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Comparison of EIQ and PRIMET models to assess the impact of pesticide use of smallholder cocoa production in western Ghana.

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Master of Science in Ecology

Dedication

This work is dedicated to the family of Ruth and William Paintsil.

The unfathomable love and care you showed me and the interest you showed in my studies gave me the push I needed to finish my studies. May God's blessings continue to abound in your life.

Acknowledgements

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Abstract

Risk assessments of agricultural systems in Ghana are often performed to ascertain the level of risk posed by agrochemicals released during application. In this thesis two risk assessment models EIQ and PRIMET are compared to determine which of them predicts risk to the consumer, farmer and, the environment. A second part of the study involved the administering of a structured questionnaire to 75 farmers to obtain pesticide usage data and perceptions of safe pesticide usage. The general objective was to calculate the level of risk posed because of chemical usage to the three compartments mentioned above. The farmer survey revealed that cocoa farmers used both registered and unapproved chemicals on their farms. Many of them partially wore protective equipment during application which can be viewed as a major health concern. Chronic pesticide poisoning symptoms reported showed varying PPE usage. This was again supported by a high number of the respondents experiencing head aches and burning sensations in the face after chemical application. Storage of procured pesticides in living houses was another surprising result given the magnitude of publications on food poisoning of farmers due to this storage choice. Almost all farmers failed to perform an assessment of pest status of farm before chemical application. In conclusion, the level of understanding of harm posed by pesticides is low and more education on this matter must be carried out in these farming communities.

List of acronymns

COCOBOD – Ghana Cocoa Board

CRIG – Cocoa Research Institute of Ghana

CSSV – Cocoa Swollen Shoot Virus

ETR – Estimated Toxicity Ratio

EIQ – Environmental Impact Quotient

EYP – Environmental Yardstick of Pesticides

MSDS – Material safety data sheets

PEC – Predicted Environmental Concentration

PNEC – Predicted No Environmental Concentration

PPDB – Pesticide Properties DataBase

PRIMET – Pesticide Risks in the tropics to Man, Environment, and Trade

PPE – Personal protective equipment

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1 Introduction

The Ghanaian agricultural sector contributes a large quota of the gross domestic product (GDP), employment and foreign exchange earnings, hence its accepted classification as an agricultural economy (Dawoe et al. 2014). Cocoa (*Theobroma cocoa*) is one of the farm cash crops that contribute to the Ghanaian foreign exchange, and Cocoa production has been an important part of economic growth in Ghana for many years. It falls behind only coffee and sugar to be the third globally exported commodity in the world (FAO 2003). Western Africa produces more than half of global cocoa, with Ghana and Cote d'Ivoire at the forefront of production (Paintsil 2016). Ghana is second only to the Cote d'Ivoire regarding world production, and virtually all beans produced in both countries is made up of "bulk" or "ordinary" beans (ICCO 2007). Nigeria and Cameroon complete the West African contingent. Other cocoa producing African nations include Uganda, Tanzania, Madagascar, Equatorial Guinea, and Sao Tome & Principe.

Cocoa agroforestry has been in existence for some time now, the additional benefit of carbon capture from this form of tree crop farming where non-cocoa trees provide shade for cocoa seedlings has stirred up interest from conservationists (Mohammed et al. 2016). Tropical conservationists and biodiversity enthusiasts welcomed empirical evidence which suggested claims that agricultural plantations in general (and cocoa plantations in this case) played a major role in biodiversity protection. Greenberg et al. (1998) exemplify this, using the pink-legged graveteiro (*Acrobatornis fonsecai*) which was discovered in the Brazilian cocoa plantations. It is a bird which is endemic to this region; foraging almost entirely on tall trees shading cocoa plantations.

These complex agricultural landscapes have undergone crop intensification through the introduction of sun loving varieties at the expense of shade loving ones. Monoculture plantations arise from this agricultural intensification. Agroecosystems with low species diversity have been known to be more susceptible to pest attacks, and cocoa monocultures are not an exception (Toana et al. 2014). A higher incidence and degree of pest infestations has been identified to be as a result of the increasing homogeneity in these newly created landscapes(Altieri & Nicholls 2004).

