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Final report

Small research and development activity

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1 Acknowledgments

We would like to thank all of the smallholder farmers in EHP / WHP and Simbu Provinces for allowing CIC to conduct the surveys over the course of the project. We would also like to thank all of the larger block holders and Processors that we interviewed.

I would particularly like to thank Mr Otto Ngere, (formerly CIC, now NAQIA), who managed to get the project started in 2012.

Finally, I would also like to thank all the CIC staff who have been involved in this SRA, and have facilitated trips made by CABI.

2 Executive summary

The main objective of this project was to estimate potential losses in smallholder coffee due to the insect pest: coffee green scale (CGS) (*Coccus celatus* De Lotto and *Coccus viridis* (Green). The project used a variety of survey methods and engaged with smallholders, larger block holders, and processors. Combining the successful elements of the project with experimental data has enabled the project to ascertain estimates of potential loss and achieve this objective.

From on station experiments, combined with previous research we estimate heavily infested CGS trees with relatively permanent infestations, can suffer up to *circa* 80% loss. However, the length of time that trees were infested prior to the experiment was unknown, and other cryptic diseases or general poor tree health may have compounded this impact. These results tie in with anecdotal evidence (up to 90%), and to some extent previous research, *circa* 40%. Combining this information, the potential loss due to heavy and persistent CGS populations is 58% (in terms of cherry on experimental trees).

Surveys across the three major Arabica coffee growing provinces revealed that the incidence of CGS was highest in Eastern Highlands Province (*circa* 95% of farms). In EHP the average number of trees per farm infested being 29%, with 15% of farms having very high infestations of CGS. Western Highlands and Simbu Provinces contrasted this with ~70% of farms having CGS but generally the on-farm infestations were <8% of the trees. The majority of trees in these two provinces were “clean”. Invasive ant species were found to be correlated with CGS and were more abundant in EHP than Simbu.

Using the potential losses from experiments and surveys, cherry losses in EHP are on average 15% due to CGS on infested farms (Provincially 11%). However, approximately 20% of farms in EHP could be losing more than 20%, with some farms losing as much as 50%. In WHP and Simbu losses are much lower, around 2%. It should be noted that these are estimates from one season, and do not take account of control practices employed by smallholders.

Smallholder knowledge has increased since ASEM/2004/047, but most have observed it independently with the majority recognising it as a problem since *circa* 2006. They estimate losses to be 10-20%, with some farmers estimating 50% and some the entire crop. This follows the general pattern from the potential losses estimated by the research from this project.

Smallholders with CGS problems were more tolerant of crop losses compared with smallholders without CGS. Smallholder perceptions of constraints to productivity are divided: those without CGS see access to finance as a constraint whereas those with CGS view other pests and diseases as major problems. These include coffee leaf rust (*Hemileia vastatrix*) which was abundant across the three Provinces, and pink disease (*Erythricium salmonicolor*) which is of concern to: smallholders; large block holders; and processors.

Recommendations include that: 1) Simbu and WHP should not be ignored as CGS outbreaks can be sporadic; 2) potential losses were highest in EHP and it needs to be monitored and addressed; 3) Smallholders in EHP should be a priority for increasing knowledge of CGS beyond sooty mould; 4) issues behind the interactions of invasive ant species, natural enemies, and CGS outbreaks need to be addressed; and 5) monitor other diseases of concern to smallholders; large block holders; and processors.

3 Introduction

The Coffee industry of Papua New Guinea involves over 30% of the total labour force. The provinces of Western Highlands, Eastern Highlands and Simbu Provinces produce 90% of exported coffee. Coffee is the second largest earner of foreign exchange, after palm oil (FAO 2008; CIC 2011), within the Papua New Guinea (PNG) agricultural sector, (> 43% of PNG agricultural exports and 10% of total exports) (The World Bank 2010b). It is primarily produced by smallholders (88%), with few management inputs (The World Bank 2010b).

Currently, coffee green scale is listed as the most serious insect pest problem affecting coffee in Papua New Guinea (Williams 1986; Murphy 1991; Simbiken 2006). Coffee green scales (CGS) suck the sap from the growing aerial parts of the shrub, and infested trees can often be distinguished by the presence of a black sooty mould caused by the "honeydew" secreted by CGS (Waller, Bigger et al. 2007). Coffee green scales are a complex of two species: *Coccus celatus* De Lotto and *Coccus viridis* (Green) the former species being the most widespread and damaging in the highlands (Murphy 1991). Yield loss can be directly proportional to infestation levels (Baker, Shaw et al. 2004) with severe infestations causing about 50% loss in Papua New Guinea (Apety and Fumo 1998). Recent reports from Kenya have suggested losses as high as *circa.* 90% at some farms (Gitonga 2010).

In the previous ACIAR project: ASEM/2004/047; *Sustainable management of coffee green scales in Papua New Guinea*; a key recommendation was "a general study on coffee yield loss due to CGS to be undertaken as a matter of priority". The issues behind this recommendation were: 1) farmers being generally unaware of both production potential and losses incurred; 2) losses that can be assigned to CGS attack were not known. This project built on the previous work and methodologies used in ASEM/2004/047 but also employed different approaches in order to determine losses in Arabica coffee. These findings help build towards potential improvements that could be made in productivity and thus improving the potential for sustainable smallholder coffee production.

The project contributes to ACIAR's research programme in Papua New Guinea by providing information on smallholder coffee losses. Key information is now available which can be built upon, and will assist National organisations like the Coffee Industry Corporation Ltd, with the ultimate aim of improving smallholder returns from coffee exports. Information presented here is also relevant to current strategy of the Australian Government: to assist the PNG Government in reducing poverty and promoting sustainable economic development (ACIAR, 2015).

4 Objectives

The overall aim was to estimate potential losses due to CGS in PNG, building on the knowledge gathered from the previous project (ASEM/2004/047). Surveys were conducted to: 1) determine the incidence and infestation levels; and 2) enable estimates of losses to be calculated from detailed studies in EHP/WHPSS (Western Highlands Province Sub-Station).

The activities collected information within EHP, a major coffee growing province. Loses resulting from CGS were estimated by gathering information from on station experiments, and by comparing losses on smallholder farms with varying degrees of CGS infestations. From this, a province based impact could be estimated and with additional information on the incidence of CGS in other provinces, an overall impact was estimated for EHP, WHP and Simbu provinces in PNG. The objectives were therefore:

Objective 1 Activities:

1. Regular surveys of CGS infestations and associated impact on yield on a selection of smallholder farms within the Eastern Highlands Province. Surveys to be conducted from the onset of flowering through to harvest for two growing seasons at approximately 1500m altitudinal zone.
2. Interview smallholders to determine both their understanding of losses due to CGS and their estimation of production costs and income.
3. Establish controlled research station experiments to determine losses due to CGS.
4. Survey and interview holders of larger farms (plantations who hold records) and processors to gather historical information on CGS and losses.

Objective 2 Activities:

5. Combine data from surveys and experiments to estimate the potential impact in the smallholder farms. ***NOTE:*** *This has now been combined with Activity 7.*

Objective 3 Activities:

6. Survey the incidence of CGS in other major Arabica producing Provinces to determine the distribution of CGS in the highlands (EHP, WHP & Simbu).
7. Using the information from activities 5 and 6: estimate the overall loss and potential impact due to CGS on smallholder production in the highlands of PNG.

5 Quantifying CGS impact, in terms of yield loss, in highland smallholder coffee farms: Activities 1- 4 (Objective 1)

5.1 Activity 1 – Surveys of CGS infestations on a selection of smallholder farms within the Eastern Highlands Province.

Sixty smallholder farms with varying degrees of CGS infestations were chosen throughout the Eastern Highlands Province ranging from zero to heavy infestations. Farms were chosen that had similar conditions e.g. management, degree of shade; other pests and diseases. All trees between the farms were of a similar age, *circa* 12 years, and varietal mixes were similar being dominated by Typica and Bourbon. These farms were surveyed in the first season from the last quarter of 2012 through to just before harvest in 2013, with data being collected at approximately 3 month intervals: 1) September / October; 2) January / February; 3) May / June. In the first season, five farmers were excluded from the survey due to non-cooperation but were replaced prior to the second season. In total fifty-five farms were assessed in the first season, and fifty-nine in the second.

At each farm 20 trees were selected and permanently marked, and were assessed for CGS infestation; number of flowering nodes; number of cherry nodes; and total number of cherry. As the trees were also scored for presence and absence of sooty mould and CGS, we were able to determine trees that were completely clean of CGS whilst categorising the infested trees into a further four infestation levels. Each tree was split into quarters and then three vertical partitions, top middle and bottom, making it easier to evaluate ¼ of a tree (see appendix 9.1 for testing of the method). The CGS infestation levels were therefore categorised as: 1 = no CGS or sooty mould; 2 = 1 – 25% of laterals with CGS; 3 = 26 – 50%; 4 = 51 – 75%; 5 = 76 – 100%. This enabled the team to categorise each farm into “with CGS” and “without CGS”, and in addition: clean, low, medium and high CGS. The size of the tree was also measured in order to standardise trees in terms of volume sampled (m^{-3}). Other factors such as altitude and distance from road were also recorded (see appendix 9.5 for an example of the type of protocol used).

Data was analysed separately for the two growing seasons because the lengths of the seasons were different, with 2013 / 2014 being slightly longer. This was probably due to differences in climatic conditions between the two seasons. Analyses were conducted using ANOVA in Genstat (VSN International, 2013), to compare the seasonal data between the farms testing for interactions between factors like district. Another factor requiring the analysis in separate years was the fact that *circa* 50% of the farms in the second season were surveyed in May / June whilst the remainder were surveyed in July / August.

5.1.1 Season 1: Smallholder coffee farms

Coffee green scale populations fluctuated on trees, peaking around December / January. Either side of this they quite often declined, even on heavily infested farms, and thus any impact was short lived. In the first season, there were no significant differences in terms of cherry nodes and cherry production between farms infested with CGS and farms without CGS (P=0.17, and P=0.266 respectively) (Figure 1). The farms were then further analysed to a finer scale categorising them as clean, low, medium and highly infested with CGS. Again no significant differences were found ($P>0.05$), so other factors were investigated further, such as interactions between district, but this only revealed that there were wide variations between districts in terms of cherry production (Figure 2). Further analyses were conducted by comparing the farms that were heavily infested (i.e. average consistent infestation per tree, between 26%-100%) versus non-infested. A non-parametric Man-Whitney U test, revealed a significant difference with the farms without CGS having more ripe cherry than farms with CGS (U = 63.0, P=0.043). This equates to approximately 38% reduction where CGS is high (18.29 (+/-3.5) vs. 29.2 (+/-3.8)) (Figure 2). For season 2, similar results were found, but the data was limited due to the final recording being conducted across several months (see appendix 9.2).

Figure 1: Year 1 results of the EHP smallholder farm cherry nodes and cherry production in EHP. Top = farms categorised as without CGS (light grey) or with CGS (dark grey). Bottom: Farms split into varying CGS infestation levels by the median CGS infestation level on that farm. Note values are standardised to numbers per m^{-3}, the scale on the Y axis = square root transformed means.

