil data was a challenge, since the quality, cost, and timeliness of local analysis was limited. Samples were sent to the U.S., requiring permits and shipping costs. Also, the high-pH soil required different analytical techniques than commonly used in Georgia.

- Access to equipment for field preparation was a limiting factor for early trial efforts due to the limited number of tractors in the country. Manual preparation was possible, but it was often exceedingly expensive and inconsistent in quality.

Collaborating Partners: Haitian farmers, agricultural technicians, and agronomists have varying, but generally limited, experience designing and conducting controlled research experiments. With a lack of mechanization for all processes of preparation, planting, management, harvest, and sample processing, the extensive use of manual labor (often untrained labor that may have extensive production experience, but no research experience) opens the door for mistakes to be made. Communication across languages and cultures proved to be challenging. Examples:

- After plots testing a biocontrol product were harvested, field laborers commingled all the replications of treatment and control plots to make drying easier.
- Hand-seeded variety trials were abandoned after the crops started to mature and obvious, consistent physiological differences appeared between rows, likely due to inattentive labor during seeding. This resulted in the loss of valuable imported seed and a failure of the trial.
- Eager field assistants reasonably not wanting to work in the hot afternoon sun completed the harvest of several trials without proper labeling resulting in a complete loss of data.
- The in-country partners often relied on short-term foreign interns, which resulted in a loss of continuity and lack of institutional learning. The experience level of interns with field agriculture varied greatly and led to handover issues and a lack of strategic direction.
- Relying on U.S. experts for research design and oversight led to an occasional lack of prioritization of research with farmer conditions or the inability to adequately supervise the implementation of trials and data collection.

Equipment and Facilities: As previously noted, the mechanization of field processes was an initial limiting factor but was resolved over time by concentrating efforts in targeted locations. Some equipment that was integral to quality data collection, but was often overlooked, included:

- Adequate and appropriate storage for seed (ideally conditioned), inputs, tools, etc.
- Weather stations with data loggers and backup rain gauges.

Simple tools for plot marking, labeling tags, mesh bags for plot samples, battery-powered scales, robust moisture meters (Dicky John miniGAC®), and simplified quantitative aflatoxin-testing equipment (Mobile Assay mReader).

- Backpack sprayers that are robust and easily calibrated for use by local technicians, including booms for multiple-row spraying to reduce variation.
- Access to quality internet has improved and allowed for better communication, including the sharing of photos and real-time data.
- Field preparation equipment, such as the use of Chinese-made two-wheel tractors were an initial improvement. The later use of larger, but still relatively small, tractors for disc plowing, harrowing, rototilling, seeding, and threshing were key to scaling beyond small plots. Successful implementation of this equipment for farmers is still elusive due to the high costs of operation, disparate small plots, slope and soil variability, and the large number of trees and rocks in many plots.

Notable Successes:

- During the final three years of the project, the intern program at MFK managed to incorporate 34 student projects from four different local universities. Agronomy students must complete a final project and the infrastructure provided by MFK, including the research agenda, field support, and supervision, was key to establishing these connections. This is a true win, but it required learning from previous efforts and establishing a functioning research team.
- Barry Tillman was able to establish a relationship with a recent doctoral graduate, Raphael Colbert, to work on bean breeding and expand his efforts into peanut evaluation. After some initial learning, the research team at CHIBAS/Quisqueya University has established a quality system for evaluating germplasm at their research farm in Cabaret. This means that three reliable sites are now available for evaluation and that there is a potential for a real long-term strategy of incorporating improved traits into the existing adapted varieties through plant breeding.
- A local commercial-scale farm, Premier Steppe Ferme, has collaborated to scale these and other inputs on their farm, planting blocks of up to 10 ha and averaging yields two to three times the local norm. There has also been learning on the adaptation of advanced mechanized technology for medium-scale ventures, such as the use of used two-row equipment from the U.S. and the Brazilian-made Colombo multi-crop thresher.

Notable Teachable Moments:

- Initial trials with breeding lines from ICRISAT India showed great promise in disease resistance and drought tolerance (Appendix IV). These varieties were very attractive to local farmers due to their agronomic traits, consistently yielding three times the local varieties even when there was crop failure due to drought. However, when a leading variety (ICGV 99030) that had been multiplied was finally tried for consumption, it was found that the flavor and oil content/quality was completely unacceptable. Assuming that this was perhaps due to improper postharvest handling, a second crop was produced with similar results. It was later learned that these varieties were not intended for release, but for sources of genetic material for making local crosses and had never been screened for consumer traits.
- While these data suggest that improved varieties have potential, the local varieties continue to be dominant. However, they are only dominant locally. Trials of runner varieties in the Central Plateau proved to be a failure, not due to yield limitations, but due to the local dislike of that variety for lack of market demand (reportedly too high in oil), farmer preference for the ease of harvesting bunch types, and the predominant strategy of squeezing two crops into the rainy season, which is only possible with the short-duration Valencia. The strategy of focusing on a single, high-yielding plantation was unacceptable to most farmers, likely for its risk. Conversely, in the North and Northeast, the Valencia variety was deemed unacceptable because it was too low yielding and supposedly difficult to harvest (the opposite of the Central Plateau) and lack of market demand for that variety (reportedly too low in oil). Even over a relatively small geographic area, people have strong preferences and research should not try to overcome these preferences, but work within their existing strategies.

Likely Lynchpins of Future Success:

- Seed affordability and quality remain critical limitations. Continued expansion of seed production, aimed at improving seed quality (maintaining germination and vigor) and reducing cost for farmers during the planting season, will be critical for improving productivity and reducing costs. It will also be critical for introducing improved varieties.

- Finding varieties that are higher yielding, more disease resistant and drought tolerant and meet local demands for quality will be critical to move past the current low yields. Progress can be made in the interim through improved agronomic practices, but the potential for genetic gains is clear in the data presented in this report.
- Efforts at mechanization at the farmer level (small-scale tillage, planters) have not proven to be cost effective to date. However, scaling production without some mechanization will not be cost effective in the future, especially as availability of rural labor continues to decline and costs increase. Both proven (animal traction) and new (mobile threshers) technologies should be evaluated.

Additional Areas for Future Research:

- Seed germination was a continuous problem during trials and resulted in higher recommended seeding rates and associated costs than if germination rates were consistently high. Seed vigor, as measured be time to emergence, revealed a surprising difference between the local varieties, which were generally quick to emerge, and imported varieties, which often took several days longer. A future project should evaluate the environmental (soil fertility and maturity impact of disease) and postharvest handling (high drying temperatures due to solar drying, storage conditions) variables that impact seed vigor and germination.
- The recommendations are based on rigorous data collected over multiple seasons, in multiple locations. However, the implementation of these recommendations needs to be evaluated at scale and on farmer fields. Gathering quality empirical data from farmer fields remains a challenge, but should also be addressed with concerted efforts with targeted farmers.

Concluding Remarks:

Finally, there is great wisdom in several commonly used Haitian proverbs that are worth recounting related to our research experience:

1. "Kabrit ak twòp met mouri anba soley" (A goat with too many owners dies in the sun). There is a requirement of clear communication and delineation of responsibility, which becomes especially important across multiple languages and cultures. With many personalities, both from abroad and locally, and high turnover of key personnel, several key lessons had to be learned more than once.
2. "Pise gaye pa kimen" (Urinating all over the place never forms foam). Though a bit crass, the idea of not spreading efforts too thin or trying to achieve too many things was key to later program success. Trials were conducted on two well-monitored and managed locations where adequate controls were taken for unexpected variables and lessons learned over time.
3. "Wòch nan dlo, pa konn doulè wòch nan soley" (The rock in the water doesn't understand the suffering of the rock in the sun). There are two key lessons from this proverb: 1) U.S.-based collaborators need to take time to thoroughly communicate and understand the local limitations, including labor and personal constraints of staff, and invest in long-term solutions; and 2) research priorities should be soundly based in the reality of the local farming system to ensure relevance of the research outputs.

Section 1.5 Research Field Sites

Locations: Field trials were conducted at research sites belonging to our in-country partners, Meds and Food for Kids (MFK) and Acceso Peanut Enterprise Corporation. The Acceso research farm is located in the Central Plateau, in the community of Coupe Gorge (located just outside of Mirebalais) (18°50'21.05"N latitude, 72° 3'29.33"W longitude), Haiti. The research plots at the MFK factory are located in the community of Quartier Morin (located east of Cap-Haïtien), Haiti (19°41'32.17"N latitude, 72° 9'16.91"W longitude).

Field rotations. At MFK, all fields had a previous history of peanut. In most cases, peanuts were planted behind peanut, with a 3- to 6-month fallow period between crops. In some cases, peanut followed a rotation of sorghum. At the Acceso research farm, peanut often followed several years of bean and/or sorghum production. As peanut studies were conducted year-round, we were ensured that a consistent inoculum source was present for fungicide and variety trials conducted for leaf spot and rust.

Soil types. Based on soil samples evaluated at the University of Georgia, the soil type in fields used at MFK was a sandy clay loam with an average of 42% sand, 27% silt, and 30% clay with a pH of 7.4, and calcium levels were also over 3,000 kg/ha. Fields used at the Acceso research farm were a clay-based comprised of 25% sand, 25% silt, and 50% clay with a pH of 7.1 ($CaCl2^{2}$), and calcium levels were over 3,000 kg/ha (*see Appendix II for soil test results*).

Part of the land devoted to research plots at Meds and Food for Kids (MFK) factory located outside of Cap-Haïtien (Quartier Morin), Haiti.

Back field being prepared for planting at the Meds and Food for Kids (MFK) factory located outside of Cap-Haïtien (Quartier Morin), Haiti.

Research plots used at the Acceso research farm located in Coupe Gorge (part of the Mirebalais commune) in the Central Plateau of Haiti.

Additional fields used for research at the Acceso research farm located in Coupe Gorge (part of the Mirebalais commune) in the Central Plateau of Haiti.

Chapter 2.1 Runner and Valencia Fungicide Timing Trials

Purpose: Determine the appropriate number and best timings of fungicide applications for reducing disease severity of foliar diseases and increasing yield for runner and Valencia market types grown in Haiti.

Experimental Design: Five trials with runner market type peanuts were conducted at the MFK research site from 2015 to 2017. All trials were laid out in a split plot design with four replications. Variety was the main plot treatment and was planted to the local Haitian runner or Georgia-06G, the predominant cultivar planted in the Southeast U.S. Fungicide treatment was the subplot and consisted of six different application regimes plus an untreated check (see Table 2.1.a for details). Dates from planting to harvest for each trial were as follows: 23 March to 13 August 2015; 9 November 2015 to 8 March, 2016; 19 February to 23 June 2016; 16 October 2016 to 19 February 2017; 31 March to 12 August 2017.

Two trials with Valencia market-type peanuts were conducted in the Central Plateau at the Acceso research site in the spring of 2015 and 2016, and three trials were conducted at the MFK research site in the spring and fall of 2016 and spring of 2017. All trials were laid out in a split plot design with four replications. Variety was the main plot treatment and was planted to the local Haitian Valencia or New Mexico Valencia A, an improved cultivar planted in the southwestern United States. Fungicide treatment was the subplot treatment and consisted of six different application regimes plus an untreated check (see Table 2.1.a for details). Dates from planting to harvest in the Central Plateau for each trial were as follows: 31 March to 30 June 2015; 8 April to 16 July 2016. Dates from planting to harvest at MFK for each trial were as follows: 14 March to 16 June 2016; 29 August to 28 November, 2016; 15 May to 29 August, 2017.

Table 2.1.a: Treatment details used for runner and Valencia fungicide timing trials in Haiti.

Market type	Total applications	Initiation[y]	Spray interval[z]	Application timings
Runner	6	30	14	30, 44, 58, 72, 86, 100
	4	37	21	37, 58, 79, 100
	4	45	21	45, 66, 87, 108
	3	37	28	37, 65, 93
	3	45	28	45, 73, 101
	2	60	28	60, 88
	0	-	-	-
Valencia	4	30	14	30, 44, 58, 72
	3	30	21	30, 51, 72
	3	45	14	45, 59, 73
	2	45	21	45, 66,
	2	45	28	45, 73
	1	45	-	45
	0	-	-	-

[y] Days after planting when the first application was made.
[z] Days between applications.

For each fungicide treatment, applications of tebuconazole (0.23 kg/ha) + chlorothalonil (0.84 a.i. kg/ha) (Muscle ADV, Sipcam Agro USA, Durham, NC) were made at 188 liters per hectare with a hand-pumped backpack sprayer.

For all trials, plots were 1.2 m wide and 4.6 m in length, consisting of two rows of peanuts bordered by a single untreated row of peanuts. Blocks were separated by a 1.5-m alley. Runner trials were planted at three seed per 30.5 cm in the first two trials and six seed per 30.5 cm in the last two trials. Valencia trials were planted at a rate of three seed per 30.5 cm in the Central Plateau and six seed per 30.5 cm in the North. Prior to planting, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop

Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Fields were disked two to three times prior to planting, and rototilled within two days prior to planting. A few days prior to planting, fields in the Central Plateau were fertilized with diammonium phosphate at a rate of 45 kg/ha; at MFK, the same rate of diammonium phosphate was used in all trials conducted in 2015. All other trials were fertilized with 20-20-10 at a rate of 67 kg/ha. Manual weeding occurred at 4, 6 and 8 weeks after planting. At the MFK research site, plots were irrigated with a rotary sprinkler system as needed (twice a week in the absence of rain) with approximately 1.3 cm of water per irrigation event. At the Acceso research site, plots were irrigated with flood irrigation similar to the local grower standard.

Data Collection: Two to three weeks after planting, stand counts were made for each plot. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100 pod sample was shelled to obtain the moisture content of the kernels. Final weights were adjusted to 10% pod moisture.

Statistical Analysis: For this report, means and standard errors of final severity of leaf spot and rust and yield were calculated across all trials with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). A more in-depth analysis of variance will be reported in a forthcoming publication.