Many pests and diseases attack cocoa (Antwi-Agyakwa 2013; Dzahini-Obiatey et al. 2010; Ntiamoah & Afrane 2009). Losses attributed to pests and diseases have been estimated to be between 30% - 40% of world production (Bos, M. M. et al. 2007; Hebbar 2007). The introduction of pesticides on farm systems is the most frequented approach to control pests.

Pesticides are chemicals or mixtures of chemicals produced for preventing, repelling, destroying, or mitigating any unwanted living organisms. Their presence at any detectable range raises concerns mainly because they do not occur naturally in the environment (Walker et al. 2012). Pesticide application in modern agriculture often involves the use of several pesticides at the same time; these mixtures may behave differently in the environment than individually (Walker et al. 2012). Pesticides use can cause undesirable effects on those applying it (farmers), consumers, and the entire environment (including non-target species). Nevertheless, a cost-benefit analysis almost always favours their use to prevent damage of potential harvest worth millions of dollars (Pimentel et al. 1992).

The proportion of pesticides reaching the target organisms has been found to be less than 0.3%, which suggests the 99.7% remaining can be considered to be redundant (Van der Werf 1996), potentially, resulting in undesirable adverse effects on other species, communities, and the ecosystem. Different pesticides currently available to farmers pose varying levels of risk from low risk to substantial levels of harm (Van der Werf 1996; Walker et al. 2012).

Expected yield is hampered on a seasonal basis by plant pests (Toana et al. 2014). Non-target arthropods are often at the mercy of these chemicals which are not necessarily applied to exterminate them, coming with the consequence of depriving these landscapes of ecosystem services (Toana et al. 2014). Some ecosystem services provided by these arthropods include pollination, seed dispersal and pest and disease control (Vaast & Somarriba 2014). Altieri and Nicholls (2004) reported that in 1995 alone about 2.1 million kilogrammes of pesticides were applied worldwide in pest control.

1.1 General objective

Farmers, consumers, and the ecology of the agroecological zone under study are at risk of pesticide pollution due to the high frequency of application of pesticides in the Bodi district of the Western Region of Ghana.

The aim of this study was to ascertain the level of good agricultural practices knowledge of farmers, and use of this knowledge to calculate the risk of application of chemicals throughout the season to applicators, and the environment. A comparative analysis of the results from EIQ and PRIMET is then performed to identify the least cumbersome and most accurate indicator model.

1.1.1 Research questions

This thesis set out to delineate the level of understanding of pesticide toxicology farmers in the three communities have and further make predictions based on pesticide usage data collected in questionnaires using two risk indicator models. In line with the aim above the following research questions were formulated:

1. What are the socio-economic characteristics of the sampled smallholder cocoa farmers in the study area?
2. What factors are influencing smallholder farmer's decisions to use agrochemical inputs in the study area?
3. What is the level of risk farmers and applicators are faced with seasonally on their farms?
4. What is the current level of Personal Protective Equipment (PPE) usage by the farmers and applicators and to what degree are they adhering to prescribed manufacturer doses?
5. What are the different types of pesticides applied, their sources, application regimes currently employed and the source of implementation knowledge?

Which of the two models gives a better estimate of the level of risk of harm to environment, consumer and farm applicator (comparison of model values).

1.2 Background: The Ghanaian cocoa framework

The Ghanaian cocoa process is overwhelmingly in the hands of small family farmers often referred to as smallholder farmers, meaning the cocoa farm is owned and maintained by them. The main source of labour for this farming system is family members. Many other African agricultural export products (tea, tobacco, and fruits) tend to be produced on larger commercial plantations with a relatively higher number of working farm hands. The cocoa production systems are labour intensive, and the Ghanaian case is no different. Farm activity fluctuates over the year with the main peak season occurring within the months of September and October. Harvesting of ripe crops dominate tasks undertaken during this period. A healthy tree has an average economic life of 25-30 years (figure 1) (Ntiamoah & Afrane 2009).

I will now enumerate the different tasks undertaken during the entire season (Figure 2). Weeding of the farm is undertaken twice a year typically, first in May/June and again before the harvest season in September/ October. Farm tool used is a cutlass or machete, after which the debris is carried out of the farm. Farm upkeep follows, this involves the trimming of cocoa shoots and regulation of shade canopy since a dense undergrowth increases the risk of fungal infections on crops. Removal of disease pods from trees and the farm is another good farming practice carried out for upkeep.