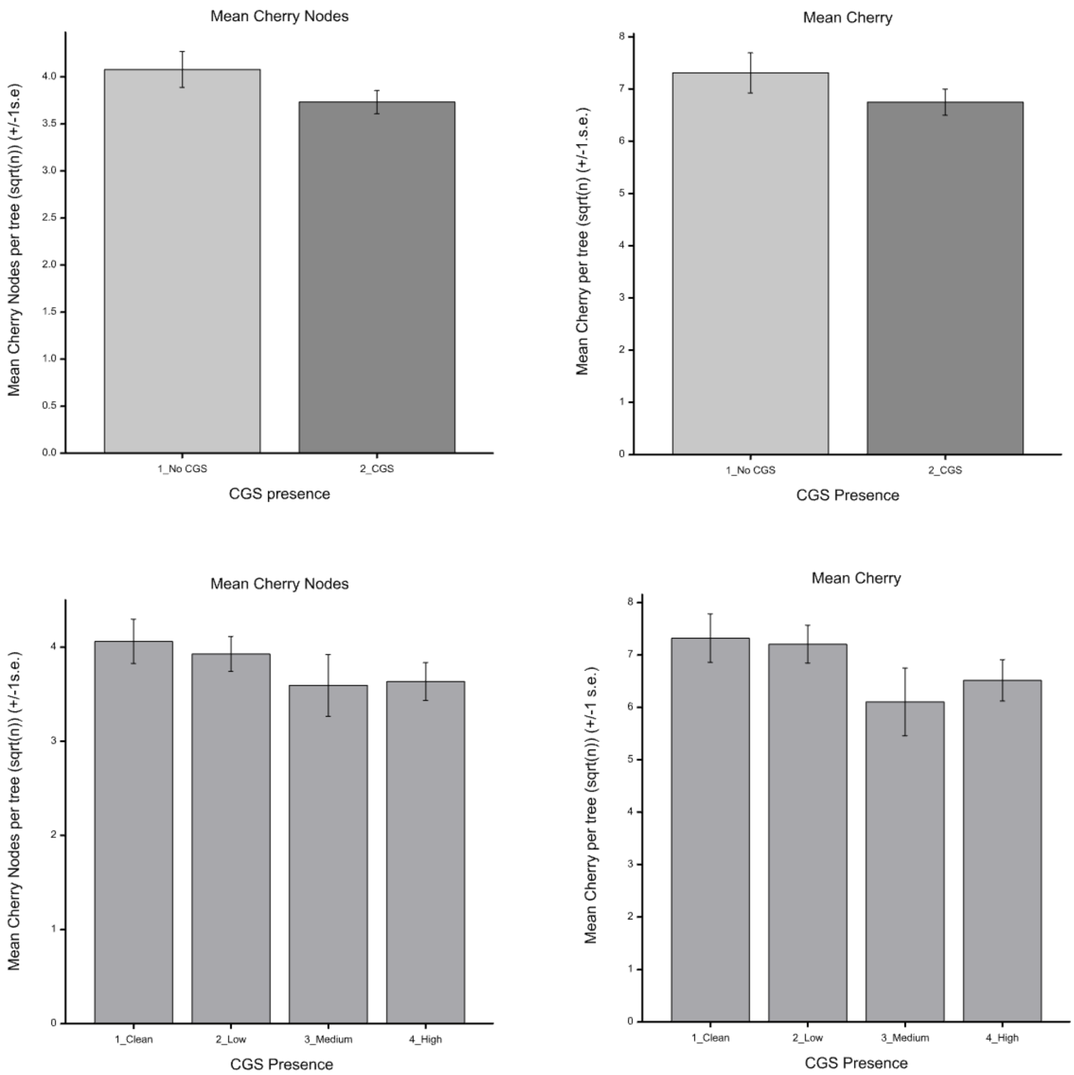
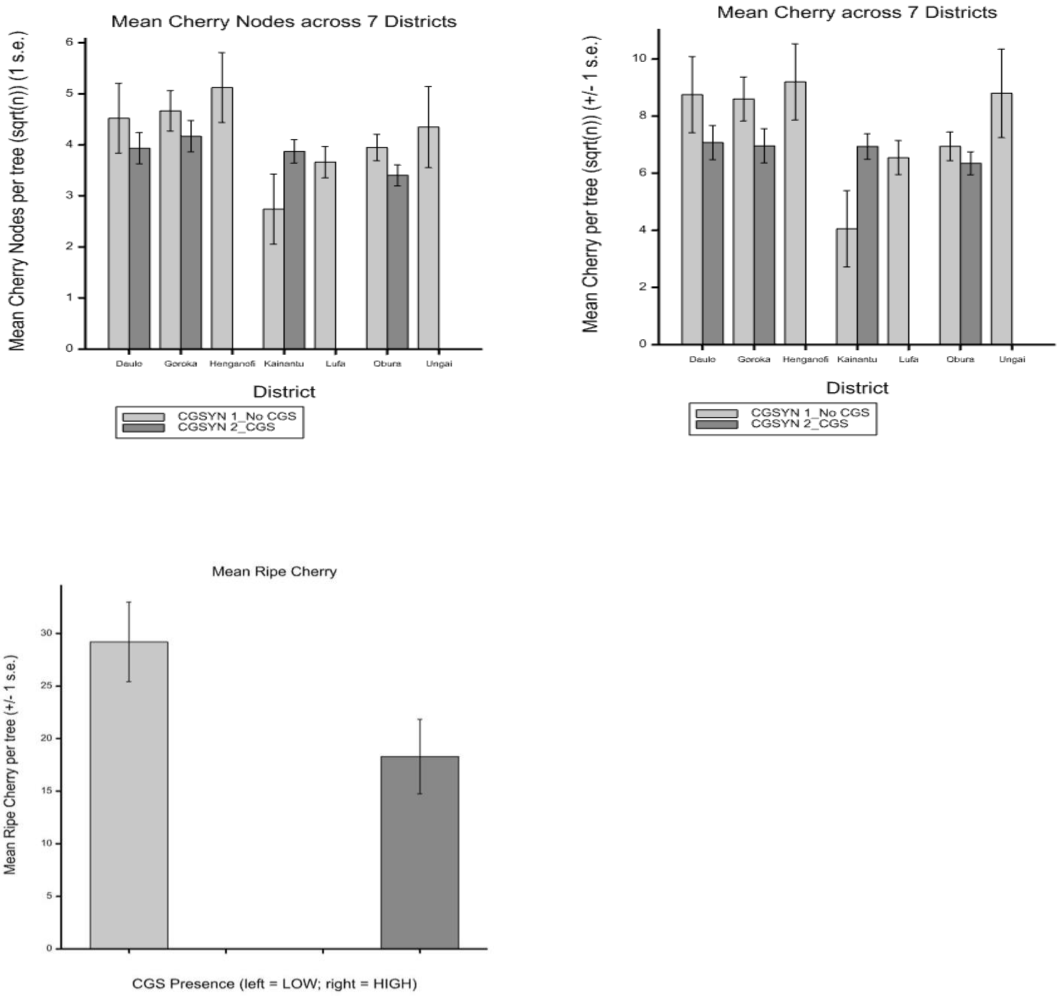


Figure 2: Year 1 results of the EHP smallholder farm cherry nodes and cherry production across the districts in EHP. Farms categorised as without CGS (light grey) or with CGS (dark grey). Note values were standardised to numbers per m^{-3}, the scale on the Y axis = square root transformed means. Bottom: Mean ripe cherry per tree ((*U* = 63.0, *P*=0.043).



5.1.2 Discussion

Despite some early indications that suggested we were able to detect CGS impact within farms, the results from these surveys analysed across farms are inconclusive. Comparing cherry loss between farms was problematic, due to fluctuating CGS populations, limited sample size and other factors that could not be taken into account e.g. soil nutrition and climatic conditions. There were also known issues with some farmers, where trees were pruned or cherries were harvested between surveys. We did attempt to compare within farms, but this proved to be difficult because of the unbalanced nature of the changing CGS populations.

As such the results contrast to with those of Activity 3; where trees with heavy CGS infestations produce significantly less cherry than trees with low infestations (corroborated by other research). These were standardised field experiments where it was possible to control for confounding factors e.g. trees being of the same age, rainfall, pruning and harvesting (see section 5.3). Therefore any such differences between smallholders with and without CGS are most likely to have been masked by the inherent variability between farms.

5.2 Activity 2: Interview smallholders to determine both their views of CGS and yield loss, and farmer perceptions / estimates of farm costs and income.

The change in smallholder sensitisation (identified in ASEM/2004/047) was to be tested and exploited by using different socio-economic survey techniques e.g. structured interview techniques. A pilot survey was conducted in the first year to see if the sensitised smallholders were real. Having these comparisons was valuable in that it enabled us to reveal that many farmers who have CGS recognise it as a problem and many who did not have it were also aware of CGS.

Using structured interview techniques, socio-economic surveys were implemented to gather information from these coffee growing smallholders. Data was gathered to establish the proportion of growers who kept records – which most did, but many of these records did not contain specific information about losses due to CGS. Most of the assessments of losses due to CGS were from farmer estimates, and not through physical records. The surveys also built on data collected for ASEM/2004/047, where additional questions about economic costs due to CGS, were asked, but again this was mainly from estimated losses, i.e. perceptions.

5.2.1 Smallholder surveys

In the early stages of the project fifty-seven small-holder farmers were interviewed using a structured survey instrument (see appendix 9.3 for a summary example). Of these 79% reported the presence of CGS and of these smallholders 63% reported the presence of CGS because they had observed ants as the indicator of CGS. Eleven of the 57 respondents indicated that someone else had identified CGS on their coffee, including extension officers and other farmers. During this project, it has been revealed that many farmers are now aware of CGS, all be it through ants as indicators. However, there are still a number of smallholders that are not aware of what CGS is, or the relationships between CGS, ants and sooty mould. Following on from ASEM2004/047, increased smallholder awareness of CGS appears to have been one of the community impacts.

Many of the results in the first survey did not reveal anything particularly useful in terms of assessing the relationship of CGS and coffee crop loss. But, the most striking result was that smallholder data suggested that there was no significant difference in the price of bags between farms identified as having CGS and farms without. This suggested that either coffee quality is not markedly different in this stage of the market chain, or it was pure weight being bought. Therefore an additional smallholder survey questionnaire was developed by UNSW (Dr Todd Walton & Associate Professor Wendy Shaw) and completed during 2014. It should be noted that this was to be followed-up, but due to the late delivery of the data this was not possible.

Surveys were conducted by CIC engaging with sixty-eight smallholder families (e.g. Figure 3), that were divided into farms “with CGS” (74%) and farms “without CGS” (26%). The short questionnaire was split into four sections containing questions to: 1) discern basic demographic information of farmers for statistical analysis and comparison; 2) gather farmer views and knowledge of CGS; 3) estimate farm production; and 4) estimate losses and impact due to CGS. After interviews, smallholders were very interested to learn more about the various pests and diseases, and asked about control methods. Children were particularly interested to learn about the difference between CGS and ants and the relationship between the two. Although the education of children was not formally measured this would have been a valuable future metric of community impact.

Figure 3: Top left to bottom right: 1) Discussions with smallholders; 2) children interested to learn more about CIC (note this is an example from WHP/Jiwaka, and not EHP).

Basic Demographics

All respondents were male, and all but one was married. Each farm / household had an average of 3.6 children, and the average age of respondents was 43. The education levels of respondents varied from a college/university education (9%) to no formal schooling at all (9%). 47% of respondents had a community schooling level of education (grades 1 to 6), and the remainder (32%) went through to provincial high school (grades 7-10).

CGS occurrence

The average size of farm in terms of numbers of coffee trees was not significantly different between the two groups, with and without CGS (2123 and 2438 respectively). This was also true for the number of newly planted trees.

The average altitude where the smallholders were surveyed was 1550m, but there were a number of smallholders surveyed outside of this range, *circa* 1350m and 1825m. The survey also found smallholders at these extremes of altitude, where CGS was seen as a problem. As reported in ASEM/2004/041 CGS was most abundant at the 1500m level, but there were also some farms that had CGS above and below this altitude. There were also significant differences between the median amount of coffee reported to be infected with CGS between districts ($H_{(9)} = 17.48$, P=0.04). The district of Ungai-Bena had higher reported infestations than Daulo, Kainantu and Obura Wonenara (P = <0.05).

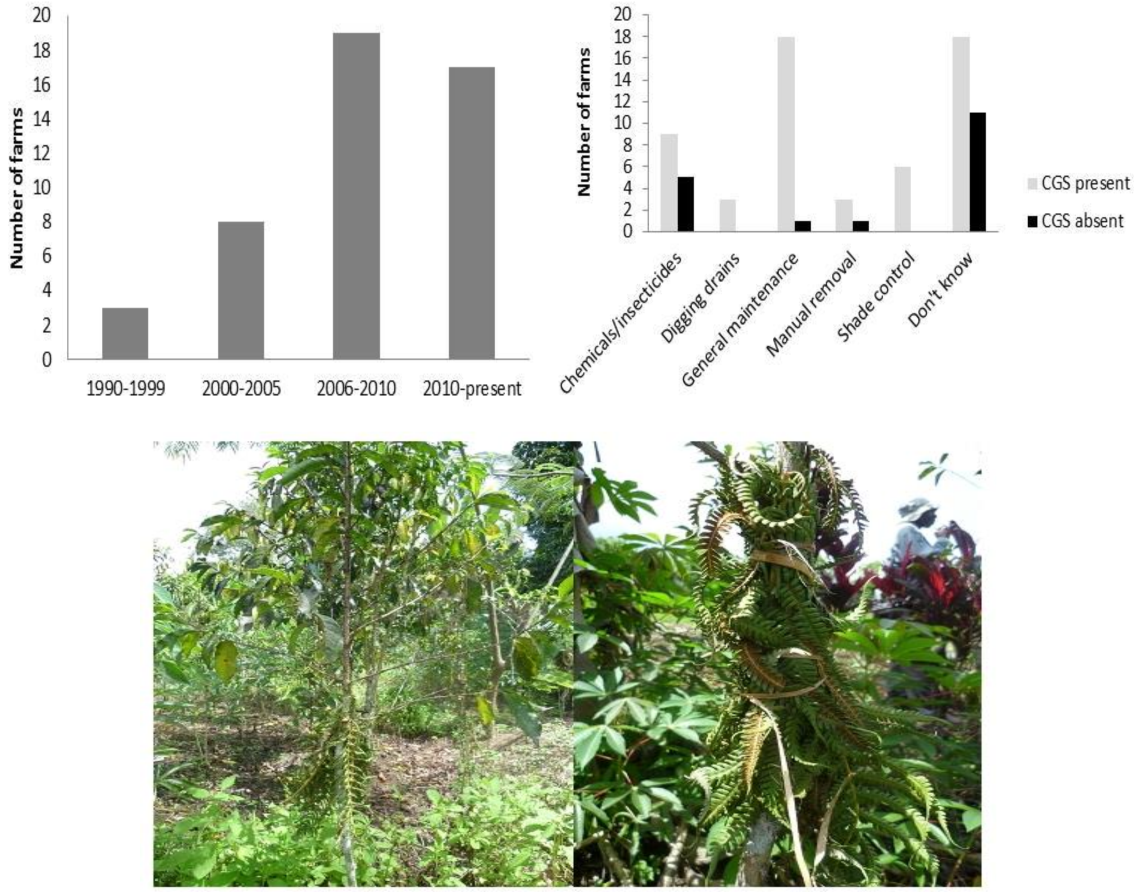
Smallholder views and knowledge of CGS

The survey revealed that five smallholders were unaware of CGS, and four of them had CGS but did not know it was present on their coffee trees. However, 70% of farmers knew about CGS independently, through observations of their own, with ants and sooty mould often being seen as the indicator and sooty mould (as in the first survey). Only 9% were informed by CIC officers, with the remaining 9% being informed by other farmers.