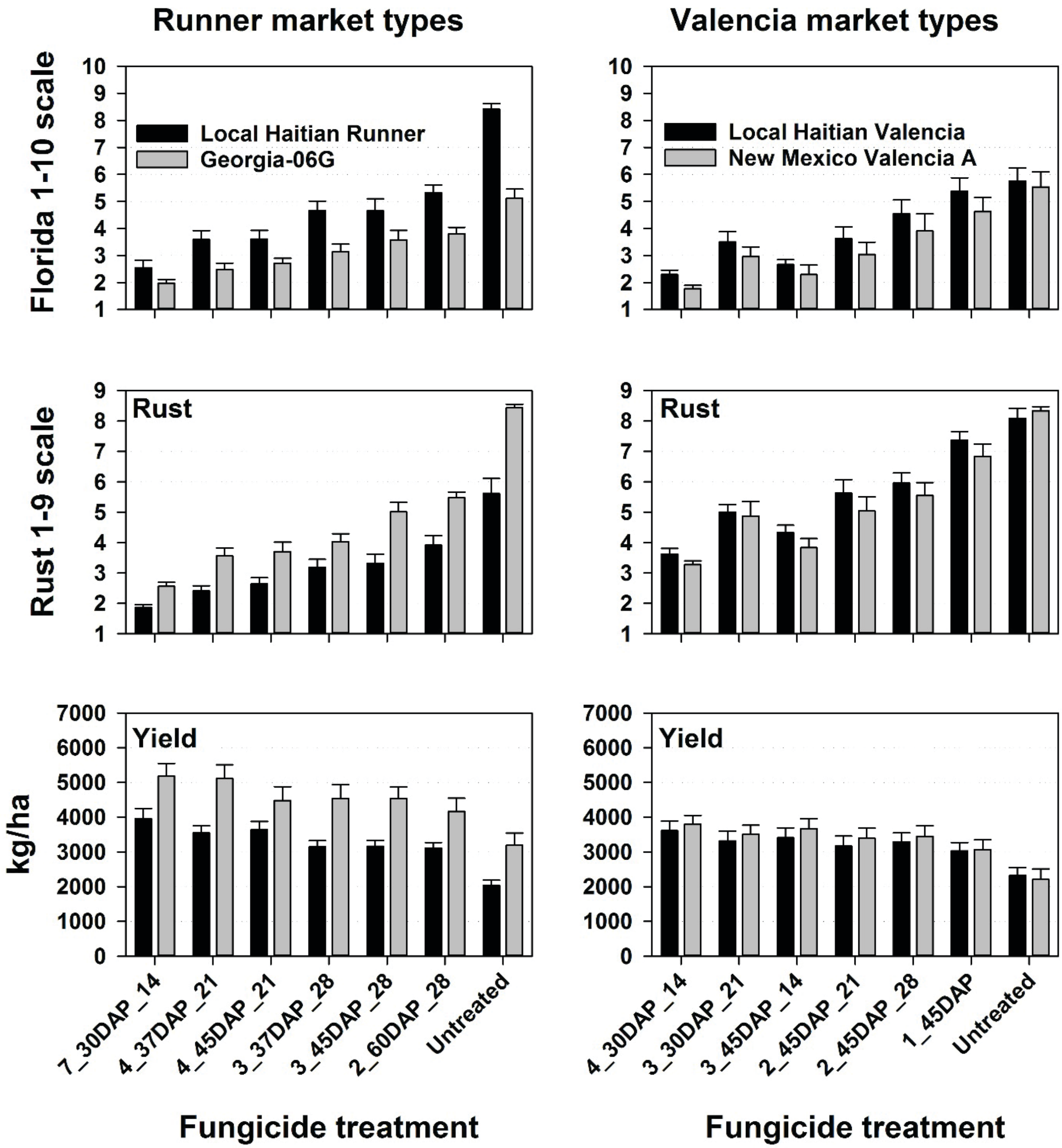


Figure 2.1.a. Effect of fungicide program on total pod yield (kg/ha) for runner and Valencia market type peanuts averaged across all trials. Fungicide treatments are labeled as follows: number of applications _ day after planting of first application _ subsequent spray interval. Error bars represent the standard error of the mean.

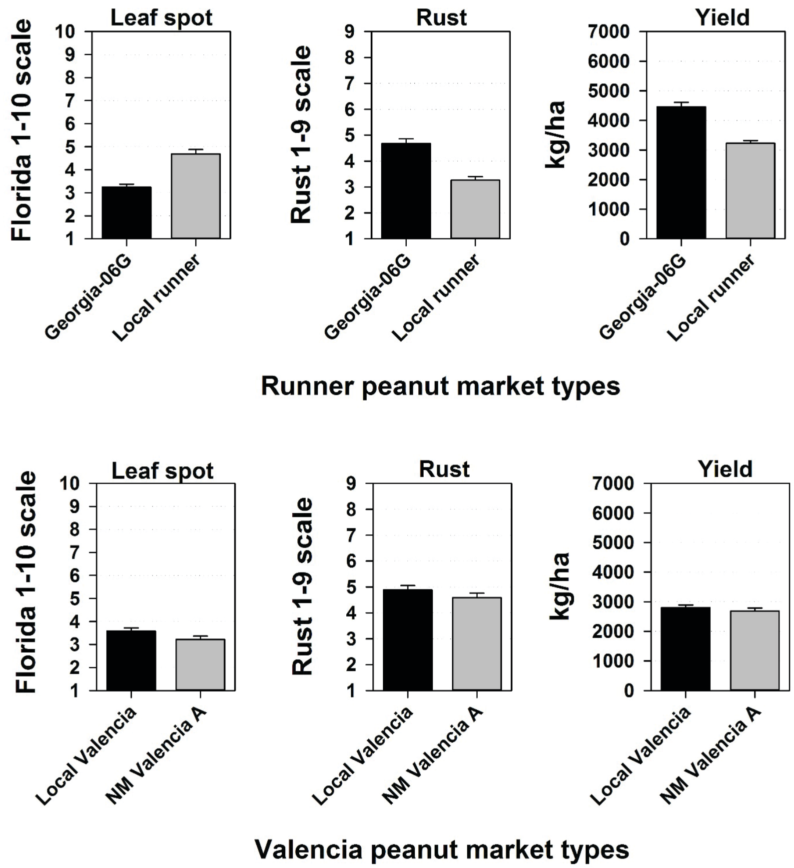


Figure 2.1.b. Effect of variety on total pod yield (kg/ha) for runner and Valencia market type peanuts averaged across all fungicide treatments and trials. Error bars represent the standard error of the mean.

Figure 2.1.c. Trial 3: Runner fungicide timing trial 1 June 2016.

Figure 2.1.d. Trial 3: Runner fungicide timing trial 23 June 2016.

Figure 2.1.e. Trial 1 at MFK: Valencia fungicide timing trial 29 April 2016.

Figure 2.1.f. Trial 1 at MFK: Valencia fungicide timing trial 1 June 2016.

Figure 2.1.g. Trial 1 in the Central Plateau: Valencia fungicide timing trial 11 June 2015 (PC, PMIL).

Figure 2.1.h. Trial 2 in the Central Plateau: Valencia fungicide timing trial 15 June 2016.

Chapter 2.2 Top 6 Valencia With/Without Fungicide Trials

Purpose: Evaluate the performance of advanced Valencia market type breeding lines developed at New Mexico State University by Dr. Naveen Puppala for possible introduction in Haiti. Primary interest is to determine varietal response to foliar diseases in relation to final severity of infection and pod yield.

Experimental Design: Five trials were conducted in Haiti from 2015 to 2017, four of which were located at MFK and one at the Acceso research farm in the Central Plateau.

Table 2.2.a. Planting dates, harvest dates, seeding rates and plot lengths for all trials in 2015 to 2017.

	Trial				
	1	2	3	4	5
Location	MFK	MFK	MFK	MFK	Central Plateau
Planting date	13 Nov, 2015	23 Mar, 2016	24 Aug, 2016	27 Jan, 2017	19 Jan, 2017
Harvest date	25 Feb, 2016	21 June, 2016	29 Nov, 2016	3 May, 2017	4 May, 2017
Seeding rate	3 seed/30.5 cm	6 seed/30.5 cm	6 seed/30.5 cm	6 seed/30.5 cm	3 seed/30.5 cm
Plot length	3.04	4.6 m	4.6 m	4.6 m	4.6 m

All trials were laid out in a split plot design with four to six replications. Six Valencia varieties were the main plot treatments and fungicide treatments (with or without three applications) were the subplot treatments. The six varieties included in these studies included the local Haitian Valencia and the following five advanced breeding lines developed by the New Mexico Agricultural State University Experiment Station located at Clovis, NM: 309 Red, 309 Tan, M2, M3, and SCGV0801.

Fungicide treatments consisted of a combination of tebuconazole (0.23 kg/ha) + chlorothalonil (0.84 a.i. kg/ha) (Muscle® ADV, Sipcam Agro USA, Inc.) sprayed at 45, 60 and 75 days after planting. A hand pumped backpack sprayer calibrated at 188 liters per hectare was used to make fungicide applications in all trials.

Plots were 1.2 m wide and plot length ranged from 3.04 m to 4.6 m length. Each plot consisted of two rows of peanuts, and were planted by hand at a rate of three seed or six seed/30.5 cm. A 1.5-m alley separated blocks, and there was no border row between subplots. Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis and irrigated biweekly in the absence of rain.

Data Collection: Two to three weeks after planting, stand counts were made for each plot. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100-pod sample was shelled to obtain the moisture content of the kernels. Final weights were adjusted to 10% pod moisture.

Statistical Analysis: For this report, means and standard errors of final severity of leaf spot and rust and yield were calculated across all trials with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). A more in-depth analysis of variance will be reported in a forthcoming publication in "Peanut Science."

Conclusion: While the 309 Tan variety showed excellent resistance to foliar disease, it did not respond as anticipated with increased yield and while other varieties showed a potential for yield increase over the local Haitian Valencia, it was not significant enough to warrant investment in large scale seed introduction. Until a higher performing variety is found, farmers interested in producing Valencia should continue with the local Haitian Valencia, which performed reasonably well and is widely available.

Figure 2.2.a. Example of plot layout at MFK for the NMSU Valencia trials.

Figure 2.2.c. 309 Red: fungicide (left of blue line) vs untreated plots (right of blue line). Pictures were from Trial 2 and taken on 21 June 2016.

Figure 2.2.d. 309 Tan: fungicide (left of blue line) vs untreated plots (right of blue line). Pictures were from Trial 2 and taken on 21 June 2016.

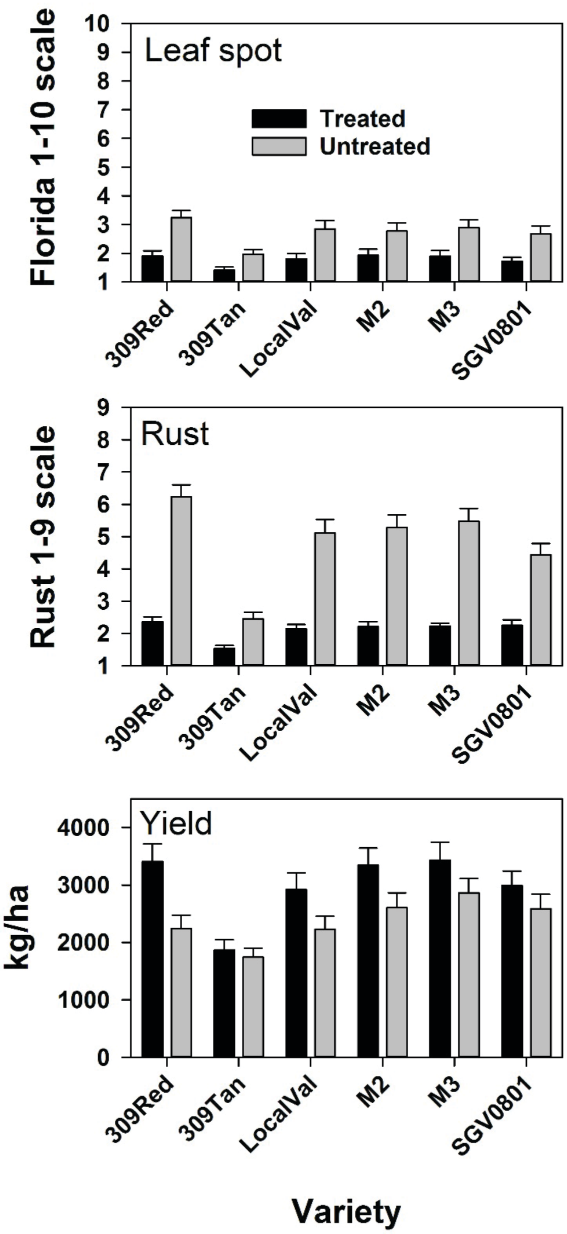


Figure 2.2.b. Means of final leaf spot and rust severity and pod yield pooled across all trials. Error bars represent the standard error of the mean.

Chapter 2.3 2016 ACI Seed Variety Trials

Purpose: Evaluate the performance of short maturing, high oleic acid breeding lines, developed by Dr. Kim Moore in Tifton, GA, through ACI Seeds for possible use in Haiti by comparing them to known standards.

Experimental Design: Field trials were conducted at two locations in Haiti: MFK and the Acceso research farm in the Central Plateau. All trials were originally laid out in a random complete block design with four to six replications. However, experiments were changed to split plot design to allow for a comparison of varietal performance with fungicide vs. no fungicide. As such, main plot treatment was fungicide (with or without two applications starting at 60 days after planting) and sub-plot treatment was peanut variety. This resulted in three replications at MFK and two replications in the Central Plateau.

Table 2.3.a. ACI Seeds breeding lines and additional varieties evaluated in these studies.

Variety	Description	Market type
WT 11-1120	ACI Seeds	Runner
N 11-0087	ACI Seeds	Runner
N 11-0029	ACI Seeds	Runner
M 15-1085	ACI Seeds	Runner
M 15-0069	ACI Seeds	Runner
309 Red	New Mexico State University	Valencia
308 Red	New Mexico State University	Valencia
308 Tan	New Mexico State University	Valencia
Local Valencia	Haitian landrace	Valencia
Local Runner	Haitian landrace	Runner
Georgia-06G	University of Georgia	Runner

At MFK, plots were planted on 25 May 2016 and harvested on 24 August (Valencia types) and 27 September 2017 (runner types). At the Acceso farm in the Central Plateau, plots were planted on 12 May 2016 and harvested on 11 August (Valencia types) and 6 September 2017 (runner types). For all trials, peanuts were planted at a rate of six seed/30.5 cm in single row plots that were 0.6 m wide and 3.0 m in length. Each Blocks were separated by a 1.5-m alley.