Figure 1 A cocoa tree crop with ripe pods ready for harvest

The production stage under review in this thesis is the agrochemical application stage (fertilisers and pesticides). The heavy incidence of farm pests and diseases necessitates the administering of chemicals for control to improve yield. Harvest season which is one of the more labour intensives on the farm follows. Here the ripe pods are cut off using a machete or a cutlass. Experience is a vital asset at this stage since it helps differentiate between ripe and unripe pods. The ripe pods are then gathered and transported to a central location often within or at the edge of the farm. The pods are then broken with a machete and prepared for the fermentation process by separating the wet beans from the mucilage of the pod. Fermentation takes between 4 to 7 days depending on the producer. A 48-hour mixing regime is employed to ensure proper fermentation. Drying in the sun on makeshift drying beds (made from bamboo) follows. The beans are regularly stirred to ensure even drying after which they are cleaned and packed in jute bags and sent to weighing centres to be sold to intermediaries (Produce buying company, Morgan agro Ltd, TF premio commodities Ghana Ltd and farmer co-operatives societies). After intermediaries have purchased the unprocessed beans, they transport them to be sold to exporters. Grinding companies most of which are in the global north initiate the processing stage to add value to the beans. The beans are crushed and the shells are removed, roasted, and then ground. The product of this process is the cocoa liquor which is used in the manufacture of chocolate or further processed into cocoa butter and cocoa powder (for making beverages). It is beyond the scope of this study to present all the processes involved during the processing stage.

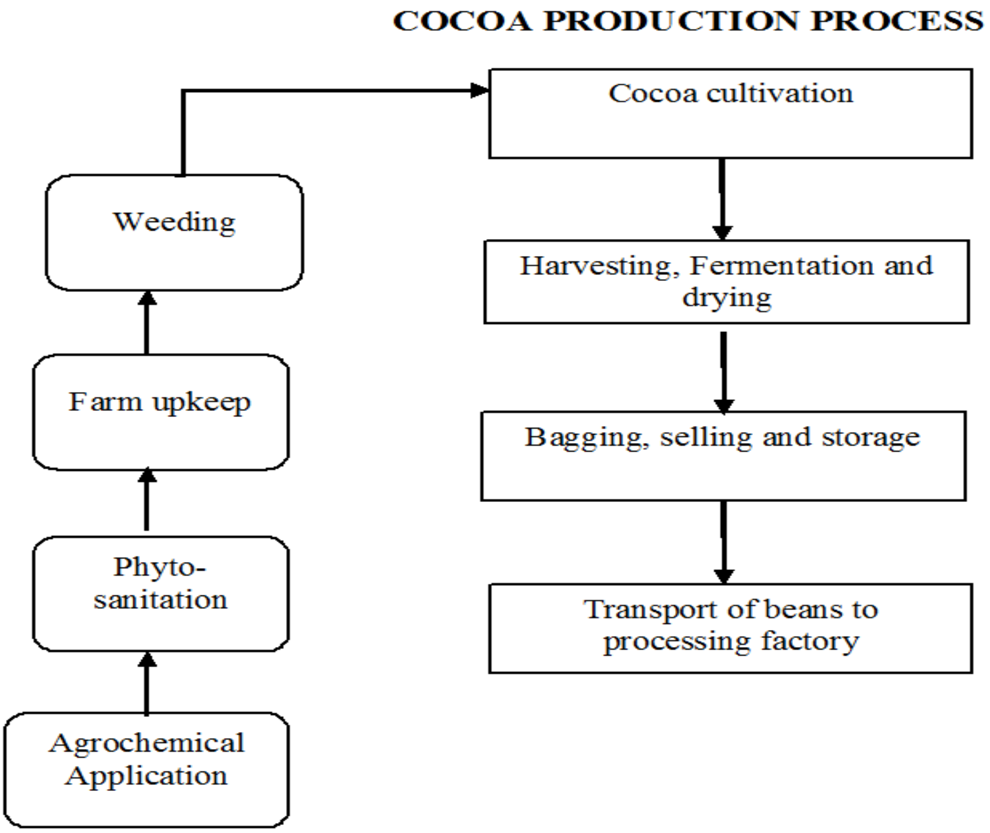

Figure 2 Stages involved in the production of cocoa; modified after (Ntiamoah & Afrane 2009)