On farms with CGS, the majority of smallholders have seen it become a problem since *circa* 2006 (Figure 4). At the time of the survey 72% reported that the insect was infesting and damaging 5-10% of their crop. The remaining smallholders reported much larger infestations with 13% estimating that over half the crop was damaged. By comparison smallholders without CGS did not regard it as a threat at all to their coffee crop, and as discussed later, would be less tolerant if they did have it (in terms of coffee crop loss).

Generally, smallholders did not know how to manage the pest, but most of them thought that a good general maintenance policy was the best method to reduce impact. There were some smallholders that were aware of CGS, and have tried to stop ants from accessing CGS through the use of bespoke physical, and also chemical barriers (e.g. Figure 4).

Figure 4: Top left: Graph illustrating the year CGS became a problem for individual farms. Right: Farmer opinions of best control method for CGS. Bottom left: Coffee tree with fern barrier in an attempt to stop ants & CGS; right close up of barrier.



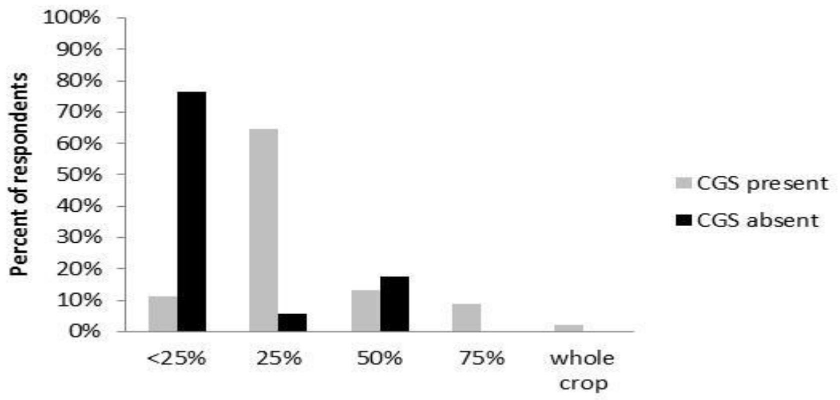
CGS impact

Farmers were asked to estimate the general impact of CGS on their coffee yield, with the average amount of crop loss being 26% (for farms categorised as having CGS). Over half of the smallholders with CGS estimated that losses can be between 10-20% of their crop, 12% estimated over half; and 4% estimated the entire crop.

Most farmers (60%) reported that CGS infestation was at its worst during the dry season and almost all farmers surveyed (apart from one) said that the season of worst infestation has changed over the years. Conversations with smallholders during Activity 6, revealed that most of the farmers perceived the growing season to be changing which was noticeable by changes in flowering and fruiting periods – some even said the rains had changed.

When smallholders with CGS were asked to indicate what they would tolerate in terms of coffee crop loss from CGS before they gave up production, most of them said over 25% (Figure 5). This was in addition to current losses and contrasted to those smallholders without CGS, who would tolerate much lower levels of crop loss (<25%). This indicates that farmers with CGS appear to be more accepting to crop loss, whereas farmers without CGS would tolerate very little. It could even be that farmers without CGS are generally less tolerant of any losses due to pests and diseases.

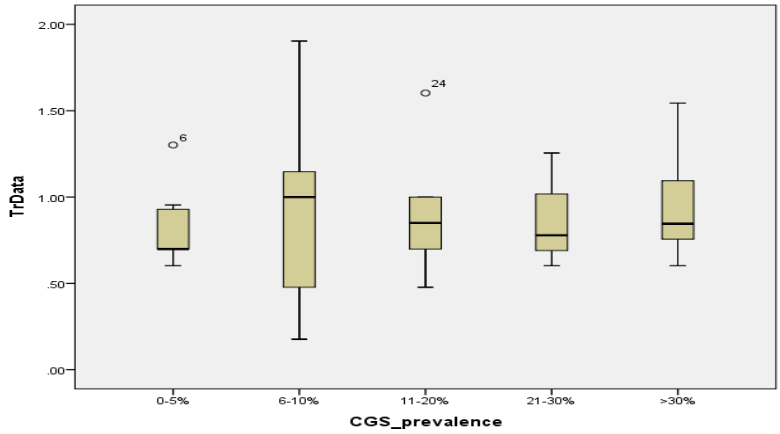
Figure 5: Farmer estimates of how much of their current crop would need to be infested with CGS before coffee production ceased (compared between farms that are currently with and without CGS).



Farm productivity

There were no significant differences in parchment bag production between smallholders with CGS versus without CGS, with the respective 2013 average production being *circa* 14 (+/-16) and 23 (+/-29) 60 kg bags (U=493, P=0.55). The same results were also found when analyses were run to compare data from previous years (2007 to 2012). Bags of cherry produced were also compared to the prevalence of CGS in the form of farmer estimates as a percentage of trees infested, and again no significant differences were found (K=1.37, P=0.85). As would be expected farm productivity was generally a function of farm size, and therefore the number of bags was then expressed as bags per tree, therefore taking account of farm size. Again, bags produced per tree were compared with the prevalence of CGS from farmer estimates, and again no significant differences were found ($F_{4,29}$ = 0.38, P=0.82) suggesting that losses were negligible (**Figure 6**). This was also the case between farmers that had CGS, who viewed it as a problem and those that had it but did not view it as a problem (t_{43}=-0.49, P=0.63).

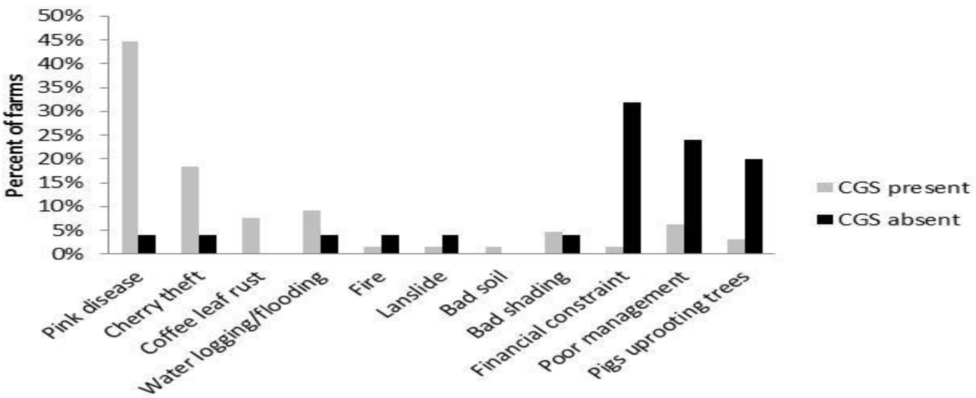
Figure 6: Box plot of bags produced versus farmer estimates of CGS prevalence. Where Y axis = cherry production per tree (log10), and X axis = CGS prevalence.



Further explorations were made on the farmer estimates of CGS infestations and the percent of coffee crop damaged, comparing this impact across the farm size classes. Again no significant differences were found indicating that farmer estimates of CGS impact do not differ between farms of differing sizes ($F_{4,24}$=0.73, p=0.58), and likewise farm age ($F_{4, 24}$=0.95, p=0.45).

There were a number of other factors that farmers indicated as major problems on CGS infested farms, notably 45% indicated that pink disease (*Erythricium salmonicolor*) was a factor impacting on coffee. This contrasts to those farms without CGS, of which only circa 4% viewed it as a problem. Given that most farmers knew about CGS, the contrasting issues between those farmers with and without CGS are evident (Figure 7). Those with CGS view pests and diseases as a major limitation to production, versus those without that view financial constraints, poor management and trees being uprooted as the major issues.

Figure 7: Factors that smallholder farmers view as issues on their farms.



5.2.2 Key findings

- ***Most smallholder farmers knew about CGS independently, through observations of their own i.e. ants & sooty mould being seen as the indicator. The majority of these farmers have seen it become a problem since circa 2006.***
- ***Given the key recognition characteristic is the presence of ants and sooty mould, these characteristics of CGS are not always obvious, depending on the season or climatic conditions. Therefore populations of CGS might be more cryptic to the smallholder and they may underestimate how much CGS is actually present on their farm at certain times.***
- ***The majority at the time of the survey reported that CGS was infesting and damaging 5-10% of their crop. The remainder reported higher levels with 13% of smallholders reporting over 50% of their coffee crop.***
- ***The majority of smallholders estimated that in general the impact of CGS on their yield was 10-20%. 16% of smallholders estimated losses to be between 50% and 100% of their coffee crop. The disparity between the proportion of trees being damaged by CGS and reported yield losses can be explained by considering: 1) the timing of the survey; 2) how the farmer perceived CGS at that time i.e. ants and sooty mould; and 3) the fact that seasonal differences are recognised. During the growing season more cryptic CGS populations can expand together with the amount of sooty mould and would become visible to the farmer, and thus the losses were based on estimates over the average season.***
- ***Smallholders with CGS were more tolerant of crop losses due to CGS compared with smallholders without CGS.***
- ***Smallholder with CGS viewed other pests and diseases as major problems in terms of productivity. Whilst those without CGS thought that financial constraints and poor management were the main issues in farm production.***

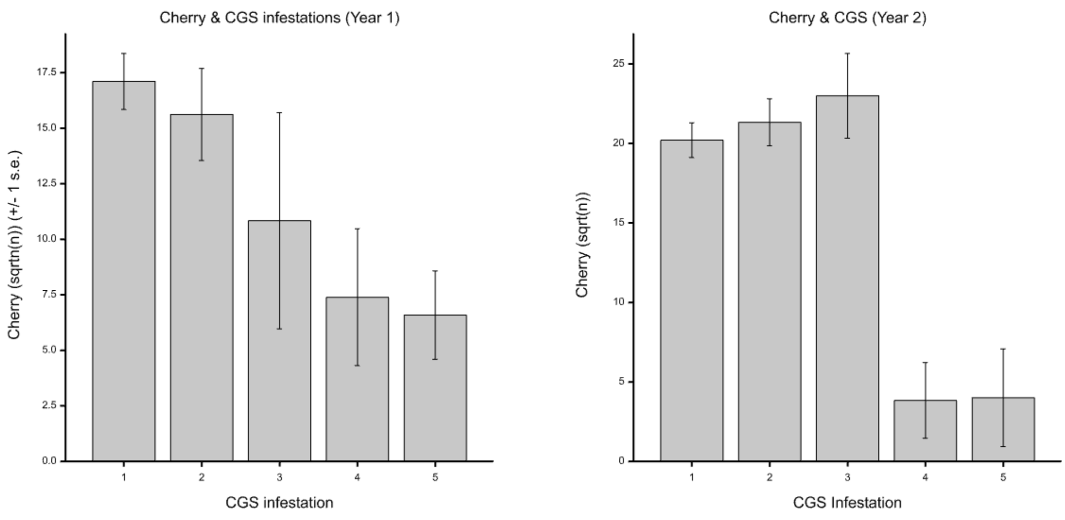
5.3 Activity 3: Establish controlled research station experiments to determine yield loss.