Other yield reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, fields were fertilized with 50 kg/ha of 20-20-10 and seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Data Collection: Two to three weeks after planting, stand counts were made for each plot. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC.

Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100 pod sample was shelled to obtain the moisture content of the kernels. Final weights (kg/ha) were adjusted to 10% pod moisture. A post-harvest test was made with the same 100 pod sample to evaluate the percentage of sound mature kernels (%SMK). Percent SMK was calculated by dividing the weight of the sound mature kernels by the total weight of the weight of the unshelled sample.

Statistical Analysis:

Stand count, leaf spot severity, rust severity and yield were subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). Each trial was analyzed separately and the model for each trial was a split plot design with fungicide and variety considered as fixed effects, with replication and replication × fungicide as random effects. In all analyses the Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test. When data violated the assumptions of normality, transformations were used.

Results:

Table 2.3.b. P-values for the fixed effects from the analysis of variance.

Location	Fixed effect	Leaf spot	Rust	Stand count[z]	Yield
		P-value	*P*-value	*P*-value	*P*-value
CP	Fungicide	0.2522	0.4729	0.8162	0.2347
CP	Variety	0.0089	0.2313	<.0001	<.0001
CP	Fungicide × Variety	0.5694	0.4346	0.6585	0.3375
MFK	Fungicide	<.0001	0.0019	0.2231	0.0356
MFK	Variety	<.0001	0.0001	<.0001	0.0014
MFK	Fungicide × Variety	<.0001	<.0001	0.3651	0.1981

[z] Number of plants emerged at ~ 3 weeks after planting divided by the number of seeds planted.

Table 2.3.c. Effect of variety on stand count and yield at two locations in Haiti.

Variety	Central Plateau				MFK			
	Stand count[y]		Yield (kg/ha)		Stand count[y]		Yield (kg/ha)	
308 Red	73	ab[z]	2029	ab	97	ab	3526	abc
309 Red	43	bc	1642	ab	85	abc	3678	abc
309 Tan	75	ab	1253	b	98	a	2258	abc
Georgia-06G	64	ab	2789	a	74	c	4391	a
Local runner	50	ab	1440	ab	38	e	3700	abc
Local Valencia	73	ab	1799	ab	83	abc	3606	abc
M150069	49	ab	1810	ab	79	bc	1866	c
M151085	78	a	1505	ab	88	abc	4126	ab
N110029	69	ab	2109	ab	85	abc	2735	abc
N110087	68	ab	1609	ab	90	abc	2474	abc
WT11_112	23	c	350	c	52	d	2021	bc

[y] Number of plants emerged at ~ 3 weeks after planting divided by the number of seeds planted.

[z] Means within the same column with the same letters are not significantly different based upon Tukey's honestly significant difference test.

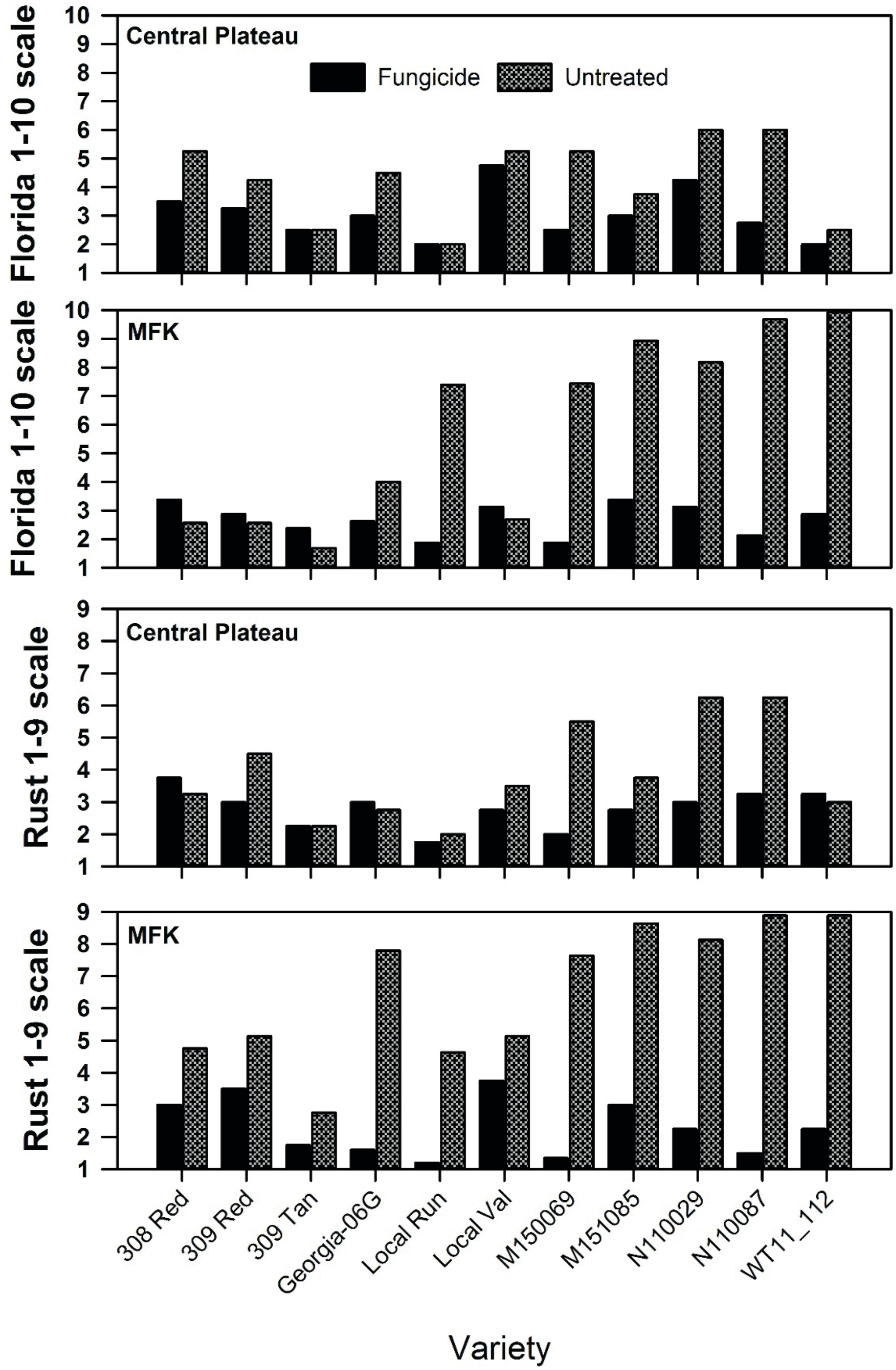


Figure 2.3.a. Final severity of leaf spot and rust for each variety in both treated and untreated plots at two locations in Haiti.

Conclusion:

The data do not suggest that it would be worthwhile to pursue large scale introduction of these varieties. The data do confirm the previous finding that the local Haitian Valencia, local Haitian Runner and Georgia 06-G maintained respectable yields. The data also suggest that planting at a higher density (six seed per 30.5cm) with the local Valencia may be advisable in both the North and Central Plateau.

Chapter 2.4 2017 ICRISAT Variety Trials

Purpose: Evaluate the performance of advanced breeding lines developed by ICRISAT (International Crops Research Institute for the Semi-Arid Tropics).

Experimental Design: A trial was conducted at MFK that was laid out in a random complete block design with two replications.

Table 2.4.a. Varieties evaluated were as follows.

Treatment	Trait	Botanical type	Branching habit	Seed color
ICGV 00338	Short-duration	Spanish	Sequential	Tan
ICGV 02038	Short-duration	Spanish	Sequential	Tan
ICGV 06237	Short-duration	Spanish	Sequential	Tan
ICGV 07210	Short-duration	Spanish	Sequential	Tan
ICGV 07235	Drought tolerant	Spanish	Sequential	Tan
ICGV 07286	Drought tolerant	Spanish	Sequential	Tan
ICGV 07390	Drought tolerant	Spanish	Sequential	Tan
ICGV 07396	Drought tolerant	Spanish	Sequential	Tan
ICGV 06138	Diseases resistant	Spanish	Sequential	Tan
ICGV 06175	Diseases resistant	Virginia	Alternate	Tan
ICGV 06176	Diseases resistant	Virginia	Alternate	Tan
ICGV 07120	Diseases resistant	Spanish	Sequential	Tan
Local Valencia	-	Valencia	-	Tan
Local Runner	-	Runner	-	Tan
Georgia-06G	-	Runner	-	Tan

At MFK, plots were planted on 6 April 2017 and harvested on 5 July (Valencia and Spanish types) and 4 August 2017 (Virginia and runner types). However, it should be noted that the maturity was not evaluated prior to harvest. Peanuts were planted at a rate of three seed/30.5 cm in single row plots that were 0.3 m wide and 4.5 m in length. Each block was separated by a 1.5 m-alley.

Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, fields were fertilized with 50 kg/ha of 20-20-10 and seeds were treated with azoxystrobin, fludioxonil, and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Data Collection: Two to three weeks after planting, stand counts were made for each plot. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100-pod sample was shelled to obtain the moisture content of the kernels. Final weights (kg/ha) were adjusted to 10% pod moisture. A post-harvest test was made with the same 100-pod sample to evaluate the percentage of sound mature kernels (%SMK). Percent SMK was calculated by dividing the weight of the sound mature kernels by the total weight of the weight of the unshelled sample.

Statistical Analysis:

Final severity of stand count, leaf spot severity, rust severity and yield were subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). In all analyses the Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test. When data violated the assumptions of normality, transformations were used.

Results:

Table 2.4.b. Effect of variety on stand count, leaf spot, rust, and yield.

Trt	Treatment	Trait	Botanical type	Stand count		Leafspot		Rust		Kg/ha	
1	ICGV 00338	Short-duration	Spanish	100.0	a	1.0	a	1.25	a	2211.0	ab
2	ICGV 02038	Short-duration	Spanish	100.0	a	1.0	a	1.00	a	2182.1	ab
3	ICGV 06237	Short-duration	Spanish	100.0	a	1.0	a	1.25	a	1309.2	b
4	ICGV 07210	Short-duration	Spanish	100.0	a	1.0	a	1.00	a	1789.6	ab
5	ICGV 07235	Drought tolerant	Spanish	65.0	c	1.0	a	1.00	a	2442.7	ab
6	ICGV 07286	Drought tolerant	Spanish	86.0	ab	1.0	a	1.00	a	2584.0	ab
7	ICGV 07390	Drought tolerant	Spanish	79.0	abc	1.0	a	1.00	a	3042.8	ab
8	ICGV 07396	Drought tolerant	Spanish	92.0	ab	1.0	a	1.00	a	2433.3	ab
9	ICGV 06138	Diseases resistant	Spanish	96.0	a	1.0	a	1.00	a	2311.0	ab
10	ICGV 06175	Diseases resistant	Virginia	88.0	ab	1.0	a	1.00	a	3532.2	a
11	ICGV 06176	Diseases resistant	Virginia	95.0	a	1.0	a	1.00	a	2880.6	ab
12	ICGV 07120	Diseases resistant	Spanish	92.0	ab	1.0	a	1.00	a	3008.2	ab
13	Local Valencia		Valencia	99.0	a	1.0	a	1.00	a	1869.9	ab
14	Local Runner		Runner	62.0	c	1.0	a	1.00	a	1200.1	b
15	Georgia-06G		Runner	73.0	bc	1.0	a	1.00	a	2925.8	ab
LSD P=.05				13.16		0.00		0.267		1179.14	
Standard Deviation				6.13		0.00		0.124		549.72	
CV				6.93		0.0		12.04		23.08	
Replicate F				2.215		0.000		2.154		5.097	
Replicate Prob (F)				0.1588		1.0000		0.1643		0.0405	
Treatment F				8.938		0.000		1.000		2.826	
Treatment Prob (F)				0.0001		1.0000		0.5000		0.0308	

Figure 2.4.a. Plots with ICRISAT varieties in a field at MFK taken on 5 June, 2017.

Conclusion: This trial had two objectives: 1) to evaluate the potential of these advanced lines from the ICRISAT breeding program in India and 2) to multiply seed for future multi-location trials, which is why fungicide and irrigation were used to assure maximum yield. These initial data suggest that these lines do hold promise and should be evaluated under field stress situations in multiple locations.

Chapter 2.5 2016-2017 Tillman Breeding Line Screenings

Purpose: To evaluate the performance of advanced breeding lines developed by Barry Tillman for resistance to foliar diseases in Haiti.

Experimental Design: In the spring of 2016, 45 breeding lines were compared to the local Haitian landraces and the predominant runner variety planted in the southeastern U.S., Georgia-06G. In the fall of 2016, the best performing lines were selected for further screening and compared to the same known standard varieties as the first trial. Both trials were laid out in a random complete block design. In the first trial, there were two replications and in the second trial there were three replications.

The first trial was planted on 23 March 2016 and harvested on 20 July. The second trial was planted on 10 October 2016 and harvested on 7 February 2017. In the first trial, peanuts were planted at a rate of 25 seed/row in single row plots that were 0.6 m wide and 2.4 m in length (~3 seed/0.3m). In the second trial, peanuts were planted at a rate of 3 seed/0.3 m in single row plots that were 0.6 m wide and 4.5 m in length. In both trials, each block was separated by a 1.5-m alley.

Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, fields were fertilized with 50 kg/ha of 20-20-10 and seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were not sprayed with fungicide, but were weeded on a biweekly basis and irrigated biweekly in the absence of rain.

Data collection. Two to three weeks after planting, stand counts were made for each plot. Final leaf spot and rust severity ratings were taken immediately prior to digging. In the first trial, leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III). In the second trial, five leaves per plot were sampled and the number of leaf spot lesions were counted. Rust severity per leaflet was estimated on a 0 to 100 % scale. Plots were sampled at 60, 75, 90, 105, and 120 DAP. For the number of leaf spot lesions and the percent rust on the leaflet, AUDPC values were calculated and standardized (stAUDPC) by dividing AUDPC values by the number of days between the first and final evaluation.

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all of the attached pods from the plant. Afterward, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying, bags were weighed.

Statistical analysis. Means were calculated for final severity of stand count, leaf spot severity, rust severity and yield were subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC).