1.3 Pesticide usage in cocoa farming areas

Since the early 2000's, there has been a considerable increase in the levels of pesticides used in Ghana, owing to the government of Ghana embarking on a pesticide spraying project through its Ministry of Agriculture. Growth rates were expected to take a nose dive due to the anticipated increase in the outbreak of diseases such as black pod *(Phytophthora megakarya)*, cocoa swollen shoot virus (CSSV) and outbreaks of mirid insects (*Distantiella Theobroma* and *Sahlbergella singularis*) (FAO 2003). In the year 2001, the government of Ghana embarked on a raid against pests and pathogens purported to affect its position as the world number two producer of cocoa (Ntiamoah & Afrane 2009). As a remedial measure, the government under the auspices of the Cocoa Research Institute of Ghana (CRIG) undertook a mass spraying program known as the Cocoa Diseases and Pests Control Programme (CODAPEC). This extensive program was in the form of a mass spraying of cocoa farms with pesticides by gangs of applicators trained and paid by the Ghana Cocoa Board (COCOBOD). In the words of Dzahini-Obiatey et al. (2010) "this control method has been considered the most ambitious and costliest eradication campaign to control a plant viral disease" in the case of Cocoa swollen shoot virus (CSSV). In recent times the government procures the pesticides and distributes to farmers to carry out spraying on individual farms (a detailed list of pesticides is shown in table 1). Ntiamoah and Afrane (2009) conducted a life cycle assessment of the production of cocoa and identified the cultivation stage to be the stage with the largest environmental footprint. Human toxicity received a high value in their study which they attributed to the high inputs of pesticides into the system. The highest chemical input in the production of 1kg of cocoa is from pesticides (Ntiamoah & Afrane 2009). Several studies carried out in Ghana analyse doses already released into the environment, in soil, groundwater or in the aquatic environment and in cocoa pod to quantify the environmental impact of their use (Fosu-Mensah et al. 2016; Frimpong et al. 2012a; Frimpong et al. 2012b; Okoffo 2015; Okoffo et al. 2017).

1.4 Factors that affect the productivity of Cocoa in Ghana

1.4.1 Pests and diseases of the cocoa farm

There are several pests and diseases insect species that both nest and forage on cocoa (Room 1971) (refer to table 2), however, there are many other species important for the functioning of the ecosystem.

1.4.2 Socioeconomic factors

Factors that proximately affect cocoa productivity in Ghana include; rural-urban migration of many youths who will otherwise work as farm labourers, high prices of inputs and availability on a sustainable basis, and farmer priorities. Educational level and capacities to incorporate research recommendations into pest management strategy, poor social circumstances of farmers and lack of workable credit and loan facilities (Dormon et al. 2004). The poor road networks in the area also contribute to productivity. Low producer price was identified in a study by Padi and Owusu (1998) as the single socioeconomic factor all farmers agree affects their ability to hire labour as well as purchase farm input. The concomitant effect of a lack of purchasing power indirectly impacts productivity.

Table 1 List of pesticides in use by cocoa farmers with their registration status. NOTE: FRE=Fully registered list, UNREG=Unregistered

Pesticide used	Active ingredient	Method of application	Recommrnded Frequency	Registration status	Recommended dosage
Fungicides					
Ridomil 72 plus WP	60% cuprous hydroxide			FRE	50g/15L
Nordox 75 WP	86% Cuprous hydroxide			FRE	50g/15L
Funguran OH WP	70 % Cuprous hydroxide	Knapsack sprayer	Eight times during each cocoa season	FRE	50g/15L
Champion WP	77% Cuprous hydroxide			FRE	100g/15L
Kocide 101 WP	60% Cuprous Hydroxide			FRE	100g/15L
Insecticides					
Akate master	27 % Bifenthrin			FRE	100mls/11L
Akate power	20% Thiamethoxam			FRE	20mls/11L
Confidor	20% Imidacloprid			FRE	30mls/11L
Condifor	30% Imidacloprid	Motorised mistblower	Four times during each season	UNREG	30mls/11L
Akate suro	50% Diazinon			FRE	30mls/11L
Actara	24% Thiamethoxam			FRE	20mls/11L
Pridapod	20% Imidacloprid			FRE	30mls/11L