Research station coffee blocks were used to provide a finer tuned measure of overall yield loss due to CGS. Within these blocks differing infestation levels were to be established and maintained. The influence of other diseases was mitigated by control measures.

Originally the EHP Aiyura research station was to be used as the on station study farm but because of the low incidence of CGS, with almost no trees having infestation levels greater than 50% the trial was conducted at the Western Highlands substation. Here sixty trees with varying degrees of CGS infestations were chosen in the last quarter of 2012, and data was collected monthly. The method was the same as in activity 1 and from the data, we were able to determine trees that were completely clean of CGS whilst categorising the infested trees into a further four infestation levels. Each tree was split into quarters and then three vertical partitions, top middle and bottom, making it easier to evaluate the whole tree. The CGS infestation levels were therefore categorised as: 1 = no CGS or sooty mould; 2 = 1 – 25% of laterals with CGS; 3 = 26 – 50%; 4 = 51 – 75%; 5 = 76 – 100%.

Given the nature of the varying number of trees in different CGS infestation levels we used an unbalanced ANOVA comparing the infestation levels with productive items on the trees: “Functional Nodes” total flower nodes plus cherry nodes; cherry nodes and cherry.
Initial analyses were conducted using a repeated measures analysis which revealed significant differences over time with the number of productive items per tree. Here we present summary data of the season totals (Figure 8). The results indicate that increasing levels of CGS infestations have a significant negative effect on cherry in year 1 and 2 ($F_{4,59}$ = 6.39; P = <.001, **Table 1**). For the remaining results and graphs see appendix 9.4.

Figure 8: Plot of treatment levels 1-5 for years 1 and 2 (left to right) total cherry. In year 2 a number of trees died and were excluded from the analysis probably due to CGS. Note the data is square root transformed. Error bars are 1.s.e.



From these results we calculated the proportion of productive items per tree at the different levels of infestation (Table 1). In year 2 a number of trees died which was thought to be due to CGS or in some cases pink disease; these were therefore removed from the analyses. Given that these trees were debilitated to such an extent we cannot discount the possibility that what caused tree death in year 2 may have been influencing the results prior to tree death i.e. the results in year 1. There are other factors that may have influenced the results from the trees prior to the experiment e.g. long term CGS infestations being established, or other undetectable diseases. Additionally a number of trees in year 2 did have some minor pruning (<10%) so the results in year 2 should be treated with caution.

These results appear to correspond with anecdotal evidence where persistently heavily infested trees do not perform as well as non-infested trees, and can lose as much as 90% (Gitonga, 2010). However, although the trend in losses are corroborated by research by Apety (1996), those losses were lower, *circa* 40% vs. 80% for cherry and thus the estimates we use from here forward are combined with those results, i.e. circa 58% for cherry. In conclusion, trees that are nearly continuously infested (51-100%) can be expected to produce less cherry, assuming the CGS population remains on the tree. These results contribute to Activity 7.

Table 1: Means from the ANOVA conducted on the five CGS treatment levels. Treatment level 1 is complete absence of sooty mould & CGS. Treatment levels: 2 = 1-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-100%. Maximum LSD (P<0.05) were calculated and where treatments share the same letter, no significant difference. All data is back-transformed from square root. Between years 1 & 2 a few trees died and were removed from the analysis.

		1	2	3	4	5	*ANOVA*
Cherry	*Year 1*	293 [a]	244 [a]	117 [ab]	55 [b]	43 [b]	$F_{4,59}$ = 6.39; P = <.001
	% reduction	0	0	0	75	80	
	Year 2	408 [a]	454 [a]	529 [a]	15 [b]	16 [b]	$F_{4,48}$ = 17.2; P = <.001
	% reduction	0	0	0	97	98	
	Mean % reduction	0	0	0	90	90	

5.3.1 Key findings

- ***High levels of CGS can cause significant cherry losses on trees exposed to CGS for prolonged periods – circa 80%.***
- ***These findings correspond to other evidence i.e. heavily infested trees can lose as much as 90%.***
- ***Combining these findings with previous research we estimate losses on heavily infested tress to be circa 58%.***
- ***Tree death may result from prolonged heavy infestations and may be compounded if other diseases are present.***

5.4 Activity 4: Survey and interview holders of larger farms (including plantations) and processors to gather historical information on CGS and yield and yield loss.

In October 2011 contact was made with commercial processors, and large block holders. For commercial processors it was hoped that the team could build links and access agronomy assessments of smallholder cooperatives, and yield. Many of these processors pointed out that they did not see CGS as a problem, although it could be in certain areas, and that it was sometimes sporadic. The major issue in their view was poor maintenance of smallholder coffee farms. Coffee diseases of particular note to processors were pink disease (*Erythricium salmonicolor*), and also coffee leaf rust (*Hemileia vastatrix*). These processors were cooperative but the records required for this project did not always exist. Where such records did exist, the information was of a commercially sensitive nature, particularly yield figures as discussed in the 2014 annual report (Brook et al 2014), and previous reports. However, the project was designed with multiple approaches to gaining information on CGS and impact on coffee losses.

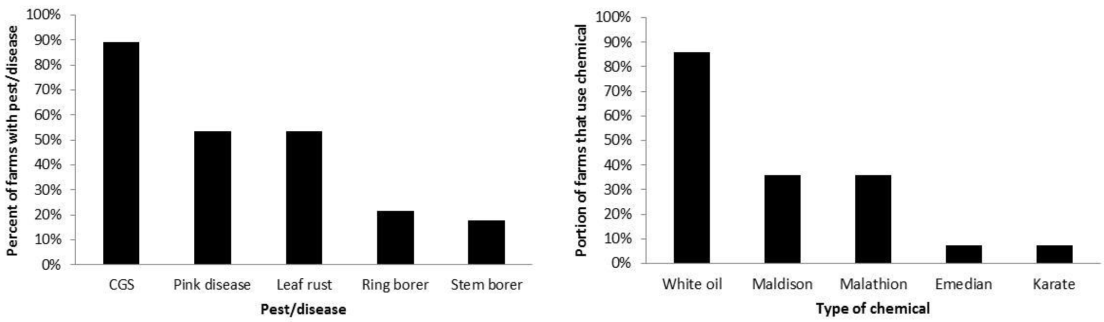
For larger block holders, those with coffee plantations, it was hoped that the team could ascertain perceptions and access records kept on issues such as yield loss due to CGS and management. These farmers were likely to be actively managing in prescribed ways, and keep records which could add to our knowledge of what impact CGS can have on yield in a well-managed system. In addition, if the levels of CGS infestations had not been quantified, proxies might be found e.g. the frequency and quantity of a pesticide applied in response to an infestation.

Many plantations in Eastern Highlands province no longer exist in the form of true plantations. The most common reason for this is that plantations have either been abandoned or partitioned amongst the local community. Despite this, the team did manage to source twenty-eight large block holders, and surveyed them in early 2013 using a more detailed survey instrument than the one used for smallholders. However, much of the data is limited either by being too course, or inconsistent between years, and it has not revealed much useful information in terms of CGS and yield loss. However, there are some findings that confirm the information collected in ASEM/2004/041, and possible reasons why the losses attributable to CGS were not detected are discussed.

5.4.1 Findings of the larger block holder coffee farm surveys

The average size of the large block holder plantations was *circa* 27Ha, earning approximately K27,000 in 2012. The majority of these growers (>80%) sold their coffee to factories, with the remaining selling to exporters or cooperatives. All these farms have had CGS since the 1990s and recognised its presence via ants and sooty mould, and 90% of the farmers said it was a problem, followed by pink disease and leaf rust (Figure 9). The majority of farmers said it was worst in the dry season and that trees infested with CGS in 2012 did not produce as much cherry relative to their non-infested trees.

Figure 9: Larger block holder surveys and the categories of major pests and diseases (left). Right: Types of pesticides used to control CGS.



CGS, Production and drivers of farm differences

The first method in analysing the data from these surveys was to use bag production (i.e. the quantity of bags produced in 2012 as a constant to determine differences between farmers and their farms, that viewed CGS as either a problem or not. However, this method did not reveal any significant results for any of the variables measured (Table 2) and as such farms were then compared in terms of the perceived infestation level on a farm. This enabled the exploration of factors that could explain the perceived abundance e.g. altitude.

In terms of the major farm costs (e.g. chemicals or labour) there were no significant differences between farms with high or low infestations of CGS indicating that the expenditure is no different (t=0.9, p=0.38). This was also true for control methods i.e. manual or chemical removal. The data for the level of farmer education and the proportion of CGS was not normally distributed but there were suggestions that lower education levels resulted in higher proportion of the farm being infested, although this result should be treated with caution.

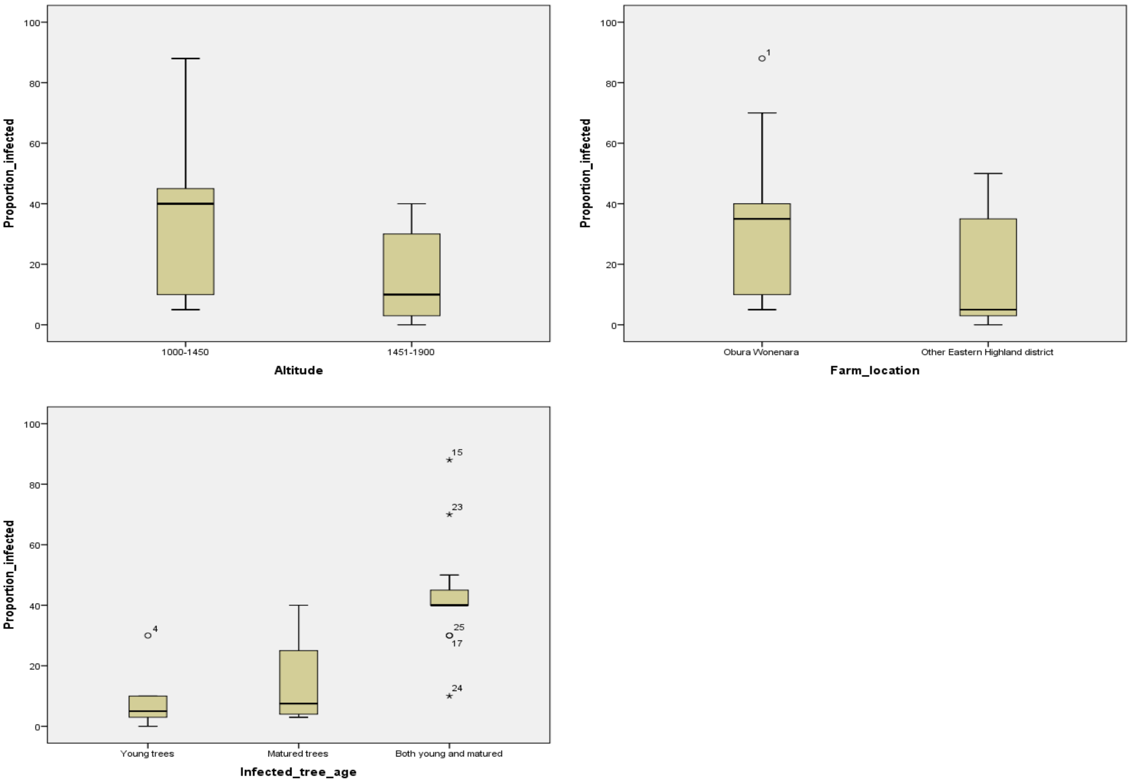
Table 2: Differences between bag production of larger farmers that either viewed CGS as a problem or not. *NS* indicates no significant difference.

	Larger Farmer Groups & differences in production	
Factor versus production	CGS a problem	CGS not a problem
CGS problem	*NS* (t=0.41, p=0.97)	
Major farm cost (chemicals / labour)	*NS* (t=-1.98, p=0.06) (α=0.05)	
CGS control method (Chemicals or Manual removal)	*NS* (t=0.01, p=1)	
Tree age (0-30; 31-60 years)	*NS* (t=-0.16, p=0.88)	
Farm location	*NS* (t=1.66, p=0.12)	
Farmer education	*NS* (F(2, 16)=0.71, p=0.51)	
Tree age (young, mature, both young and mature)	*NS* (H=0.17, p=0.99)	

The major factor in larger block holders having high versus low levels of CGS infestations appears to have been driven by altitude and location. At 1000-1450m, and in the Obura Wonenara district, CGS infestations were significantly higher, than higher altitudes, and other districts (t=2.61, p=0.02 and t=2.22, p=0.04 respectively) (Figure 10). Further, an analysis was conducted on the age of trees when the first CGS infestations occurred. There was no difference between the infestation levels at farms that had exclusively young or mature trees, but where farmers had both young and old trees there were higher infestation rates.