Results

Figure 2.5.a. Plots from the first trial at MFK on 1 June 2016.

Figure 2.5.b. Plots from the first trial at MFK on 21 June 2016.

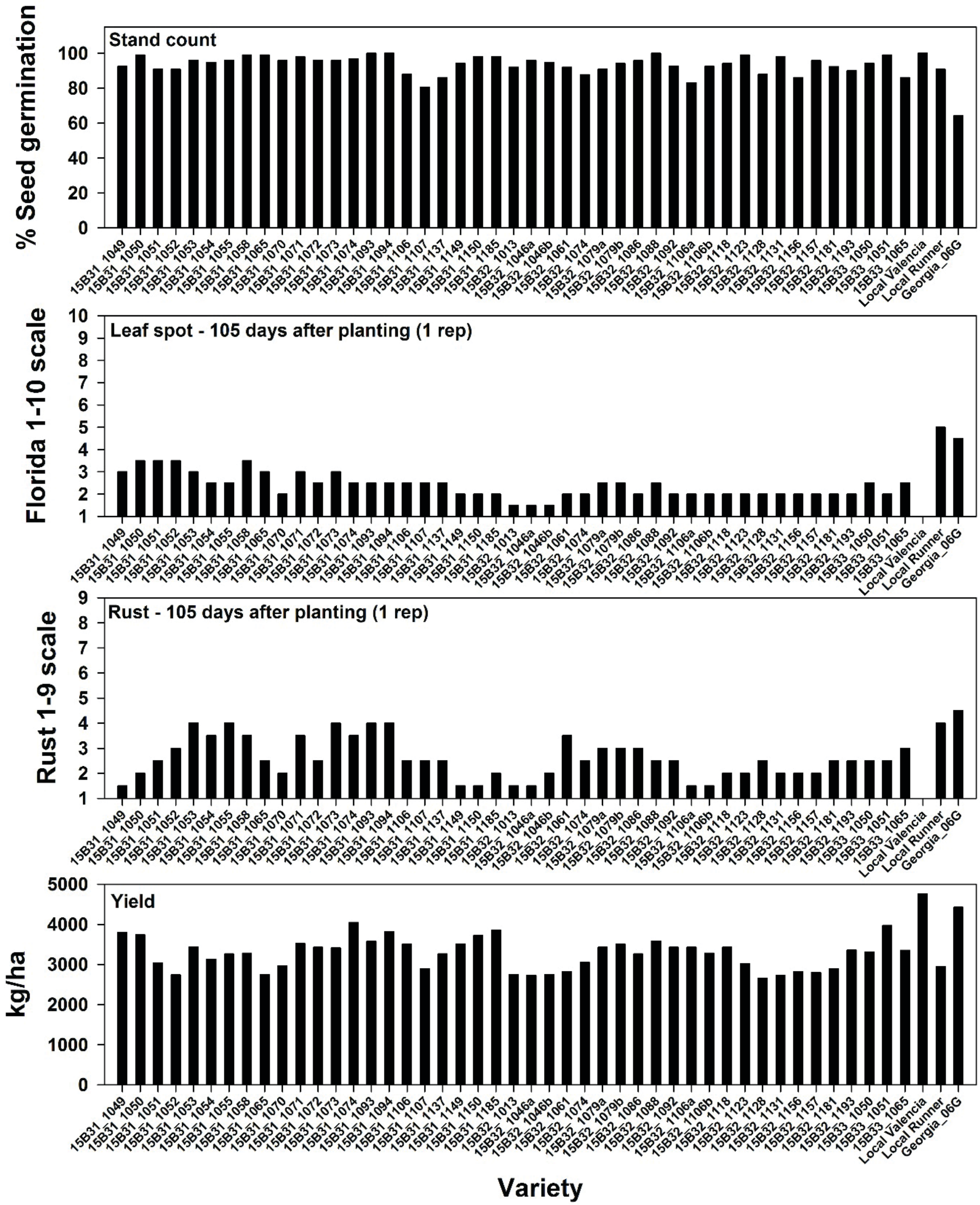


Figure 2.5.c. Trial 1: Tillman breeding line screening conducted at MFK during the spring/summer of 2016. Seed germination = stand count (number of plants emerged at ~ 3 weeks after planting divided by the number of seeds planted)

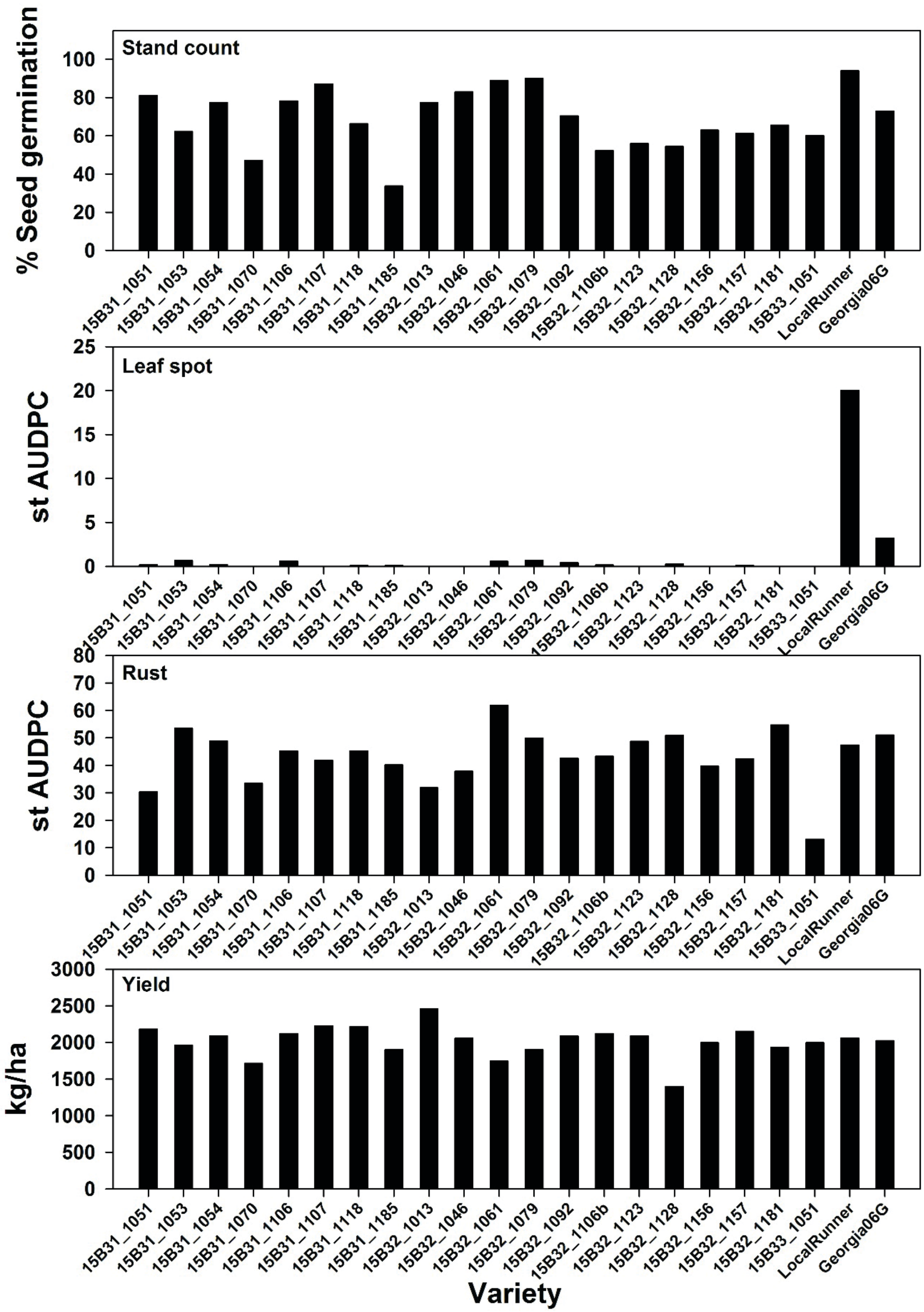


Figure 2.5.d. Trial 2: Tillman breeding line screening conducted at MFK during the fall/winter of 2016/2017.

Conclusion: Some of these varieties show promise and should be multiplied and evaluated in multiple locations.

Chapter 3.1 Inoculant × Fertilizer Interaction Studies

Purpose: Determine whether rhizobia nodulation, fertilizer or a combination of the two factors are yield-limiting factors for peanut production at two sites in Haiti.

Experimental Design: Two inoculant/fertility trials were conducted during the spring of 2015. One trial was at the Meds & Food for Kids factory in the community of Quartier Morin, Haiti and the other at the Acceso research farm in the Central Plateau. Both trials were laid out in a split plot design with four replications. Presence or absence of liquid Bradyrhizobia (Optimize® liquid inoculant for peanut; Novozymes, Inc., Bagsvaerd, Denmark) was the main plot treatments, and granular fertilizer type was the subplot treatments. At MFK, there were four subplot treatments – diammonium phosphate (DAP) at a high rate (67.2 kg ha-1), DAP at a low rate (22.4 kg ha-1), monoammonium phosphate (MAP) at a high rate (67.2 kg ha-1) and an untreated control plot.

Prior to planting, fields were disc plowed two to three times, and/or rototilled within two days prior to planting. On the day prior to planting, the various granular fertilizer treatments were applied (an even broadcast) and rototilled twice at the rates mentioned above to the respective plots. The liquid inoculant was applied in-furrow with a hand pumped backpack sprayer at a rate of 1.0 oz/1,000 feet of row (29.57 mL/304.8 m of row).

Dates from planting to harvest, respectively, for MFK and Acceso were as follows: 26 March 2015 to 1 July 2015 and 29 April 2015 to 30 July, 2015. For all trials, the New Mexico Valencia A was planted at a rate of three seed/0.3m in two rows spaced 0.762 m apart in plots that were 1.5 m wide and 3.04 m in length. Blocks were separated by a 1.5-m alley. Other yield-reducing factors were managed in order to mitigate confounding results. As such, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Data Collection: Two to three weeks after planting, stand counts were made for each plot. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100-pod sample was shelled to obtain the moisture content of the kernels. Final weights (kg/ha) were adjusted to 10% pod moisture. A post-harvest test was made with the same 100-pod sample to evaluate the percentage of sound mature kernels (%SMK). Percent SMK was calculated by dividing the weight of the sound mature kernels by the total weight of the unshelled sample.

Statistical Analysis: Final severity of stand count, yield and %SMK were subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). Each trial was analyzed separately and the model for each trial was a split plot design with inoculant and fertilizer considered as fixed effects, with replication and replication × inoculant as random effects. In all analyses, the Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test.

Table 3.1.a. Two-way analysis of variance for stand count, yield and %SMK for each location in Haiti.

Location	Fixed effect	Stand count		Yield (KgHa)		%SMK	
		F-value	*P*-value	F-value	*P*-value	F-value	*P*-value
CP	Fungicide	3.05	0.1013	0.15	0.7279	-	-
CP	Variety	1.13	0.3482	0.72	0.5088	-	-
CP	Fungicide × Variety	0.01	0.9923	0.48	0.6326	-	-
MFK	Fungicide	4.08	0.0899	0.01	0.932	0.97	0.3689
MFK	Variety	0.91	0.4546	1.47	0.2618	0.59	0.6304
MFK	Fungicide × Variety	0.24	0.8666	1.14	0.3641	0.99	0.4226

Table 3.1.b. Effect of inoculant and fertilizer on stand count, yield and %SMK at each location in Haiti.

Location	Fixed effect	Treatment	Stand count		Yield (KgHa)		%SMK	
CP	Inoculant	Inoculated	71.9	a[z]	532	a	-	
		Non-inoculated	67.4	a	509	a	-	
	Fertilizer	High DAP	67.1	a	511	a	-	
		Low DAP	71.8	a	554	a	-	
		None	70.0	a	497	a	-	
MFK	Inoculant	Inoculated	89.0	a	3456	a	79.2	a
		Non-inoculated	95.4	a	3430	a	84.8	a
	Fertilizer	High DAP	91.0	a	3337	a	86.7	a
		High MAP	93.9	a	3450	a	78.0	a
		Low DAP	94.3	a	3578	a	81.7	a
		None	90.6	a	3411	a	81.8	a

[z] Means within the same column with the same letters are not significantly different based upon Tukey's honestly significant difference test.

Conclusion: The data suggest that the crop does not respond to either inoculation or phosphorus fertilizer. It may be that adequate inoculum of Bradyrhizobia was present in the soil as evidenced by the level of nodulation on the untreated plots. However, this may or may not hold true for areas that have not had recent peanut cultivation and could require future research.

Peanut roots with nodules containing Rhizobium bacteria from non-inoculant treated plots at MFK.

Chapter 3.2 Foliar × Granular Fertilizer Interaction Trials

Purpose: Determine if foliar applications of micronutrient foliar fertilizer, various rates of granular fertilizers, including high nitrogen granular fertilizers, or a combination of the two inputs can increase pod yield in high pH soils in Haiti.

Experimental Design: Two fertility trials were conducted during the spring and summer of 2017 at the Meds & Food for Kids factory in the commune of Quartier Morin, Haiti. Both trials were laid out in a split plot design with four replications. Presence or absence of foliar fertilizer was the main plot treatments, and granular fertilizer type was the subplot treatments. Dates from planting to harvest, respectively, for each trial were as follows: 3 March 2017 to 1 June 2017; 11 April 2017 to 10 July 2017. For all trials, the local Haitian Valencia was planted in plots that were 1.2 m wide and 4.6 m in length; rows were spaced 0.6 m apart, and one untreated row was planted between each treatment plot. Blocks were separated by a 1.5-m alley.

For the main plot, Nurish® (FERSAN, Santo Domingo, Dominican Republic) fertilizer was applied one time to all treated plots in the first trial; the concentrated fertilizer was diluted in water to a concentration of 1951 ppm. Solubor® 20.5% elemental boron soluble liquid organic fertilizer (Rio Tinto, Inc., London, United Kingdom) was also applied once to the both trials at a rate of 2.4 kg ha-1, so as to provide 0.6 kg ha-1 of elemental boron to the plants. The subplot consisted for four treatments; namely, 112.1 kg ha-1 20-20-10 N-P-K, 44.8 kg ha-1 diammonium phosphate (DAP), 112.1 kg ha-1 urea, and an untreated control plot.

Table 3.2.a. Ingredients contained in the foliar fertilizer Nurish.

Total Nitrogen (soluble)	20%	Iron	1500 ppm
NO3	5.94%	Zinc	750 ppm
NH4	3.91%	Manganese	750 ppm
Water soluble organic Nitrogen	10.15%	Copper	750 ppm
Phosphorus P2O5	20%	Boron	300 ppm
Potassium K2O	20%	Molybdenum	105 ppm

The various granular fertilizer treatments were applied at the rates mentioned above to the respective treatments at 28 and 23 days after sowing for the first and second trials, respectively. All granular fertilizers were applied using the side dressing method by tracing a line perpendicular to each treatment row approximately 6 cm away from the row and spreading the fertilizer along this line by hand; after the fertilizer was spread, it was covered up with a thin layer of soil. Nurish® foliar micronutrient fertilizer was applied to the first trial at 45 days after sowing using a one-gallon hand-held pump sprayer, and was not applied to the second trial. This is because the research team had already obtained foliar boron fertilizer by the time the second trial was planted, and boron was judged to be the most plant-limiting micronutrient for peanut cultivation in the area and hence the most likely to have a positive effect on growth. To this effect, Solubor® foliar boron fertilizer was applied at 61 and 43 days after sowing to the first and second trials, respectively; the same one-gallon hand-held pump sprayer that was used to apply the Nurish® fertilizer was also used to apply the Solubor® fertilizer. Both foliar fertilizers were applied to the entirety of the rows making up the treatment plots.

Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Data Collection:
Two to three weeks after planting, stand counts were made for each plot; average stand count across all plots was 71.4% for Soil Fertility Trial No. 1 and 91.8% for Soil Fertility Trial No. 2. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100-pod sample was shelled to obtain the moisture content of the kernels. Final weights were adjusted to 10% pod moisture. A post-harvest test was made with the same 100-pod sample to evaluate the percentage of sound mature kernels (%SMK). Percent SMK was calculated by dividing the weight of the sound mature kernels by the total weight of the unshelled sample.

Statistical Analysis:
Pod yield was subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). The model was a split-split plot design with trial, foliar fertilizer and granular fertilizer considered as fixed effects, and replication, replication × trial and replication × foliar fertilizer as random effects. The Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test.

Table 3.2.b. P values from the three-way analysis of variance for stand count, yield and %SMK.

Effect	Stand count[z]	Yield (kg/ha)	%SMK
Trial	0.0056	0.0067	0.0249
Fertilizer	0.9211	0.932	0.0018
Fertilizer × Trial	0.6612	0.5688	0.1052
Foliar Fertilizer	0.1381	0.6065	0.1877
Foliar Fertilizer × Trial	0.1705	0.8087	0.4659
Fertilizer × Foliar Fertilizer	0.7121	0.4554	0.7346
Fertilizer × Foliar Fertilizer × Trial	0.1691	0.8227	0.5202

[z] Number of plants emerged at ~ 3 weeks after planting divided by the number of seeds planted.

Fig 3.2.a. Plots from the first trial at MFK prior to harvest.

Table 3.2.c. Effect of trial, granular fertilizer and foliar fertilizer for two field trials conducted at MFK.

Effect	Stand count[y]		Yield (kg/ha)		%SMK	
Trial						
1	94.2	a[z]	3326.3	a[z]	65.6	a
2	70.7	b	2711.2	b	60.2	b
Granular fertilizer						
20-20-10_100 lbs	85.2	a	3047.8	a	64.3	a
Urea_100 lbs	84.5	a	3002.8	a	63.9	a
DAP_40 lbs	84.0	a	2988.1	a	63.2	a
Untreated	83.3	a	2974.1	a	60.2	b
Foliar fertilizer						
Treated	85.7	a	3024.8	a	63.4	a
Untreated	82.7	a	2981.5	a	62.4	a

[y] Number of plants emerged at ~ 3 weeks after planting divided by the number of seeds planted.

[z] Means within the same column with the same letters are not significantly different based upon Tukey's honestly significant difference test.

Conclusion: These data suggest that the crop does not significantly respond to foliar micronutrient or granular fertilization. However, these plots were completed on land that is known to have received previous fertility treatment and plants in areas with more deficient soil may respond differently.

Chapter 3.3 2016 Fulvic Acid Trials

Purpose: Determine the effect of fulvic acid on pod yield. It is hypothesized that fulvic acid would allow more nutrient availability in the high pH soils found in Haiti.

Experimental Design: Plots were laid out in a random complete-block design with four replications.

Treatments were as follows:

1. 55kg/ha Fulvic acid
2. 70 kg/ha Fulvic acid
3. 70 kg/ha Fulvic acid + 70kg/ha 20-20-10
4. 120 kg/ha Fulvic acid
5. Untreated

The local Haitian Valencia was planted in plots that were 1.5 m wide and 3.04 m long with three rows spaced 0.4 m apart at a rate of three seed/30.5 cm. Each plot was separated by 1.2 m fallow, buffer zone, and blocks were separated by a 1.5 m alley. Plots were planted on 11 December 2015 and harvested on 10 March 2016. Fulvic Acid + 20-20-10 were weighed before and applied after sowing 2-5 cm away from seed. Seed and fertilizer depth were identical.

Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Results:

Table 3.3.a. Effect of fulvic acid treatment on stand count and pod yield at MFK.

Trt.	Treatment description	Stand count		Yield	
1	Fulvic Acid (Low) 55 kg/ha	0.89	a	2707.9	a
2	Fulvic Acid (High) 70 kg/ha	0.89	a	2205.1	b
3	Fulvic Acid (High) 70 kg/ha + 20-20-10 (70kg/ha)	0.89	a	2158.9	b
4	Fulvic Acid (Very High) 120 kg/ha	0.86	a	2214.3	b
5	Untreated	0.91	a	2445.0	ab
Tukey's HSD P=.05		0.155948		436.37	
Standard Deviation		0.069157		190.97	
CV		7.76		8.14	
Replicate F		1.915		16.041	
Replicate Prob(F)		0.1811		0.0002	
Treatment F		0.235		5.839	
Treatment Prob(F)		0.9131		0.0090	

Fig 3.3.a. Applying a protective fungicide cover spray on the plots at MFK.

Conclusion: Current data do not support the use of fulvic acid as an input for peanut production in Haiti. Further research could consider different products, application rates or trial locations.

Chapter 4.1 Seed/Row Spacing Trials

Purpose: The primary objective was to determine the best planting density for optimizing yield in runner and bunch-type peanuts. A secondary objective was to determine the effect of seed/row spacing on virus intensity.

Experimental Design: A total of five seed/row spacing trials were conducted from 2015 to 2017.

The first two were conducted at two locations during the summer of 2015. These locations included the MFK research site and a local university-owned property in Trou-Du-Nord. However, it should be noted that the first two trials were preliminary and did not include the 12-inch row-spacing, did not have a buffer area between plots, were not irrigated as heavily and had fewer records available. Therefore, we will only include the yield data as an appendix (see Appendix V).

In 2016, two seed-spacing trials were conducted at the MFK research site in spring and fall, and the last trial was conducted at the same site in the summer of 2017. All trials were laid out in a split-split plot design, with five replications for Trial No. 1 and four replications for Trials No. 2 and No. 3. Variety was the main plot treatment, row spacing was the subplot treatment, and seed spacing was the sub-subplot treatment.

Table 4.1.a. Factors and associated treatment levels for seed/row spacing trials in 2016 and 2017.

Split-split plot design	Factor	Level
Main plot	Variety	Local Haitian runner
		Local Haitian Valencia
Subplot	Row spacing (distance between rows)	30.5 cm (12 in.)
		45.7 cm (18 in.)
		61.0 cm (24 in.)
Sub-subplot	Seed spacing (distance within row)	3.3 seeds m-1 (1 seed/ft.)
		9.8 seeds m-1 (3 seed/ft.)
		19.7 seeds m-1 (6 seed/ft)

For all trials, plots were 1.8 m wide and 3.0 m in length. Plots were separated by 0.61 m unplanted space and blocks were separated by a 1.5 m alley (with the exception of the 2017 trial which had a 0.61 m alley). In all plots, target rows were first marked with stakes and string, and hoes were used to create furrows with an average depth of 3.8 cm. The number of furrows made for 30.5, 45.7 and 61.0 cm row spacings was six, four and three, respectively. Plots were planted by hand, and uniformity was ensured by placing PVC pipes (marked with the appropriate respective seeding rates) within the furrow while planting. Dates from planting to harvest, respectively, for each trial were as follows: Trial No. 1: 11 March 2016 to 14 June, 2016 (Valencia) and 13 July 2016 (runner); Trial No. 2: 14 October 2016 to 14 January 2017 (Valencia) and 16 February 2017 (runner); Trial No. 3: 26 May 2017 to 24 August 2017 (Valencia) and 27 September 2017 (runner).

Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, fields were disked two to three times prior to planting, and rototilled within two days prior to planting. 20-20-10 N-P-K fertilizer was applied to each of the study fields at a rate of 112.1 kg ha-1. Prior to planting, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Data Collection: Two to three weeks after planting, stand counts were made for each plot. Virus intensity was assessed as the number of 0.3 m sections of peanut plants with symptomatic infection (see Appendix VI for detailed virus symptoms). Virus ratings were made at 5 May and 8 December 2016, for the first and second trial, respectively. Ratings were not taken for 2017 trial.

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100-pod sample was shelled to obtain the moisture content of the kernels. Final weights were adjusted to 10% pod moisture. A post-harvest test was made with the same 100-pod sample to evaluate the percentage of sound mature kernels (%SMK). Percent SMK was calculated by dividing the weight of the sound mature kernels by the total weight of the unshelled sample.

Statistical Analysis: Yield and %SMK were subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). Due to differences in seed spacing between trials, and to better understand the effect of each factor for a given environment, each trial was analyzed separately. For all three trials, the model was a split-split plot design with variety, row spacing, and seed spacing considered as fixed effects, and with replication and replication × variety as random effects. Due to significant variety × row spacing and variety × seed spacing interactions ($\alpha = 0.05$), the effect of seed spacing was analyzed by variety and row spacing for the main response variable. The SLICE option in SAS was used to explore all two-way interactions. In all analyses, the Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test.

Figure 4.1.a. 2017 Seed- and row-spacing trial at MFK taken 5 June. 2017.

Figure 4.1.b. 2017 Seed- and row-spacing trial at MFK taken 28 August. 2017.

Table 4.1.b. P-values from the analysis of variance for virus, stand count, pod yield and %SMK for each trial and variety.

Trial	Variety	Effect	Stand count[z]	Kg/ha	% SMK
1	Runner	Between-row (B)	0.2868	0.0222	0.5072
		Within-row (W)	<.0001	0.0001	0.0002
		B × W	0.3551	0.5495	0.1799
	Valencia	Between-row (B)	0.8325	<.0001	0.8847
		Within-row (W)	<.0001	<.0001	0.0424
		B × W	0.8259	0.0006	0.0808
2	Runner	Between-row (B)	0.8122	0.439	0.3871
		Within-row (W)	0.0511	<.0001	0.6163
		B × W	0.3877	0.0047	0.9347
	Valencia	Between-row (B)	0.0260	0.0458	0.9809
		Within-row (W)	0.0258	<.0001	0.7215
		B × W	0.5390	0.0200	0.6823
3	Runner	Between-row (B)	0.1732	0.7546	0.0595
		Within-row (W)	0.0113	0.2352	0.9072
		B × W	0.0384	0.7218	0.4646
	Valencia	Between-row (B)	0.9861	0.0025	0.1895
		Within-row (W)	0.0287	<.0001	0.0306
		B × W	0.1181	0.5169	0.128

[z] Number of plants emerged at ~ 3 weeks after planting divided by the number of seeds planted.

Table 4.1.c. Effect of between-row spacing on pod yield for each within-row seed spacing for runner and Valencia market types for each trial conducted at MFK during 2016 and 2017.

Variety	Within-row spacing	Between-row spacing	Yield (kg/ha)					
			Trial 1		Trial 2		Trial 3	
Runner	3.3 per meter	.3 meter (12 inches)	5081	a	1703	A	3557	a
		.46 meter (18 inches)	3492	b	1077	B	3479	a
		.6 meter (24 inches)	3967	ab	1083	B	3333	a
	9.8 per meter	.3 meter (12 inches)	5649	a	1746	A	3122	a
		.46 meter (18 inches)	4691	a	1805	A	3257	a
		.6 meter (24 inches)	5055	a	1854	A	3400	a
	19.7 per meter	.3 meter (12 inches)	6322	a	1931	A	2943	a
		.46 meter (18 inches)	5506	a	1950	A	3317	a
		.6 meter (24 inches)	5314	a	1987	A	3150	a
Valencia	3.3 per meter	.3 meter (12 inches)	4202	a	1553	A	2128	a
		.46 meter (18 inches)	2859	b	1275	A	2010	a
		.6 meter (24 inches)	2084	c	844	B	1899	a
	9.8 per meter	.3 meter (12 inches)	6900	a	2328	Ab	3304	a
		.46 meter (18 inches)	5955	a	2966	A	3059	ab
		.6 meter (24 inches)	4923	b	1949	B	2220	b
	19.7 per meter	.3 meter (12 inches)	7596	a	3691	A	3820	a
		.46 meter (18 inches)	7517	a	3519	Ab	3571	ab
		.6 meter (24 inches)	6086	b	2408	B	2740	b

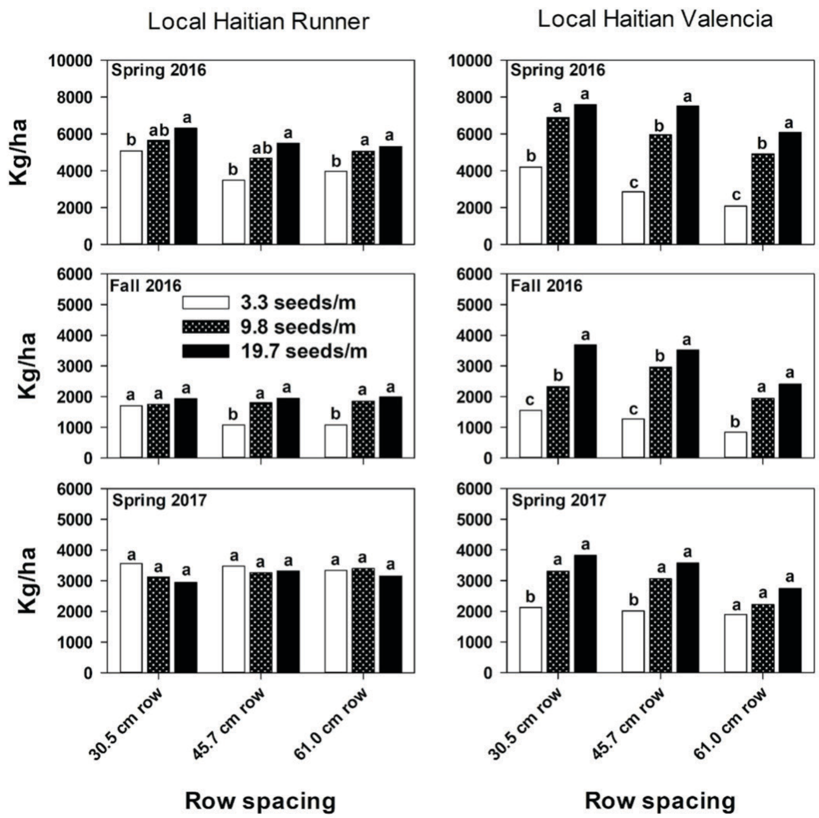


Figure 4.1.c. Effect of seed spacing on total pod yield (kg/ha) for each market type and row spacing. Grouped bars for each row spacing treatment with the same letters are not significantly different based upon Tukey's honestly significant difference test.