Although these findings do not reveal the quantity of coffee lost though CGS, they do confirm that many larger block holders consider it as a major pest, with the majority saying that trees with CGS do not perform as well as non-infested trees. The findings also confirm some of the previous findings in ASEM/2004/047, where CGS appears to be attitudinally limited (*circa* 1500m). The survey has also identified the district of Obura as a major area of infestation. Also, farms with mixed ages of trees, i.e. both young and old trees, appeared to suffer significantly higher infestation levels than farms that had either exclusively young or mature trees. If CGS infestations had a preference for either young or mature farms it might be expected that mixed age farms would have infestations between the other two groups. The high infestation rates on mixed aged farms could be due to a number of factors, e.g. expansion, regeneration etc. Although we have no evidence, it could equally be due to the farmer having to replace the trees because of high levels of established CGS infestations.

Figure 10: Proportion of farm infested with CGS at: left = differing altitudes; right = district. Bottom = infestation level in percentage compared between farms based on the age of their infected trees.



5.4.2 Key findings

- ***For processors: CGS was not viewed as a problem throughout PNG but it was more of a problem in certain areas. The major issues for processors in smallholder coffee production were: 1) poor maintenance; and 2) other coffee diseases - pink disease (Erythricium salmonicolor), and coffee leaf rust (Hemileia vastatrix).***

- ***Larger block holders have had CGS since the 1990s, and 90% believe it to be a real problem by reducing productivity. However, we could not confirm these views as we were unable to detect losses due to CGS, in terms of income and effort used to control CGS. There were suggestions that heavy infestations were associated with farmers who had lower education levels.***

- ***High infestations of CGS were on mixed age coffee – it did not appear to be age specific. The higher infestations appear to be around the Obura Wonenara district.***

- ***Larger block holders also view Pink disease (Erythricium salmonicolor) and coffee leaf rust (Hemileia vastatrix) as problems.***

6 Estimating the potential impact of CGS on smallholders, and loss in highland smallholder production: Activities 5 – 7 (Objectives 2 & 3)

Note: Activities 5 and 7 are essentially the same, and as such have been amalgamated and follow on from Activity 6 which is a prerequisite for estimating the overall yield loss of CGS on smallholder production.

6.1 Activity 6 – Surveys of the incidence of CGS in other major Arabica producing provinces.

To estimate overall loss due to CGS, surveys were conducted in three major Arabica growing provinces of Eastern Highlands, Simbu and Western Highlands (including Jiwaka). These surveys provide an estimate of the current CGS situation, and are used to provide information for calculating the potential estimated loss in production (Activity 5 & 7).

Surveys covered the altitudes where coffee is grown but with an emphasis on 1500m as this is where CGS is most abundant in EHP (ASEM/2004/047). The “W” transect method from ASEM/2004/047, was used to assess the incidence and infestation level of CGS (October 2013 & February 2014) at 61 farms (see appendix 9.5 for protocol). This provided a sample of the coffee trees present, and each coffee tree was assessed using the Upreti quadrant (quarter) method (Upreti, *et al.,* 1991), and CGS infestation levels were scored. The presence of other diseases was also recorded (e.g. pink disease and coffee leaf rust, see Figure 11). The farms were mapped using GPS Figure 12 and other factors such as: altitude; shade level; and age of trees, and variety were also recorded. All analyses were conducted using Genstat (VSN International, 2013) using a combination of analysis of variance and multiple regression.

Figure 11: Top left to bottom right: CGS, sooty mould, pink disease, and coffee leaf rust.

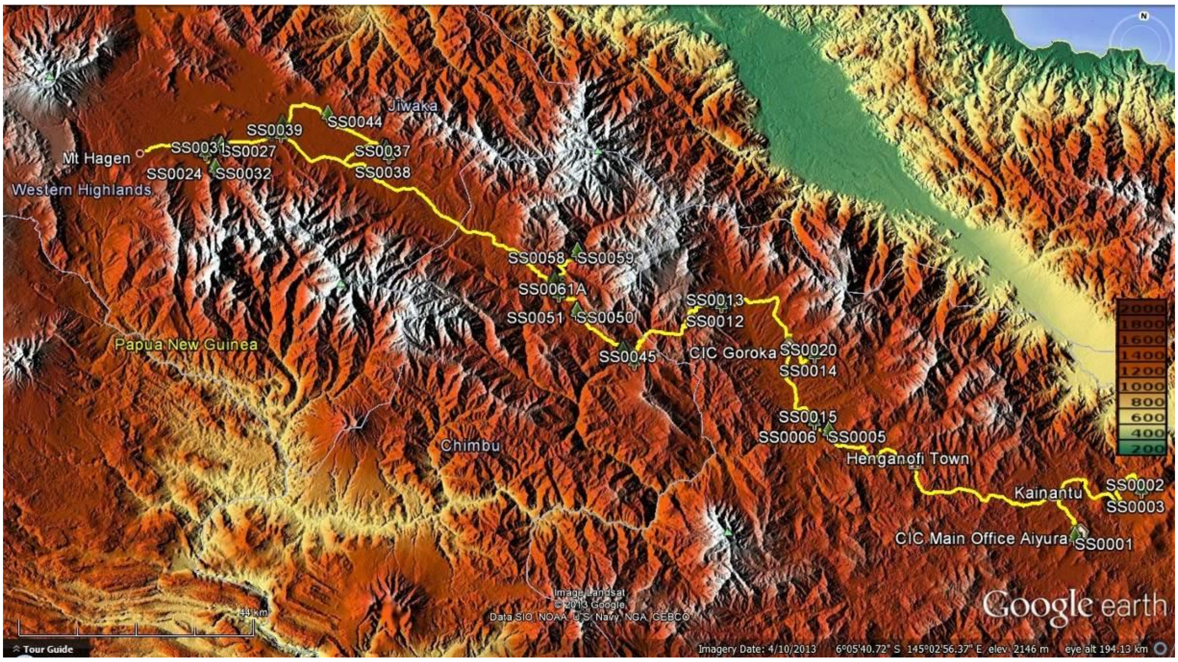


Figure 12: Overview map of WHP, Jiwaka, Simbu and EHP (left to right).This shows the positions of farms visited (not all farms are shown at this resolution). Note basic altitudinal scale on right hand side.

The majority of farms had varietal mixes of coffee, with the three most dominant being: 1) Typica; 2) Bourbon; and 3) Arusha. As such, any inter-farm and provincial differences were compared taking account of these mixes by calculating varietal diversity per farm using Shannon–Wiener Index. The level of shade was lowest in EHP, where on average it was 21% compared to circa 35% in the other two provinces (Table 3).

The highest incidence of CGS occurred in EHP with 95% of farms having the pest, with an average of 29% of trees being infested, significantly higher than WHP and Simbu ($F_{2,58}$ = 9.47, P = <.001; **Table 3**). Within WHP and Simbu province, CGS was also present but the number of farms with CGS was lower: 72% and 70% respectively. Likewise, the proportion of trees on farms infested with CGS in these two provinces was much lower than EHP, with WHP farms having an average of 3.9% of their trees infested, and in Simbu 8.2%. Trees on farms in both WHP and Simbu had much lower CGS infestation levels, with >90% of trees having zero infestations. By contrast 30% of trees in EHP had infestation levels equal or greater than 1-26%, with 15.75% having infestation levels of CGS between 76-100%, significantly higher than in the other two provinces.

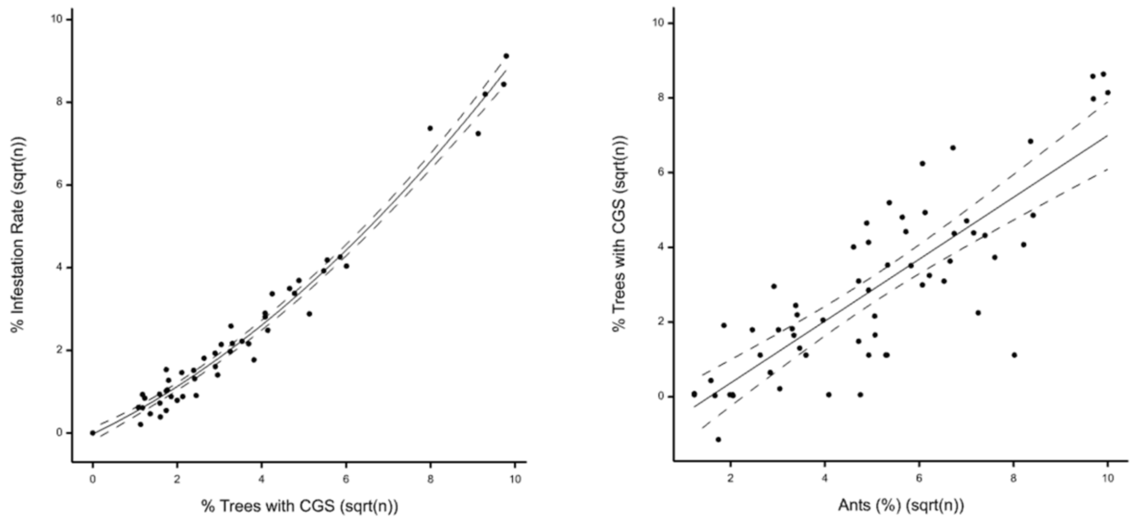
Other diseases and farm factors were also analysed for differences between provinces. Coffee leaf rust (*Hemileia vastatrix*) occurred in *circa* 92% of the trees surveyed on the farms, and there were no differences between the provinces. Pink disease (*Erythricium salmonicolor*) however, was most abundant in WHP with 23% of trees having the disease. Ants, which have strong associations with CGS, were significantly more abundant in EHP and WHP, than Simbu.

Multiple regression analysis using Genstat (VSN International, 2013) was used to explore the relationship of CGS infestations across the farms and potential explanatory variables. The strongest relationship with the severity of CGS infestations was the number of trees infested, i.e. farms with high numbers of trees infested with CGS had higher infestation rates (Figure 13). Only the relationship with ants and CGS was significant and other factors such as shade, distance from road, and other pests and diseases were not (Figure 13). However, there was a significant, but weak interaction with the number of trees infested with ants, shade and distance from road. Ants generally declined with increased shade, and shade increased with distance from the road (R^2 = 0.14 respectively).

Table 3: Comparison of the incidence and infestation levels of CGS in three major Arabica producing provinces, and incidence of other pests and diseases. Farm factors such as shade are shown at the bottom.

Factors (% trees)	EHP	Simbu	WHP	ANOVA
CGS % trees / Farm	29.68 (7.046)[a]	3.897 (1.047)[b]	8.171 (12.5)[b]	$F_{2,58}$ = 9.47, P = <.001
Infestation level 1	70.79 (4.382)[a]	96.31 (4.98)[b]	91.94 (4.382)[b]	$F_{2,58}$ = 9.06, P = <.001
Infestation level 2	4.551 (0.93)[a]	1.5 (0.94)[a]	3.912 (0.83)[a]	$F_{2,58}$ = 3.14, P = 0.051
Infestation level 3	6.187 (1.435)[a]	0.71 (0.213)[b]	1.485 (0.408)[b]	$F_{2,58}$ = 11.35, P = <.001
Infestation level 4	3.196 (0.82)[a]	0.867 (0.244)[b]	0.188 (0.135)[b]	$F_{2,58}$ = 7.66, P = 0.001
Infestation level 5	15.75 (5.036)[a]	1.906 (0.573)[b]	1.498 (0.719)[b]	$F_{2,58}$ = 7.78, P = 0.001
Other pests & diseases				
Ants (% trees)	40.5 (7.444)[a]	14.31 (2.629)[b]	33.73 (3.368)[a]	$F_{2,58}$ = 5.86, P = 0.005
CLR (% trees)	89.27 (3.047)	95.16 (1.269)	94.84 (1.827)	$F_{2,58}$ = 2.15, P = 0.126
Pink (% trees)	15.46 (4.175)[a]	7.304 (1.37)[a]	23.09 (2.573)[b]	$F_{2,58}$ = 7.92, P = <.001
Farm factors				
Shade (%)	21.14 (3.25)[a]	39.71 (5.1)[b]	32.84 (4.45)[b]	$F_{2,58}$ = 4.5, P = 0.015
Variety Diversity	0.91 (0.041)[a]	0.876 (0.055)[a]	0.627 (0.063)[b]	$F_{2,58}$ = 9.43, P = <.001
Distance to Road (m)	333.7 (101)	352.6 (94.2)	275.9 (47.42)	$F_{2,58}$ = 0.53, P = 0.591
Year planted	1988 (3.78)	1992 (1.68)	1984 (3.36)	$F_{2,58}$ = 1.24, P = 0.297

Figure 13: Left: Relationship between the percentage of trees with CGS and increasing infestation rate (R^2 = 0.979; $F_{4,56}$ = 714.16, P = <.001). Right: relationship between ants and CGS (R^2 = 0.707; $F_{3,57}$ = 49.29, P = <.001). All data was square root transformed. Solid line = regression line, dashed lines = 95% C.I.