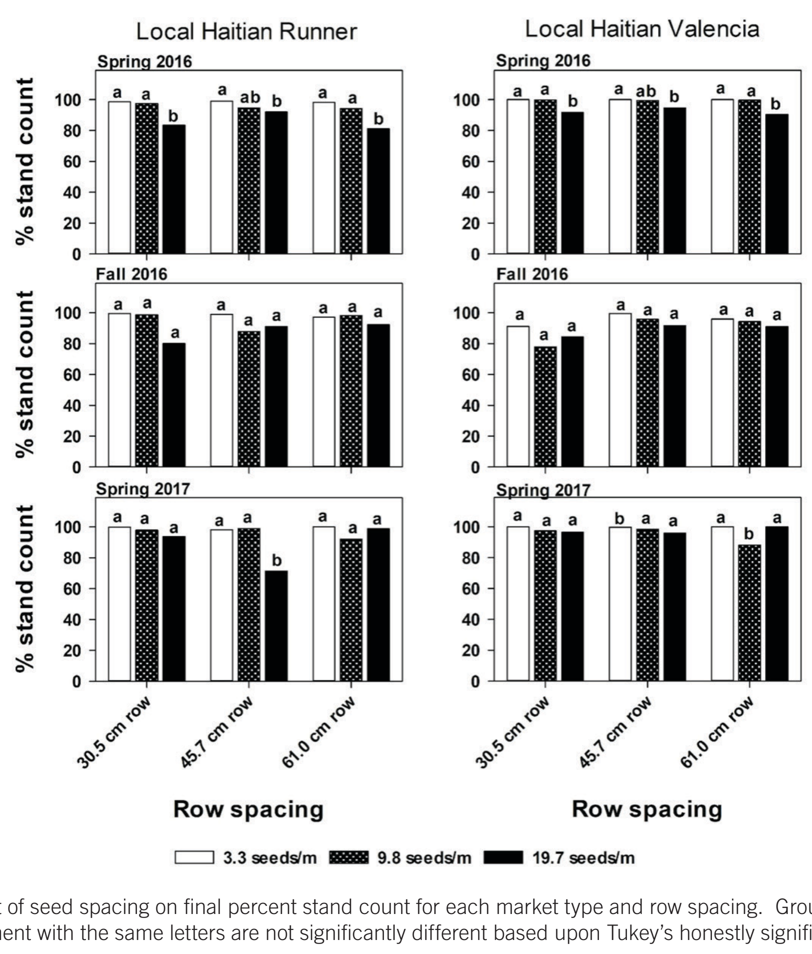


Figure 4.1.d. Effect of seed spacing on final percent stand count for each market type and row spacing. Grouped bars for each row spacing treatment with the same letters are not significantly different based upon Tukey's honestly significant difference test.

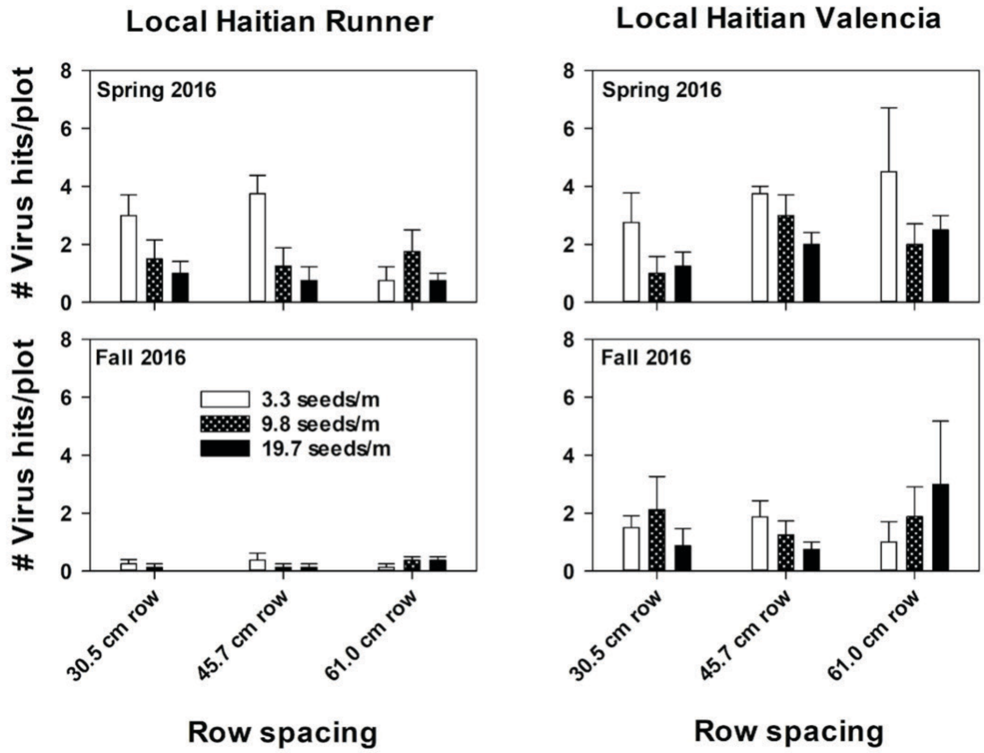


Fig 4.1.e. Mean number of 0.3 m sections of peanuts with symptomatic viral infection. Error bars represent the standard error of the mean.

Table 4.1.d. Effect of variety, between-row spacing and within-row seed spacing on percent virus incidence for runner and Valencia market types for two trials conducted at MFK during 2016.

Variety	Effect	Treatment	% SMK					
			Trial 1		Trial 2		Trial 3	
Runner	Between-row spacing	.3 meter (12 inches)	71.0	a	66.0	a	59.3	ab
		.46 meter (18 inches)	70.5	a	62.4	a	61.6	a
		.6 meter (24 inches)	69.8	a	62.7	a	56.8	b
	Within-row spacing	1 seed/30.5 cm (1 seed/ft)	67.8	b	64.4	a	58.9	a
		3 seed/30.5 cm (3 seed/ft)	70.9	a	64.7	a	59.2	a
		6 seed/30.5 cm (6 seed/ft)	72.7	a	62.1	a	59.7	a
Valencia	Between-row spacing	.3 meter (12 inches)	65.9	a	72.0	a	60.2	a
		.46 meter (18 inches)	66.6	a	72.2	a	59.7	a
		.6 meter (24 inches)	66.2	a	71.9	a	56.8	a
	Within-row spacing	1 seed/30.5 cm (1 seed/ft)	64.1	b	71.5	a	56.0	b
		3 seed/30.5 cm (3 seed/ft)	67.3	a	72.7	a	59.2	ab
		6 seed/30.5 cm (6 seed/ft)	67.3	a	72.0	a	61.5	a

Conclusions: These trials strongly suggest that the ideal planting density is not the same for the local runner and the local Valencia. Effect of planting density on virus intensity was inconsistent, partly due to limited disease pressure. However, these data suggest that in years with heavier virus incidence (e.g., 2016), higher planting densities could reduce the number of infected plants; more research is needed to substantiate this interpretation.

Valencia. Overall, regardless of between-row spacing or within-row spacing, the Valencia variety yields consistently increased with increasing planting density (Table 4.1.c and Fig. 4.1.c). However, there is generally less of a yield gap between 30.5 and 45.7 cm row spacing than 45.7 and 61 cm row spacing, and 9.8 and 19.7 seed/m than between 3.3 and 9.8 seed/m (Fig. 4.1.c).

Runner. We did not find the same consistency in the response to seed/row spacing treatments for the runner variety (Table 4.1.c and Fig. 4.1.c). However, yield in plots with 3 and 6 seed/ft within-row spacing were more often higher than plots with the 1 seed/ft spacing (Fig. 4.1.c). Row spacing did not have an effect on yield when planted at 3 or 6 seed/ft (Table 4.1.c), suggesting the within-row spacing is more important for the runner variety.

Chapter 4.2 Planting Method Trials: Rows vs. Traditional Scatter Planting

Purpose: Our recommendation has been to plant in rows, yet many growers in Haiti do not plant in this way. Therefore, the objective was to determine if there is a yield benefit to planting in rows vs. the traditional scatter method. The second objective was to determine if there is a yield benefit from increasing the planting density with the traditional scatter method for both runner and Valencia market types.

The trial involved yield, but not labor time or other measures. This research does not address the question of total economic return of row- vs scatter-planting methods.

Challenges for Interpretation: The number of seeds is not always the same for planting in rows vs. scatter. There is no feasible way to use the same amount of plot space to mimic both traditional methods and planting in rows and keep a uniform number of seeds per plot. Therefore, a compromise was made by selecting a plot size that would allow for making a direct comparison of the two planting methods with the same number of seeds in several (but not all) scenarios.

Experimental Design: Two planting method trials were conducted at the MFK research site in 2017. Both trials planted at MFK were laid out in a split-plot design with four replications. Market type was the main plot (local Haitian Valencia landrace and local Haitian runner landrace) and planting method was the subplot (see Table 4.2.a for details). An additional trial with only the local Haitian Valencia landrace market type was conducted at the Acceso research site in Mirebalais in 2017. This trial was laid out in randomized complete-block design with six replications. Dates from planting to harvest, respectively, for each trial were as follows: MFK No. 1: 13 March 2017 to 11 June (Valencia) and 11 July (runner) 2017. MFK No. 2: 4 April 2017 to 3 July 2017 (Valencia) and 25 April 2017 to 4 September 2017 (runner). Mirebalais: 5 May 2017 to 9 August 2017.

Table 4.2.a. Planting method treatments used in trials conducted at MFK during 2017.

Treatment description		Total seed planted	Total rows
English units	Metric units		
24 Inch Row (1 seed/ft)	61.0 cm Row (1 seed/30.5 cm)	30	3
12 Inch Row (1 seed/ft)	30.5 cm Row (1 seed/30.5 cm)	60	6
24 Inch Row (3 seed/ft)	61.0 cm Row (3 seed/30.5 cm)	90	3
12 Inch Row (3 seed/ft)	30.5 cm Row (3 seed/30.5 cm)	180	6
18 Inch Scatter (1 seed/divot)	45.7 cm Scatter (1 seed/divot)	30	-
12 Inch Scatter (1 seed/divot)	30.5 cm Scatter (1 seed/divot)	60	-
18 Inch Scatter (2 seed/divot)	45.7 cm Scatter (2 seed/divot)	60	-
12 Inch Scatter (2 seed/divot)	30.5 cm Scatter (2 seed/divot)	120	-

For all trials, plots were 1.8 m wide and 3.0 m in length. Each plot was separated by a 0.6 m alley within blocks, and blocks were separated by a 1.5 m alley. For the plots planted in rows, target rows were first marked with stakes and string, and hoes were used to create furrows with an average depth of 3.8 cm. Fields were disked two to three times prior to planting, and rototilled within two days prior to planting. 20-20-10 N-P-K fertilizer was applied to each of the study fields at a rate of 112.1 kg ha-1. Plots were planted by hand, and uniformity was ensured by placing PVC pipes (marked with the appropriate seeding rate) within the furrow while planting. For the scatter-planted plots, individual furrows/divots were created with hoes in a randomized fashion while respecting the appropriate planting distance in accordance with treatment; furrows were made with an average depth of 3.8 cm. The scatter plots were then planted by hand by placing either one or two seeds into each individual furrow in accordance with the treatment specifications for each individual plot. Due to germination issues in the first trial, the runner market type in MFK No. 2 trial and the entirety of the Mirebalais trial were planted at double the desired planting rate; subsequently, after the stand count evaluation, plots with too many plants were thinned and plots with too few plants were replanted with transplanted plants.

Other yield-reducing factors were managed in order to mitigate confounding results from the experimental factors. As such, seeds were treated with azoxystrobin, fludioxonil and mefenoxam (Dynasty PD®, Syngenta Crop Protection, Greensboro, NC) at a rate of 85 g of product per 45.4 kg of seed. Plots were weeded on a biweekly basis, sprayed every 15 days (starting 30 days after planting) with fungicide (Muscle® ADV, Sipcam Agro USA, Inc.) and irrigated biweekly in the absence of rain.

Data Collection:

Two to three weeks after planting, stand counts were made for each plot; average stand count across all plots was 70.9% for MFK Trial #1, 96.9% for MFK Trial #2, and 100% for the Central Plateau trial. Final leaf spot and rust severity ratings were taken immediately prior to digging. Leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III). Rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Peanuts were manually harvested by first pulling the entire plant from the ground and removing all the attached pods from the plant. Afterwards, the soil in each plot was filtered through by hand to recover the remaining pods left in the ground. Pods were placed in large, green, mesh cabbage bags (Cady Bag Company, LLC. Pearson, GA) and washed after harvest in order to remove any remaining soil, and then placed on a large concrete pad to dry in the sun. The bagged pods were allowed to dry for a minimum of three days, and were moved under a shelter each night. After drying bags were weighed, and immediately afterwards, a 100-pod sample was shelled to obtain the moisture content of the kernels. Final weights (kg/ha) were adjusted to 10% pod moisture. A post-harvest test was made with the same 100-pod sample to evaluate the percentage of sound mature kernels (%SMK). Percent SMK was calculated by dividing the weight of the sound mature kernels by the total weight of the unshelled sample.

Statistical Analysis: Yield was subjected to analysis of variance with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). Because preliminary analyses indicated a significant variety × planting method treatments, varieties were analyzed separately. For both market types, the model was a split plot design with trial and planting method treatment considered as fixed effects, with rep and rep × trial as random effects. In all analyses, the Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test.

Fig 4.2.a. 2017 Planting Method Trial No. 1 at MFK taken 18 April 2017.

Fig 4.2.b. 2017 Planting Method Trial No. 1 at MFK taken 5 June 2017.

Table 4.2.b. Analysis of variance performed separately for runner and Valencia market types.

Market type	Effect	Yield	%SMK
		Prob > F	Prob > F
Runner	Trial	0.0331	0.0004
	Treatment	0.0821	0.7282
	Trial × Treatment	0.9942	0.1838
Valencia	Trial	0.0008	<.0001
	Treatment	<.0001	0.4134
	Trial × Treatment	0.3070	0.9737

Table 4.2.c. Effect of trial (location) on pod yield and %SMK for runner and Valencia market types.

Market type	Effect	Yield		%SMK	
Runner	(MFK) Spring 2017	2899.3	b	58.9	b
	(MFK) Summer 2017	4044.2	a	90.6	a
Valencia	Central Plateau	1454.5	b	-	
	(MFK) Spring 2017	2800.5	a	61.9	b
	(MFK) Summer 2017	1403.8	b	88.9	a

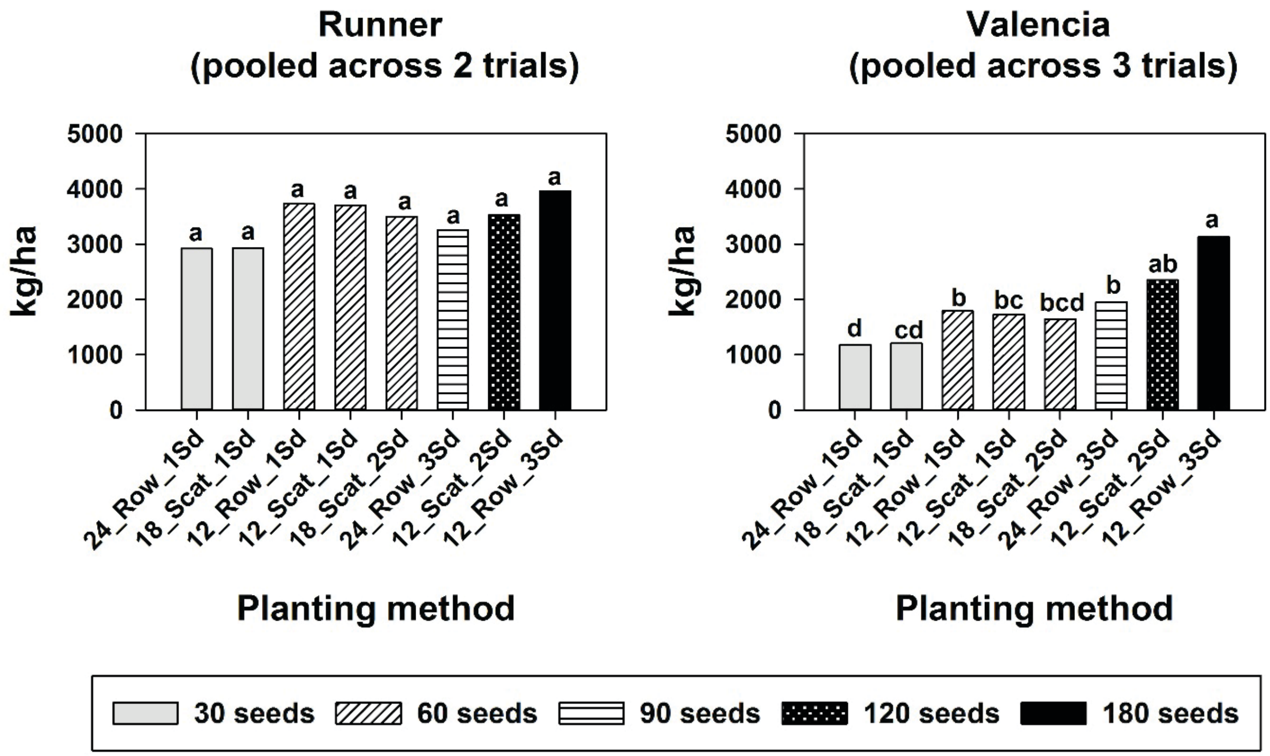


Fig 4.2.c. Effect of planting method on total pod yield (kg/ha) for each market type. Planting method treatments are labeled as follows: width between row or scatter divot, planting method type, number of seed planted within the row per foot or per divot. Therefore, 24_Row_1Sd signifies, a 24-inch row planted at 1 seed/ft. Treatment with the same letters are not significantly different based upon Tukey's honestly significant difference test.

Conclusions: These results suggest that the traditional scatter planting method used in Haiti can provide similar yields to those obtained when the same/similar number of seeds are planted in rows. In these trials, higher yield for both varieties was more a function of increased plant density than the type of planting method utilized. However, as seen in chapter 4.1, plant density tends to impact yield more in the local Haitian Valencia than in the local Haitian runner.

Appendix I Monthly Rainfall Data from the MFK Research Site Located Near Cap-Haïtien, Haiti, from 2015 to 2017

Year	Month[x]	Rain (mm)[z]	Rain events[y]		
			> 0.254 mm	> 0.63 mm	> 12.7 mm
2015	1	336	7	5	5
2015	2	176	6	3	3
2015	3	90	9	4	2
2015	4	2	1	0	0
2015	5	114	13	7	3
2015	6	128	14	6	3
2015	7	121	17	8	2
2015	8	17	6	0	0
2015	9	5	2	0	0
2015	10	65	6	4	1
2015	11	72	4	3	2
2015	12	1	1	0	0
2016	1	41	7	2	2
2016	2	455	11	8	6
2016	3	23	6	1	0
2016	4	135	12	7	3
2016	5	188	12	5	3
2016	6	112	5	5	2
2016	7	0	0	0	0
2016	8	98.9	2	2	2
2016	9	106.8	7	5	3
2016	10	221	16	10	4
2016	11	828	22	14	12
2016	12	11	5	0	0
2017	1	50	5	2	2
2017	2	15	4	1	0
2017	3	228	11	7	4
2017	4	81	10	3	2
2017	5	225	9	8	6
2017	6	126	4	4	3
2017	7	138	7	4	2
2017	8	1	1	0	0

[x] Where 1 = January and 12 = December.

[y] Number of days that received > 0.25, > 0.63 or > 12.7 mm of rain during each interval day after planting interval. Rainfall data was measured with two on-station Decagon rain gauges set to record at hourly intervals.

[z] Rainfall data was recorded hourly at the MFK research site with a Decagon ECRN-50 rain gauge (Decagon Devices, Inc., Pullman, WA).

Appendix II Soil Samples from Research Plots in Haiti

Supplementary Figure II.a. 2015 soil sample results from research plots at Meds & Food for Kids (MFK) factory located outside of Cap-Haïtien (Quartier Morin), Haiti.

				Mehlich 1 mg/kg (ppm)					
Sample	LBC 1 (ppm $CaCO_3$/ pH)	pH CaCl2[2]	Equivalent water pH	Ca	K	Mg	Mn	P	Zn
1 MFK – student field (control)	N.A.	7.78	8.38	4409	37.3	583.3	37.41	41.3	0.46
2 MFK – student field (biochar)	N.A.	7.59	8.19	3838	41.7	600.1	47.58	70.6	0.76
3 MFK – back field (west side)	529	7.10	7.70	3720	51.4	689.4	62.60	34.3	1.51
4 MFK – back field (east side)	N.A.	7.70	8.30	3962	48.0	585.3	55.62	46.8	0.98
5 MFK – east side of drive (near septic)	N.A.	7.82	8.42	4728	31.0	598.2	21.73	4.4	<0.21
6 MFK – west side of drive (near gate)	498	7.14	7.74	3807	47.8	543.2	47.44	143.8	1.19
7 MFK – front field A (w trees)	482	7.01	7.61	4480	105.5	478.7	53.62	501.3	2.98
8 MFK – front field B (w bananas)	398	7.14	7.74	3760	78.5	423.0	54.86	325.3	2.33
9 MFK – banana field	423	7.30	7.90	3366	91.0	523.1	60.88	106.0	1.67

Samples were taken in December 2014 and completed 10 March 2015. Soil Samples were analyzed by the University of Georgia Soil, Plant, and Water Laboratory.

Supplementary Figure II.b. 2016 soil sample results from research plots at Meds & Food for Kids (MFK) factory located outside of Cap-Haïtien (Quartier Morin), Haiti and from research plots at the Acceso research farm located in the Central Plateau (Coupe Gorge).

	Mehlich 1 mg/kg (ppm)									
Sample	LBC 1 (ppm $CaCO_3$/pH)	pH CaCl2[2]	Equivalent water pH	Ca	K	Mg	Mn	P	Zn	B
MFK student field at 4-inch depth	N.A.	7.62	8.22	3604	48.3	814	56.88	58.4	0.62	1.36
MFK student field at 10-inch depth	N.A.	7.56	8.16	3283	40.0	832	57.25	59.3	0.58	1.37
MFK back east field at 4-inch depth	N.A.	7.69	8.29	5747	91.9	1567	95.99	93.9	1.01	1.53
MFK back east field at 10-inch depth	N.A.	7.65	8.25	3485	47.9	1004	57.84	44.9	0.62	1.45
MFK back west field at 4-inch depth	476	7.36	7.96	3319	55.7	1094	58.76	47.4	0.81	1.46
MFK back west field at 10-inch depth	511	7.35	7.95	3066	49.8	1166	60.75	32.4	0.85	1.55
MFK front field at 4-inch depth	389	6.99	7.59	4119	106.5	555	62.11	670.9	3.74	1.26
MFK front field at 10-inch depth	422	7.03	7.63	4033	99.7	589	51.89	539.1	3.35	1.16
Central plateau sample 1 at 4-inch depth	522	7.17	7.77	4347	32.8	121	14.36	1.7	0.65	0.56
Central plateau sample 1 at 10-inch depth	561	7.05	7.65	3975	28.2	126	19.18	1.2	0.67	0.43
Central plateau sample 2 at 4-inch depth	578	7.17	7.77	4644	31.7	124	14.00	1.5	0.74	0.41
Central plateau sample 2 at 10-inch depth	587	7.20	7.80	4098	29.8	117	16.91	1.0	0.64	0.40
Central plateau sample 3 at 4-inch depth	547	7.19	7.79	4362	36.6	123	15.92	1.9	0.75	0.44
Central plateau sample 4 at 4-inch depth	633	7.31	7.91	4532	32.1	120	14.29	1.6	0.63	0.35

Samples were taken in August 2014 and completed 20 October 2016. Soil Samples were analyzed by the University of Georgia Soil, Plant, and Water Laboratory.

Supplementary Figure II.b. (Continued) 2016 soil sample results from research plots at Meds & Food for Kids (MFK) factory located outside of Cap-Haïtien (Quartier Morin), Haiti and from research plots at the Acceso research farm located in the Central Plateau (Coupe Gorge).

Sample	OM [3]	Sand	Silt	Clay	Soil Type
MFK student field at 4-inch depth	3.31	44.0	25.9	30.1	Sandy Clay Loam
MFK student field at 10-inch depth	3.39	44.0	25.8	30.2	Sandy Clay Loam
MFK back east field at 4-inch depth	3.52	37.9	27.8	34.2	Sandy Clay Loam
MFK back east field at 10-inch depth	3.60	37.9	27.8	34.2	Sandy Clay Loam
MFK back west field at 4-inch depth	4.65	29.8	33.9	36.2	Clay Loam
MFK back west field at 10-inch depth	4.86	25.8	34.0	40.3	Clay
MFK front field at 4-inch depth	3.88	61.8	20.0	18.3	Sandy Loam
MFK front field at 10-inch depth	3.92	57.8	21.9	20.3	Sandy Clay Loam
Central plateau sample 1 at 4-inch depth	5.87	24.1	26.0	49.9	Clay
Central plateau sample 1 at 10-inch depth	5.94	24.1	24.0	51.9	Clay
Central plateau sample 2 at 4-inch depth	5.90	26.1	26.0	47.9	Clay
Central plateau sample 2 at 10-inch depth	5.99	22.1	24.0	53.9	Clay
Central plateau sample 3 at 4-inch depth	5.94	26.1	26.0	47.9	Clay
Central plateau sample 4 at 4-inch depth	5.96	24.0	26.0	50.0	Clay

Samples were taken in August of 2014 and completed 20 October 2016. Soil Samples were analyzed by the University of Georgia Soil, Plant, and Water Laboratory.

Appendix III Leaf Spot and Rust Rating Scales Used to Assess Foliar Disease Severity in Haiti

Supplementary Figure III.a. Florida 1 to 10 scale used to assess leaf spot severity.

Florida 1 - 10 Rating Scale (Chiteka *et al.,* 1988)		
Score	**Description**	**% Defoliation**
1	No disease	0
2	Very few lesions (only on the bottom part of the canopy)	0
3	Numerous lesions on bottom and a few lesions on upper canopy	0
4	Severe lesions on bottom; intermediate middle; moderate top	~ 5 %
5	Bottom defoliated; severe middle; intermediate top	~ 20 %
6	Bottom and middle defoliated; top heavy	~ 50 %
7	Bottom and middle heavily defoliated; top severe pressure	~ 75 %
8	90% defoliated	~ 90 %
9	99% defoliated: Very few leaves remaining and those covered with lesions	~ 98 %
10	Plants dead	~ 100 %

Supplementary Figure III.b. Modified ICRISAT 1 to 9 scale used to assess rust severity.