The findings from these surveys corroborate the findings of ASEM/2004/047, in that invasive ant species are closely related to the levels of CGS infestations. Such a relationship is well documented (e.g. Philpott, *et al.,* 2006; Abbott & Green, 2007) and appears to be a major driver of these CGS infestations. In addition the surveys also provide a provincial estimate of CGS infestations and their severity at a farm level which can be used to estimate the impact of CGS on production, with EHP having the heaviest infestations. Coffee leaf rust is present on almost all farms, and is likely to be on the limits of its altitudinal range (Waller, J.M. pers. comm., 2015). It is more severe on coffee grown at lower altitudes below 1500m (Rayner, 1961), but this disease still remains a concern for CIC. From conversations with processors in Activity 4, pink disease appears to be a concern, and given the high levels in WHP and to some extent EHP these results highlight its prevalence. Pink disease is not specific to coffee, and it has a very wide host range (over 500 species), and the literature suggests that the impact on coffee is not generally a major concern. It is of concern on rubber, cocoa and citrus (Waller *et al*., 2007), and as these crops form livelihoods for other PNG communities, future explorations on factors driving the abundance in coffee and possible impacts on coffee and other crops might be considered.

6.1.1 Key findings

- ***The incidence of CGS was highest in EHP (95%) with WHP and Simbu having less than 72% of farms infested***
- ***The average number of trees infested on EHP farms was 29%, with 15% of farms having very high infestations***
- ***Coffee leaf rust (Hemileia vastatrix) occurred in circa 92% of the trees surveyed on the farms, and it is abundant across the provinces***
- ***Pink disease (Erythricium salmonicolor) was most abundant in WHP with 23% of trees having the disease.***
- ***Ants, which have strong associations with CGS, were significantly more abundant in EHP and WHP, than Simbu.***

6.2 Activity 7 (including 5) – Combine data from surveys and experiments to estimate the potential economic impact in smallholder farms in major Arabica producing provinces.

Using the estimates from previous Activities (1 & 3) plus literature, we combined this information with the results of Activity 6 (surveys in the other main coffee growing Provinces). Thus an overall impact of CGS was estimated for smallholder Arabica coffee farms for the provinces: EHP, Simbu and WHP.

It should be noted that these estimates are based on 61 farms across these provinces visited twice within one growing season (2013 / 2014) and provide a snap-shot at that time. Therefore estimates should be treated with caution as outbreaks of CGS can sporadically occur under certain conditions. It should also be noted that the potential loss in production at varying levels of CGS was derived from: 1) the marginal smallholder losses found in activity 2, losses from the experimental blocks, and losses due to CGS found in the literature, e.g. Apety (1996). As we were unsure about the results from the year 2 experimental blocks and the specific causes of tree death, we excluded these from the estimates of potential loss (**Table 4**).

Table 4: Figures used to estimate yield loss due to CGS. Note year 2* is excluded from the calculation, but is included here for reference.

		3 (26-50%)	4 (50-75%)	5 (75-100%)
Cherry Nodes	Apety Model (1996)	0.00	10.72	16.75
	Yr 1 Expt Block	0	60.00	71.00
	Yr 2 Expt Block *	(0.00)	(95.00)	(96.00)
	Mean	**0**	**35.36**	**43.88**
Cherry	Apety Model (1996)	0.00	0.00	37.62
	Yr 1 Expt Block	0	75.00	80.00
	Yr 2 Expt Block *	(0.00)	(97.00)	(98.00)
	Mean	**0**	**37.5**	**58.81**

6.2.1 Predicting coffee loss due to CGS

From Activity 6 the number of individual trees on a farm that were not infested were calculated as a proportion of the total number of trees surveyed. Likewise, the total number of trees that had CGS infestation levels 2 - 5 were also calculated as a proportion of the total number of trees (e.g. Table 5).

For each individual tree within a farm, and across the three provinces, the proportions of trees within the CGS categories were used to predict a potential farm level loss from CGS. By applying the estimate of potential loss at differing levels of CGS infestation to each individual tree enabling the predicted cherry yield loss on an individual farm level to be calculated (e.g. Table 5). Here we see, that Farm 1 has a greater proportion of trees in the higher infestation rates >76% infested, versus Farm 2 where CGS infestations were mainly absent. This estimate was therefore based on infestation rates on farms that were surveyed in Activity 6 during October 2013 and February 2014, providing a sample within one growing season.

From the surveys in activities 6 and 7 the major loss from CGS appears to be in Eastern Highlands where CGS is abundant compared to WHP and Simbu. From the surveys we estimate that 95% of farms within EHP have CGS, with on average 31% of their trees being infested with varying degrees of CGS. Using the estimates of loss this equates to an average of 11% loss within EHP at *circa* 1500m. In some farms the number of trees infested was the majority and were heavily infested, these farms could be losing up to *circa* 50%, or more if the trees die. These losses tie in with the small holder estimates where, on average, they estimated losses at around 5-10% due to CGS in EHP.

Table 5: Example of the proportion of trees on two farms with differing CGS. Level 1 is complete absence of sooty mould & CGS. Levels: 2 = 1-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-100%. Predicted loss from Activity 3, season 1, model combined with the Apety model is shown below for these two examples.

	Proportion of trees with CGS categories (%)				
Farm	Level 1	Level 2	Level 3	Level 4	Level 5
1	4.1	0	11.4	6.8	77.7
2	98.6	1.4	0	0	0
	Predicted loss per farm (%)				
Farm	% Cherry Nodes		% Cherry		
1	39		50%		
2	0		0		

In the Western Highlands the number of farms with CGS was much lower, circa 72%, with on average 11% of trees being infested. These low levels are apparent in the predicted loss with those infested farms estimated to be losing around 2% and up to 8% on some farms. Simbu province followed a similar pattern to WHP, where 75% of farms were infested but with an average of 5.5% of trees being infested, and of those infested farms the loss due to low level infestations was predicted to be on average *circa* <1% with some farms loosing up to 7%. From our small sample of 61 farms (x 2 visits), it appears as though losses in these provinces could be minimal, but more surveys would be prudent to ensure that this is correct.

6.2.2 Key findings

- ***Potential cherry losses in EHP are on average 11 % (15% on infested farms) with some farms losing as much as 50% on heavily infested farms. This corroborates the most common estimate of loss by smallholders 10-20% (see section 2)***
- ***Potential cherry losses in WHP and Simbu appear to be lower, around 2%, but up to 8%.***

7 Conclusions

Persistent and heavy infestations for prolonged periods can cause up to 80% loss in terms of cherry produced on a tree. The results match anecdotal evidence where up to 90% losses have been reported in some smallholder coffee farms in Kenya (Gitonga 2010). Previous research by Apety (1996) found that losses were around 40%, but estimates of over 50% have also been noted (Apety and Fumo, 1998). By combining the estimates from this project and other literature, the potential loss due to heavy and persistent CGS infestations is estimated to be 58%. We cannot exclude the possibility that other diseases may compound this effect, but such interactions would be expected on smallholder farms, given the presence of other pests and diseases.

This figure provides the project with key information and was used in conjunction with surveys across the three major Arabica coffee growing provinces (EHP, WHP and Simbu). Coffee green scale abundance was highest in EHP, and the estimated potential cherry loss is on average ~15% on infested farms and 11% across the Province. The nature of the CGS problem is not uniform across EHP, with some smallholders losing more than 20%, and in extremes as much as 50% or more if the trees die. These estimates of crop loss are similar to EHP smallholders, i.e. 10-20%, with some estimating 50%. In Western Highlands and Simbu the severity of infestations was much lower than EHP, with potential losses in these Provinces being around 2% and up to 8% on a limited number of farms. As infestations by pests and diseases are not static, on-farm infestations can vary through time and these estimates are a snap-shot of the situation in 2013 – 2014, and not a prediction of future levels. However, the methods employed during the Activity 6 surveys can be used to monitor the situation, tracking CGS through time.

Smallholders have viewed CGS as a real problem since 2006, which contrasts to larger block holders who have recognised its impact since the 1990s. Whilst smallholders know about CGS their key recognition characteristic is the presence of ants and sooty mould. These visual characteristics of CGS are not always obvious, depending on the season or climatic conditions. On trees or in periods where sooty mould is not present, populations of CGS will be more cryptic to the smallholder and they may underestimate how much CGS is actually present on their farm. By increasing awareness of what CGS actually is, smallholders may begin to determine the real level of infestations within their farms.

The last project (ASEM/2004/041) identified that farmers were in general unaware of the production potential of their coffee crop and associated losses. Since then smallholders with CGS problems are estimating crop losses but are more tolerant than smallholders without. This may be a result of perpetual infestations for which they do not have either the knowledge or the tools to address the problem, and become resigned to crop loss. These smallholders also consider other diseases as a real constraint to farm productivity e.g. coffee leaf rust and pink disease. Given that farmers without CGS did not perceive pests and diseases as an issue, this obviously suggests that key drivers of CGS outbreaks (and other diseases) are not present on those farms. This could be entirely due to management, but also factors identified in ASEM/2004/041 e.g. human mediated and natural pathways, the presence of local natural enemies, and invasive ant species. Invasive ant species are well known for driving scale populations and reducing natural enemies, and this project again identified these close associations with ants and CGS in EHP.

7.1 Recommendations

- Simbu and WHP should not be ignored, CGS is present but at the time of the two survey periods, CGS abundance was relatively low. Pest outbreaks can be sporadic and there is the possibility that the surveys missed peak presence / abundance in those Provinces.

- Both the abundance of CGS and potential losses were highest in EHP. The nature of the CGS problem is not uniform across EHP, and it therefore needs to be monitored. A series of farms known to have varying degrees of CGS, and those without, could be used for gauging the Provincial CGS problem through time.

- Smallholders in EHP should be a priority for increasing knowledge of CGS beyond sooty mould. Their understanding of more cryptic CGS populations within their crop will then be increased. Tools or a management strategy will need to be developed and implemented in order to address the situation.

- The issues behind the interactions of invasive ant species, natural enemies, and CGS outbreaks need to be addressed. What are the key drivers to these invasive ant species? A quantitative survey of natural enemy populations and invasive ants would be required.

- Monitor other diseases of concern to smallholders; large block holders; and processors. The impact of pink disease is of concern given that it can damage other cash crops in PNG.

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9 Appendixes

9.1 Assessing in-situ yield

In order to quantify the impact of CGS on yield, four methods were tested (see Brook et al., 2011) to estimate the various growth parameters involved in cherry production. The most accurate method was that of the Upreti *et al* (1991) and like their study this method achieved an accuracy of 93%. Here a quadrant based sampling procedure is employed which estimates the two most important components of yield, fruiting nodes/tree and fruits/node. Total cherry production from a tree is estimated by counting the total cherry from vertical quadrant of a tree (equal to one quarter of the total tree). The estimate is then multiplied by four to estimate total tree cherry production.

The method was tested across coffee blocks at Aiyura and a limited number of smallholder farms. Total measures of cherry were counted together with the sampling method (see Figure 14 and Table 6). As can be seen in Table 6, all estimates of tree characteristics were reliable achieving an accuracy of between 75% and 90%. The results of the regression analysis resulted in highly significant relationship confirming this as a reliable method.

Figure 14: Plot of fitted and observed estimates from the most accurate method trialled of various coffee tree characteristics e.g. cherry. In all cases the explanatory x axis, is total, where the total on a tree was counted and paired with the results of the estimated method, the response variable y axis = Estimated total cherry. Scattered crosses are observed data and the red line is the fitted data with 95% confidence intervals (blue line).