ICRISAT Peanut Rust 1 - 9 Scale (Subrahmanyam *et al.,* 1995)		
Score	**Description**	**% Severity**
1	No disease	0
2	Lesions sparsely distributed largely at lower leaves (a few lesions on the bottom leaves only)	1 - 5 %
3	Many lesions on lower leaves, necrosis evident; very few lesions on middle leaves; no lesions on top	6 - 10 %
4	Numerous lesions present on lower and middle leaves; severe necrosis on lower leaves. A few lesions on top leaves	11 - 20 %
5	Severe necrosis of lower and middle leaves; lesions on top leaves but not severe	21 - 30 %
6	Extensive damage to lower leaves. Lesions densely present on middle leaves with necrosis; lesions also on top leaves	31 - 40 %
7	Severe damage to lower and middle leaves; lesions densely distributed on top leaves	41 - 60 %
8	100% damage to lower and middle leaves; lesions on top leaves with severe necrosis	61 - 80 %
9	Almost all leaves withering; bare stems present	81 - 100 %

References:

Chiteka, Z., Gorbet, D., Shokes, F., Kucharek, T., & Knauft, D. (1988). Components of resistance to late leafspot in peanut. I. Levels and variability-implications for selection. *Peanut Sci.* 15:25-30.

Subrahmanyam, P., McDonald, D., Waliyar, F., Reddy, L., Nigam, S., Gibbons, R., Rao, V. R., Singh, A., Pande, S., & Reddy, P. (1995). Screening methods and sources of resistance to rust and late leaf spot of groundnut. Information Bulletin No. 47. International Crops Research Institute for the Semi-Arid Tropics.

Appendix IV 2010-2011 ICRISAT Trials

Purpose. Evaluate the performance of foliar disease resistant breeding lines developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for suitability for use in Haiti.

Experimental design. Three field trials were conducted at three different locations in northern Haiti between 2010 and 2011. In 2010, one trial was conducted in the community of Bois Rouge and another trial was conducted at the Université Chretienne du Nord d'Haiti (UCNH) in Limbé, Haiti. In 2011, an additional trial was conducted in the community of Isle Adam. All trials were laid out in a randomized complete block design with four replications. Treatments consisted of 15 advanced breeding lines from ICRISAT and at each location a known check was included. These were Tamnut OL06 (Bois Rouge), Tifguard (UCNH) and the local Haitian runner and the local Haitian Valencia (Isle Adam).

Table IV.a. ICRISAT breeding lines evaluated in trials conducted in Haiti during 2010 and 2011.

Identity	Branching Habit	Botanical Type	Seed Color
ICGV 99027	Sequential	Spanish	Tan
ICGV 99028	Sequential	Spanish	Tan
ICGV 99029	Sequential	Spanish	Tan
ICGV 99030	Sequential	Spanish	Tan
ICGV 99031	Sequential	Spanish	Tan
ICGV 99032	Sequential	Spanish	Tan
ICGV 99033	Sequential	Spanish	Tan
ICGV 99036	Alternate	Virginia	Red
ICGV 99046	Sequential	Spanish	Red
ICGV 99050	Alternate	Virginia	Tan
ICGV 99051	Alternate	Virginia	Tan
ICGV 99052	Alternate	Virginia	Tan
ICGV 99053	Sequential	Spanish	Tan
ICGV 99054	Sequential	Spanish	Tan
ICGV 99057	Sequential	Spanish	Red

At each location, peanuts were planted in two rows in plots that were 1.2 m wide and 3.04 m long. Seeding rate was not recorded but is assumed to be three seed/0.3 m. Plots were planted on 16 June 2010 at Bois Rouge and 30 October 2010 at UCNH. Date of planting was not able to be determined for the trials at Isle Adam. Plots were weeded several times throughout the season, did not include insecticide or fungicide application and were not irrigated.

Prior to digging, final leaf spot severity was assessed with the Florida 1 to 10 scale (Appendix III) and final rust severity was assessed with a modified 1 to 9 scale (Appendix III).

Results

Table IV.b. Effect of variety at Bois Rouge, 2010.

Trt.	Variety	Leaf spot		Rust		Kg/ha	
1	ICGV 99027	2.6	B	1.8	b	1274.4	ab
2	ICGV 99028	2.6	B	2.0	b	1440.0	ab
3	ICGV 99029	2.6	B	1.8	b	1296.4	ab
4	ICGV 99030	2.5	B	2.3	b	1237.6	ab
5	ICGV 99031	2.5	B	1.8	b	1352.8	ab
6	ICGV 99032	2.5	B	1.7	b	1351.5	ab
7	ICGV 99033	2.2	B	1.7	b	1295.2	ab
8	ICGV 99036	2.5	B	1.6	b	1721.4	a
9	ICGV 99046	2.6	B	1.5	b	1671.8	a
10	ICGV 99050	2.0	B	1.7	b	1278.0	ab
11	ICGV 99051	2.2	B	1.6	b	1502.2	ab
12	ICGV 99052	2.6	B	1.8	b	1278.8	ab
13	ICGV 99053	3.1	B	1.8	b	1052.1	b
14	ICGV 99054	2.8	B	2.4	b	1357.1	ab
15	ICGV 99057	2.1	b	2.0	b	1446.7	ab
16	TN	6.7	a	8.1	a	245.5	c
Tukey's HSD P=.05		1.5		0.2		610.2	
Standard Deviation		0.6		0.1		237.7	
CV		20.4		12.1		18.3	
Replicate F		0.1		0.5		0.2	
Replicate Prob(F)		0.0429		0.6316		0.0446	
Treatment F		14.868		22.413		7.652	
Treatment Prob(F)		0.0001		0.0001		0.0001	

Table IV.c. Effect of variety on leaf spot, rust, and pod yield at UCNH, 2010.

Trt.	Variety	Leaf spot		Rust		Kg/ha	
1	ICGV 99027	0	a	3.7	bc	1529.3	abc
2	ICGV 99028	0	a	3.5	bc	1227.8	abc
3	ICGV 99029	0	a	3.2	bc	1288.6	abc
4	ICGV 99030	0	a	3.5	bc	1573.7	abc
5	ICGV 99031	0	a	3.2	bc	1785.9	abc
6	ICGV 99032	0	a	3.5	bc	1320.1	abc
7	ICGV 99033	0	a	3.7	bc	1160.6	bc
8	ICGV 99036	0	a	2.0	d	2172.9	ab
9	ICGV 99046	0	a	3.5	bc	2246.0	a
10	ICGV 99050	0	a	3.2	bc	1754.4	abc
11	ICGV 99051	0	a	2.7	cd	1670.4	abc
12	ICGV 99052	0	a	3.0	cd	1299.4	abc
13	ICGV 99053	0	a	3.7	bc	945.3	c
14	ICGV 99054	0	a	4.2	b	884.3	c
15	ICGV 99057	0	a	3.2	bc	1704.5	abc
16	Tifguard	0	a	6.0	a	759.2	c
Tukey's HSD P=.05		0		0.3		1034.0	
Standard Deviation		0		0.12		401.9	
CV		0		5.93		27.58	
Replicate F		0		1.25		1.39	
Replicate Prob(F)		1		0.3029		0.2587	
Treatment F		0		11.326		4.533	
Treatment Prob(F)		1		0.0001		0.0001	

Fig IV.a. Planting plots at UCNH in 2010.

Table IV.c. Effect of variety on leaf spot and rust at Isle-Adam, Haiti, 2011.

Trt.	Variety	Leaf spot		Rust		Kg/ha
1	ICGV 99027	3.5	bc	1.8	cde	Not available
2	ICGV 99028	3.7	bc	1.5	cde	-
3	ICGV 99029	3.7	bc	1.8	cde	-
4	ICGV 99030	3.0	c	2.3	bc	-
5	ICGV 99031	4.0	bc	1.5	cde	-
6	ICGV 99032	3.7	bc	1.5	cde	-
7	ICGV 99033	3.7	bc	1.1	e	-
8	ICGV 99036	4.0	bc	1.5	cde	-
9	ICGV 99046	4.7	b	1.5	cde	-
10	ICGV 99050	2.7	c	1.5	cde	-
11	ICGV 99051	3.5	bc	2.0	bcd	-
12	ICGV 99052	3.0	c	1.5	cde	-
13	ICGV 99053	4.5	b	1.3	de	-
14	ICGV 99054	3.7	bc	2.0	bcd	-
15	ICGV 99057	4.0	bc	1.5	cde	-
16	Local runner	7.0	a	2.8	b	-
17	Local Valencia	7.0	a	8.0	a	-
Tukey's HSD P=.05		0.13		0.82		
Standard Deviation		0.03		0.20		
CV		4.62		9.86		
Replicate F		0.312		0.045		
Replicate Prob(F)		0.5843		0.8348		
Treatment F		15.632		122.348		
Treatment Prob(F)		0.0001		0.0001		

Appendix V Summer 2015 Seed- and Row-Spacing Trial Results

Experimental Design: Everything was the same as those conducted in 2016 and 2017 (see Chapter 4.1) with the exception that the 2015 trials did not include the 12-inch (0.3 m) between-row spacing treatment and did not have a 2-foot (0.6 m) border between plots within the same block. Otherwise, plots were maintained in a similar fashion. The only known difference is that plots at Trou-Du-Nord were irrigated by hand and less frequently than at MFK. Lastly, there are no stand-count records, but we assume that the germination was similar across treatments.

Statistical Analysis: Yield was subjected to analysis of variance for each trial with PROC GLIMMIX (SAS 9.4 Institute, Cary, NC). The model was a split-split plot design with variety, row spacing, and seed spacing considered as fixed effects, and with replication, replication × variety and replication × between-row spacing as random effects. The SLICE option in SAS was used to explore all two-way interactions. In all analyses, the Kenward-Roger option was used to adjust the degrees of freedom, and differences in the least square means were tested by Tukey's multiple comparisons test.

Table V.a. Analysis of variance results for pod yield for two trials conducted in Haiti in 2015.

Location	Effect	F-value	P-value
MFK	Variety (V)	42.44	0.0019
	Between-row spacing (B)	1.59	0.2614
	V × B	0.48	0.496
	Within-row spacing (W)	24.87	<.0001
	V × W	1.69	0.2043
	B × W	0.73	0.4927
	V × B × W	0.17	0.8464
Trou-Du-Nord	Variety (V)	14.43	0.0115
	Between-row spacing (B)	0.77	0.4392
	V × B	5.97	0.0214
	Within-row spacing (W)	5.48	0.01
	V × W	0.75	0.481
	B × W	1.31	0.2864
	V × B × W	0.26	0.7767

Table V.b. Effect of variety, between-row spacing and within-row spacing on pod yield at two locations in Haiti during 2015.

Location	Effect	Treatment	Yield (kg/ha)	
MFK	Variety	Local runner	2486	a
		Local Valencia	1242	b
	Between-row spacing	18	1909	a
		24	1618	a
	Within-row spacing	1 Seed/ft	1276	b
		3 Seed/ft	1931	a
		6 Seed/ft	2203	a
Trou-Du-Nord	Variety	Local runner	1316	a
		Local Valencia	637	b
	Between-row spacing	18	963	a
		24	870	a
	Within-row spacing	1 Seed/ft	784	b
		3 Seed/ft	865	b
		6 Seed/ft	1132	a

Table V.c. Simple effect of between-row spacing on pod yield for each variety at two locations in Haiti during 2015.

Trial	Variety	Between-row spacing	Yield (kg/ha)	
MFK	Local runner	18	2762	a
		24	2237	a
	Local Valencia	18	1319	a
		24	1170	a
Trou-Du-Nord	Local runner	18	1235	a
		24	1403	a
	Local Valencia	18	751	a
		24	540	b

Appendix VI Virus Symptoms on Peanut in Haiti

Virus Rating Method: Virus intensity was assessed as the number of 0.3 m sections "hits" of peanut plants with symptomatic viral infection per foot of row.

Primary Symptoms:

Ringspots
Dense clustering of stunted leaves at the terminal
Chlorosis/mosaic
Extreme stunting
Death of terminal leaves

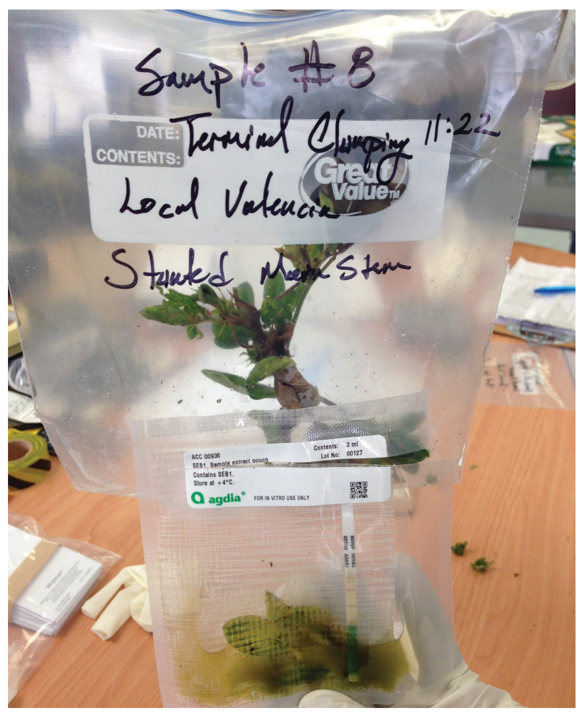
Local Haitian runner with extreme stunting and chlorotic leaves.

Local Haitian Valencia leaves with ringspots and mosaic.

Local Haitian Valencia leaflets with ringspots.

Local Haitian Valencia with dense cluster of stunted leaves at the terminal.

Local Haitian Valencia with death of terminal leaves.



Confirmation of tospovirus in Haiti with Agdia immunoStrip® for tomato spotted wilt virus (TSWV). Test strips are known to have cross reactivity with tomato chlorotic spot virus (TCSV) which has previously been reported in Haiti (Adegbola *et al.,* 2016).

References:

Adegbola, R., Fulmer, A., Williams, B., Brenneman, T., Kemerait, R., Sheard, W., Woodward, J., Adkins, S., & Naidu, R. (2016). First report of the natural occurrence of tomato chlorotic spot virus in peanuts in Haiti. *Plant Dis.* 100:8, 1797.

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