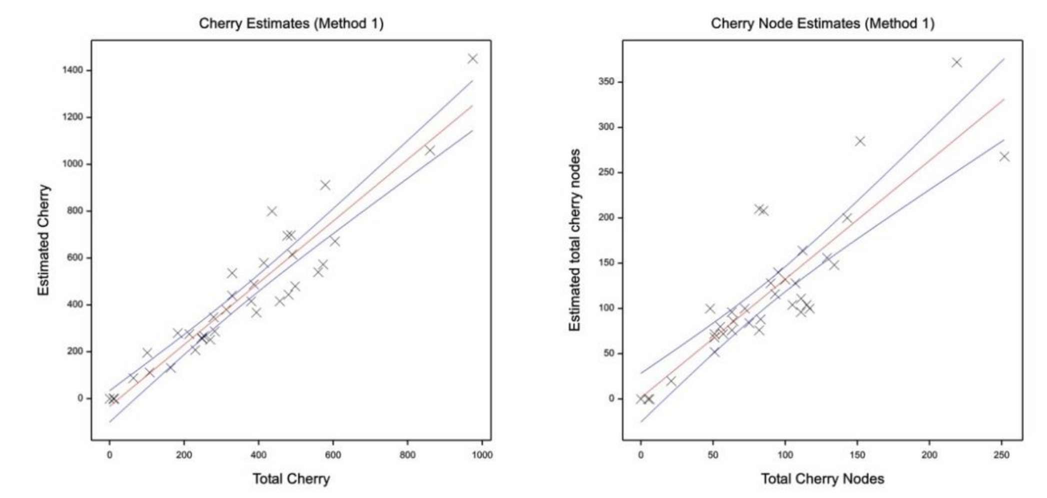


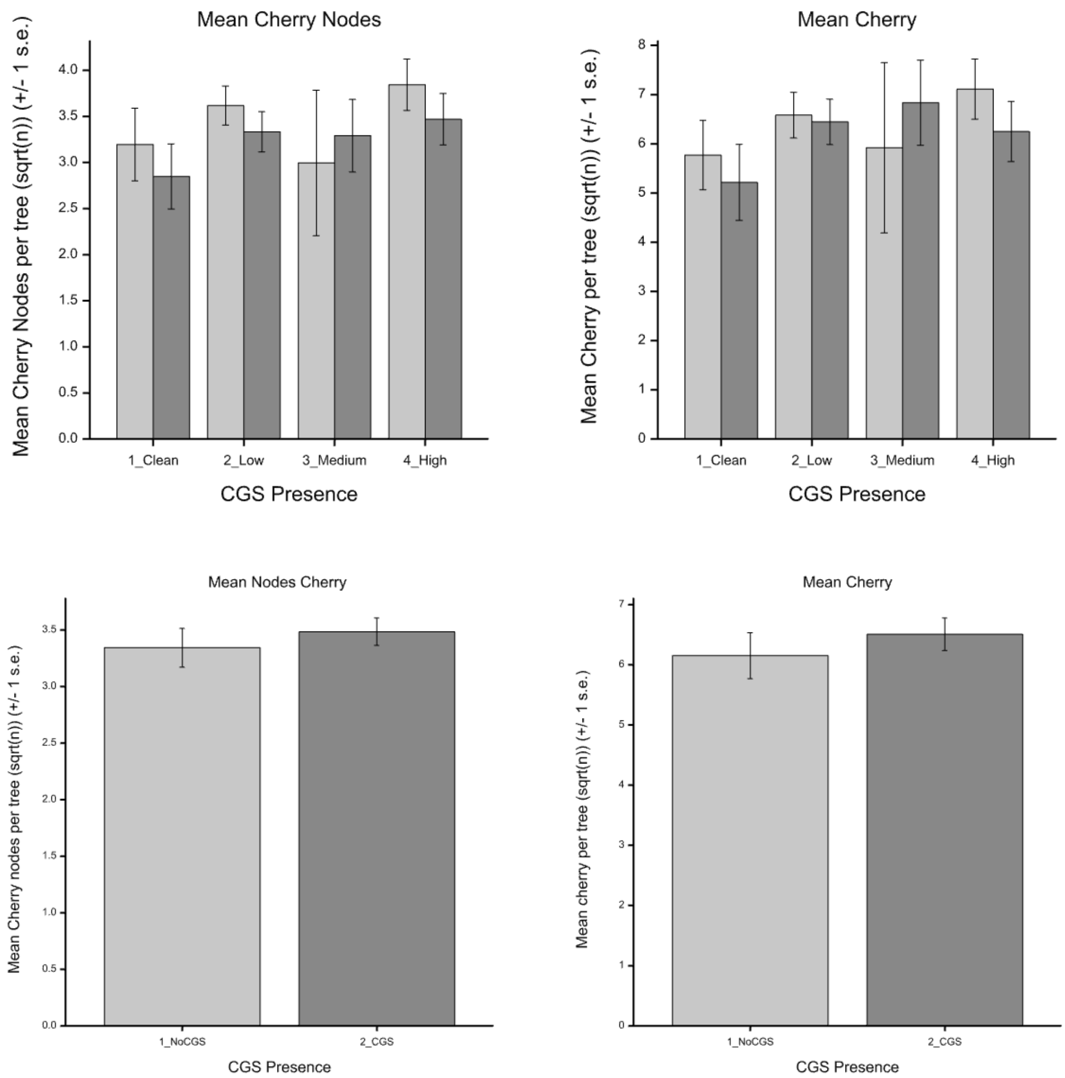
Table 6 Accuracy of cherry estimates from the chosen method (method 1) tested in coffee farms in PNG. “F value and significance” shows if the estimated method had a significant relationship with the actual total cherry on a tree. The “R2” value indicates the accuracy, and the methods are then ranked in order of their respective accuracies.

Characteristic	F-Value & Significance	Regression Line	R^2	Accuracy (ranked)
Cherry	$F_{1,34}$ = 273.14; $P <$ 0.001	y = -32.8 + 1.3174	R^2 = 0.8892	2
Cherry Nodes	$F_{1,34}$ = 103.06; $P <$ 0.001	y = 1.5 + 1.309	R^2 = 0.7519	4
Flower Nodes	$F_{1,34}$ = 202.18; $P <$ 0.001	y = 7.7 + 0.9602	R^2 = 0.8560	3
Flowers	$F_{1,8}$ = 76.34; $P <$ 0.001	y = -92 + 1.245	R^2 = 0.9051	1

9.2 Smallholder farm yield loss – year 2

There were no significant differences between the farms categorised as clean, low medium and highly infested with CGS ($F_{3,56}$=1.44; P=0.244; Figure 15). There were no interactions between late and early sampled farms ($F_{3,59}$=0.31 *P*=0.813), although it is worth noting that there were again wide variations between Districts in terms of cherry production, following the same pattern as in year 1. We detected no significant differences between smallholder farms, which might be due to the variation between farms and underlying factors that were not taken into account.

Figure 15: Year 2 results of the EHP smallholder farm cherry nodes and cherry production in EHP. Top = Farms split into varying CGS infestation levels by the median CGS infestation level on that farm. Light bars indicate those farms that were sampled on time vs. those farsm that were sampled late. Bottom: Farms categorised as without CGS (light grey) or with CGS (dark grey). Note values are standardised to numbers per m^{-3}, the scale on the Y axis = square root transformed means.



9.3 Example of Smallholder questionnaire

ACIAR Coffee Green Scale Project

Smallholder Farmers Survey

Date: Time: Interviewer: Interviewee:

Living in the same household (hh)	Husband	Wife 1	Wife 2	other	other
Name:					
Age:					
Marital Status:					
Gender:					
Education level:					
District:					
Hauslain/Village:					
Altitude:					
Coffee Holding: No. tree/no. garden/yr planted					
Newly planted (no of trees. age)					

Number of children living in household____

A. Farmers views and knowledge on CGS (Circle the correct answers)

1. Yu klia long CGS? **Are you aware of CGS?**
   Yes/No/Not sure/others (specify) ______________________________________
2. Sapos yes, au yu bin save long CGS? **If yes, how do you know about CGS?**
   Observation (ants)/extension/farmers/others (specify) ________________________________
3. Yu lukim i kamapim problem lo gaden bilong yu or nogat? **Do you see it as a problem in your coffee garden? If yes, go to Q4, if No or Not Sure, go to section B.**
   Yes/No/Not sure/others (specify)____
4. Wonem taim CGS i kamapim hevi long gaden bilong yu? **When did CGS become a problem for you?**
   What year ____
5. Dispela binatang i bagarapim bikpela kofi diwai i karim pinis cherry o nogat? **Is CGS damaging you bearing (matured) coffee trees?**
   Yes/No/Not sure/other answer (specify)
   If yes, what percentages of your mature coffee trees are damaged?____________________________
6. Where do you think it (CGS) came from? ____
7. Hamas bikpela kofi diwai insait long gaden igat planti binatang? **Estimate number of bearing trees that have CGS.**

   ____
8. Do you keep records on how much coffee you produce each year?
   a. If yes, would you be so kind to answer some short questions about it? (If no, go to section C)

B. Farmers yield

1. How many bags of cherry do you pick from each of your trees? ______________________________
2. Do you sell your coffee as;

   A) Cherry
   B) Parchment
   C) Green Bean
   D) Other- (please state) ____
3. How many bags do you usually sell during the good coffee seasons (maximum)?

   A) Cherry……………………
   B) Parchment……………..
   C) Green bean…………….
4. How many bags do you usually sell during the bad coffee seasons (minimum)?

   A) Cherry…………………
   B) Parchment…………….
   C) Green bean……………

5. What was the crop production like from 2007-2012?

- ✓ Please indicate number of parchment bags produced to compare each season's yearly production. State also the productivity for that year and reason for the production of that year.
- ✓ For 'Was this a good year' please select a response from: 'Very poor', 'Poor', 'Average', 'Good', or 'Very good'.

Year	Production (no. of bags)	Was this a good year?	Reasons
2012			
2011			
2010			
2009			
2008			
2007			

6. Hamas tru yu bin wokim lo last kofi sesan? **How much did you earn in the last coffee season, please state the price/per/kg and where it was sold (factory/roadside/others (specify)**

____

C. Farmers estimates of farm costs, income and losses due to CGS

1. Do you think CGS is having an impact on your coffee yield? How big is this impact (eg 10%... 50%... 75%?)

____

2. How low would you coffee yield (due to cgs) have to be for you to not grow coffee? (eg ¼ of current yield, half current yield, ¾ of current yield)?

____

3. In what months or season is CGS infestation level at its highest in the year?

____

   a. Have you noticed any changes in this over the years?

   ____

4. From your experience growing coffee, what is the best method of getting rid of CGS?

____

5. Is there anything else that is impacting on your coffee yield that we should know about? What is it/or what are they?

____

THANK YOU FOR YOUR TIME AND CONTRIBUTION TO THIS STUDY.

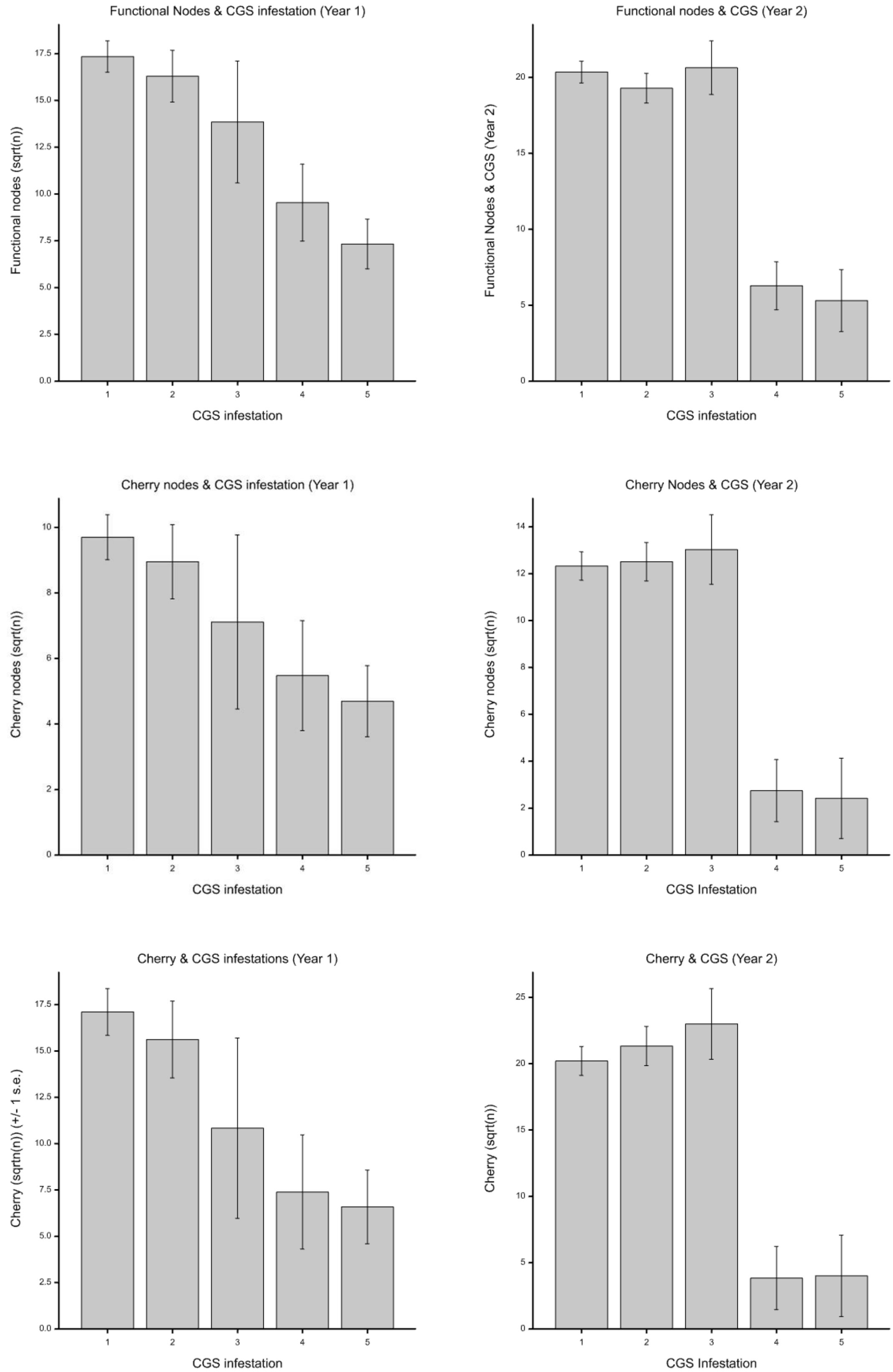
We are hoping to conduct more research into the farming of coffee in PNG by farmers such as you.

If you think you are able to help us later this year by answering a few more short questions, it would be greatly appreciated!

9.4 Activity 3 experimental block results

Means from the ANOVA conducted on the five CGS treatment levels. Treatment level 1 is complete absence of sooty mould & CGS. Treatment levels: 2 = 1-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-100%. Maximum LSD were calculated and where treatments share the same letter, no significant difference. All data is back-transformed from square root.							
		1	**2**	**3**	**4**	**5**	*ANOVA*
Functional nodes	*Year 1 mean*	301[a]	266 [a]	192 [ab]	91 [b]	54 [b]	$F_{4,59}$ = 12.04; P = <.001
	% reduction	*0*	*0*	*0*	*64*	*79*	
	Year 2	414[a]	372 [a]	426 [a]	39 [b]	28 [b]	$F_{4,48}$ = 27.05; P = <.001
	% reduction	*0*	*0*	*0*	*93*	*90*	
	Mean % reduction	0	0	0	78.5	84.5	
Cherry nodes	*Year 1*	94 [a]	80 [a]	51 [ab]	30 [b]	22 [b]	$F_{4,59}$ = 4.61; P = <.001
	% reduction	0	0	0	60	71	
	Year 2	190 [a]	187 [a]	114 [a]	7.5 [b]	5.8 [b]	$F_{4,48}$ = 18.43;4 P = <.001
	% reduction	0	0	0	95	96	
	Mean % reduction	0	0	0	77.5	83.5	
Cherry	*Year 1*	293 [a]	244 [a]	117 [ab]	55 [b]	43 [b]	$F_{4,59}$ = 6.39; P = <.001
	% reduction	0	0	0	75	80	
	Year 2	408 [a]	454 [a]	529 [a]	15 [b]	16 [b]	$F_{4,48}$ = 17.2; P = <.001
	% reduction	0	0	0	97	98	
	Mean % reduction	0	0	0	90	90	

Figure 16: Plot of treatment levels 1-5 for years 1 and 2 (left to right; top to bottom: functional nodes; cherry nodes and cherry. In year 2 a number of trees died and were excluded from the analysis probably CGS. Note the data is square root transformed. Error bars are 1.s.e.



9.5 Protocol – surveying CGS in farms

Protocol: Spot Surveys in other provinces: Assessing the incidence and infestation levels of CGS (Objective 3 Activity 6)

Context: Proposal Extract…

Objective 3: To estimate the overall loss due to CGS on total highland smallholder production.

Activity 6: Survey the incidence of CGS in other major Arabica producing Provinces.

Surveys will be conducted in other major growing provinces (i.e. Western Highlands and Simbu) to ascertain the incidence and levels of CGS infestations. This will take the form of ecological surveys using the diagonal transect method as used in ASEM/2004/047. Surveys will cover the altitudes where coffee is grown but with a special emphasis on 1500m as this is where CGS is most abundant in EHP.

This information will feed into…

Activity 7: Using the information from activities 5 and 6: estimate the overall loss and economic impact due to CGS on total smallholder production in the highlands of PNG.

9.5.1 Protocol – outline

A "W" transect method (see Figure 1) will be used to assess the incidence within a farm, and therefore provide a sample of the coffee trees present. Each of these sampled coffee trees will be assessed using the Upreti quadrant (quarter) method, and CGS infestation levels will be scored. Other factors such as number of trees, shade level, age, and other diseases will be recorded. The protocol at each farm is as follows and will record (see example recording sheet on page 4):

- Date, Altitude, Province, District, Village, Farmers Name
- Total Trees / Area of the block: i.e. an estimate of total number of trees of the small holder garden / block OR an estimate of the garden / block size in Ha. (once only, unless new trees planted / removed).
- Soil type (once only)
- Shade level: an estimate as a percentage cover
- Age OR year planted, of the garden / block being surveyed (once per small holder garden / block).
- GPS coordinates of garden / block using either longitude or latitude OR Eastings and Northings – note which system is used (once only).

9.5.2 The data recorded from each tree is as follows:

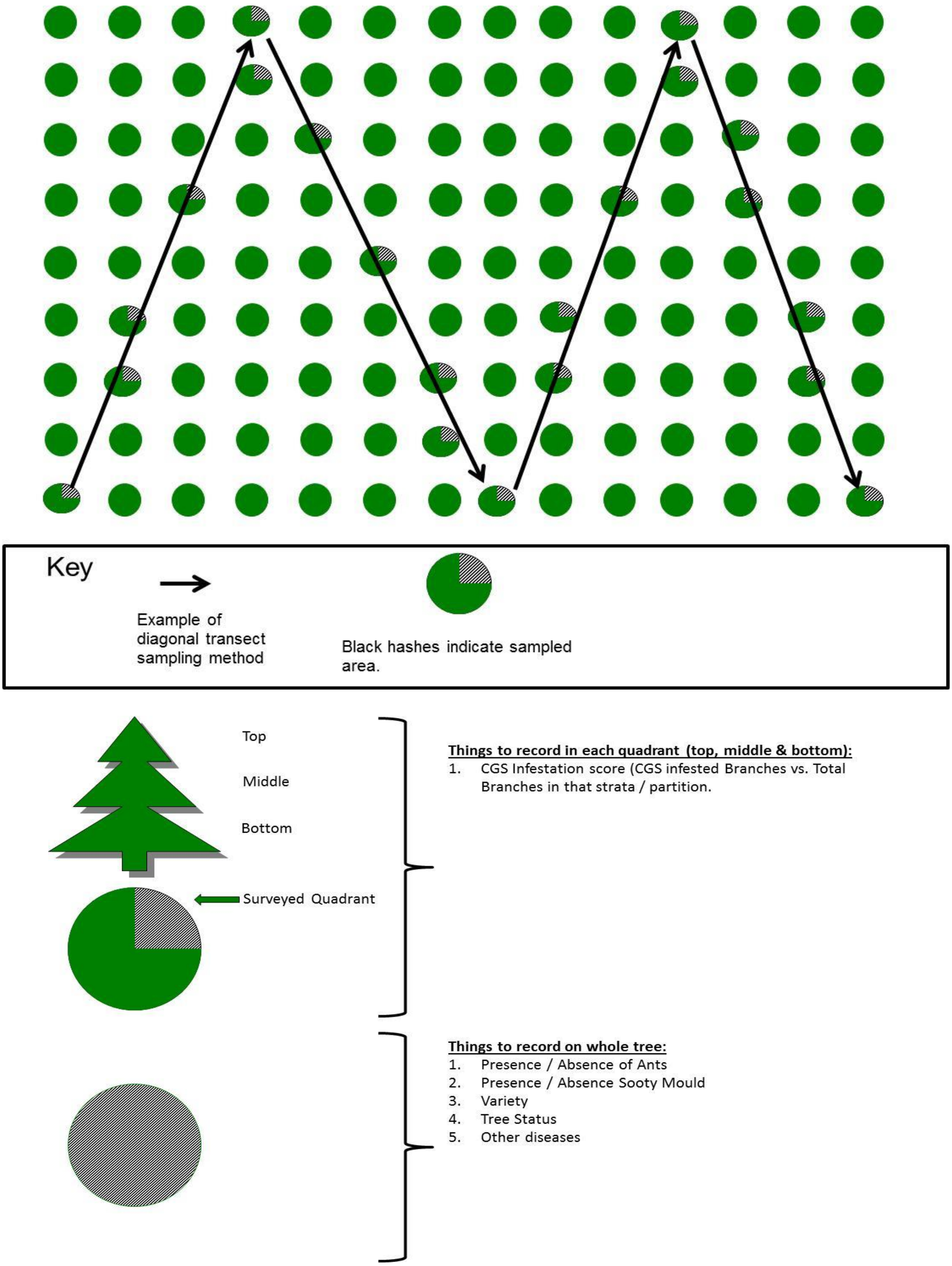
1. A "W" transect method as used in ASEM/2004/047 will be used to assess the incidence of CGS within a farm (Figure 17**Error! Reference source not found.**) [**NOTE:** this can take the form of multiple "W" zigzagging across the garden / block – the main point being to obtain a representative sample]. Then for each tree surveyed on the transect the following will be recorded:
2. Presence / Absence of ants (Y/N)
3. Presence / Absence of CGS / sooty mould in the whole quarter of each tree (Y/N)
4. CGS infestations in the quarter of each of the bottom, middle and top partitions of the canopy will be scored as number of branches with CGS versus total number of branches in that strata. This will enable a % infestation level to be calculated.
5. Variety e.g. Typica (T); Arusha (Ar); Bourbon (BB); Catimor (Catimor); Caturra (Caturra); Maragogype (Mar); Mundo Novo (MN).
6. Status of tree scored 1 – 5: 1 = No defoliation; 2 = Defoliation WITH regrowth; 3 = Defoliation NO regrowth; 4 = Defoliated completely; 5 = Defoliated & dry cherry (die back).
7. Any other diseases on the tree should be noted e.g.; Pink disease (PD); coffee leaf rust (CLR).

9.5.3 Assessing CGS infestation levels - details

1. The total number of branches (both CGS and non CGS infested) are counted in each of the Top, Middle & Bottom partitions of the canopy.
2. In order to estimate the infestation levels the total number branches within each layer the total number of CGS infested branches is counted e.g.
    a. A quarter of a tree might have 12 branches so dividing this by 3 (the number of partitions in the canopy) = 4
    b. Therefore if 1 branch is infested in the top partition, then a score of "1 out of 4" is given; noted as "1 / 4" . Conversely if 4 branches are infested then a score of "4 out of 4" is given; noted as "4 / 4".
    c. It is important to remember that the first number is the number of CGS infested branches and the second is the total number of branches in those strata.
    d. This is completed for each of the partitions, top middle and bottom.

Once the data is entered into Excel a % infestation level will be calculated which will be akin to the scoring from 0 – 4: 0 = (no CGS or sooty mould); 1 = (1 – 25% of laterals with CGS); 2 = (26 – 50% of laterals with CGS); 3 = (51 – 75% of laterals with CGS); 4 = (76 – 100% of laterals with CGS).

Figure 17: Vertical diagram of a coffee block with coffee trees represented by circles. Trees with hashed quadrants are those that are sampled. Black arrows represent a hypothetical path of the diagonal transect to assess overall incidence of CGS. **<u>NOTE:</u> this can take the form of multiple "W" zigzagging across the garden / block – the main point being to obtain a representative sample.**



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ASEM/2010/051 Spot Survey Recording Sheet (Objective 3 Activity 6)

Survey ID:	GPS:	Latitude / Easting	Longnitude / Northing
Date:			
Farmers Name:		Altitude:	
Province:		Total Trees / Area of block:	
District:		Age / Year Planted:	
Village:		Shade Level:	
		Soil Type:	

			CGS Branches / Total Branches					
Tree No.	Ants (Y/N)	Sooty Mould (Y/N)	Bottom	Middle	Top	Variety	Tree Status (1,2,3,4,5)	Other diseases
1			/	/	/			
2			/	/	/			
3			/	/	/			
4			/	/	/			
5			/	/	/			
6			/	/	/			
7			/	/	/			
8			/	/	/			
9			/	/	/			
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30			/	/	/			
31			/	/	/			
32			/	/	/			
33			/	/	/			

Tree Status:

1 = No defoliation
2 = Defoliation WITH regrowth
3 = Defoliation NO regrowth
4 = Defoliated completely
5 = Defoliated dry cherry (die back)