1.5 Risk assessment models

Risk assessment indicators measure or give an estimate of the changes in the environment which are induced by anthropogenic activities. These activities could be in the form of pesticide application to control pests. Risk indicators combine several methods with the goal of assessing pesticide impacts (Levitan 1997). Methods involved in simulating environmental effects include using already defined models, sampling, monitoring, and identifying long-term changes in species diversity. A good pesticide assessment tool is required to meet certain criteria: (1) Provide farmers with necessary information to make informed decisions with regards to pest management choices (Eklo et al. 2003), (2) serve as a green labelling or "ecological-labelling"

Table 2 List of pests and diseases affecting cocoa production in Ghana and the level of harm they pose

Common Name (Local Name)	Scientific name	Degree of incidence
Insects		
Capsid (Akate)	*Distantiella theobroma* (Dist.)	Major
Capsid (Akate)	*Sahlbergella singularis* Hagl	Major
Stink bugs or shiled bugs (Atsee)	*Bathycoelia thalassina*	Major
Mealy bugs	*Planococcoides njalensis* (Laing)	Major
Mealy bugs	*Ferrisia virgate* (Ckll)	Minor
Stem borer	*Eulophonotus mymeleon* Fldr.	Minor
Termites	*Macrotermes*	
Coreid bug	Pseudotheraptus devastans	Minor
Fungi		
Black pod	*Phytophthora megakarya*	Major
Virus		
Cocoa swollen shoot virus	Cocoa swollen shoot virus	Major
Parasitic plants (weeds)		
Mistletoe	*Tapinanthus bangwensis*	Major
Rodents and other vertebrates		
Rats		Minor
Squirrels		Minor

system which influences market patterns and consumer behaviour (Levitan 1997; Levitan 2000), and finally, (3) serve as a research tool for academic research in government and private research institutions which feeds back into policy-making frameworks at government level (Levitan 1997; Levitan 2000). Several assessment tools have been developed to measure environmental and health risks; some of which include the Environmental Yardstick of Pesticides (EYP), the GIS-based SYNOPS, Pesticides Environmental Impact Indicator (Ipest), Environmental performance indicator for pesticides (p-EMA), Pesticide risks to Man, Environment and Trade (PRIMET) and the Environmental Impact Quotient model (EIQ). Existing indicators vary in their purposes for development, from supporting farmers, extension service officers, food industry and finally policy makers (Reus et al. 2002). Differences in the scale of assessment also influence the choice of tools; focusing on which pesticide, measuring on a crop by crop basis, considering an entire farm as the study system, focusing on entire regions or country (Levitan 1997).

EIQ has been selected due to its proven track record in Africa and Asia as a good indicator model. Several Ethiopian, Vietnamese, Peruvian and Chinese agricultural systems have been studied using the model with varying levels of success (Ayano-Negawo 2016; Eklo et al. 2003; Kniss & Coburn 2015). This reveals its adaptability to tropical systems despite its initial design for fruit and vegetable farmers in New York State. PRIMET on the other hand is used in this study because it was designed specifically with the tropical environment in mind. This is evident in the regions with published research using this model (South Africa and Ethiopia) (Ansara-Ross et al. 2008; Peeters et al. 2008; Van den Brink et al. 2005; Van der Werf 1996). Specific climatic conditions are included in input data requirements, and this produces output with local significance.

EIQ and PRIMET models selected to be used in this thesis will generate output that helps farmers adjust and select the pesticides which have a lower environmental load, hence preventing the release of highly toxic chemicals into the environment in the first place. Therefore, it looks at introducing the concept of proactive environmental stewardship on the part of farmers through the better dissemination of lowest environmental load pesticide combinations. It is the first time in Ghana a risk assessment model will be used to predict levels of risk posed by agrochemical use in cocoa production. There is the need to provide organised information in a form that can be usable to make informed and environmentally sound pest management decisions.

2 Methods

2.1 Study site

The study was conducted in the western region of Ghana (see Figure 3) which has an approximate land cover of 23,921 km^2, constituting about 10% of Ghana's total land mass and 10% of its human resource. The region receives the highest amount of precipitation nationwide and has almost 75% of its vegetation interspersed with the high forest zone of Ghana. As much as 44% of the total closed forest of the country is located within this region, hence, its high relevance when biodiversity and conservation are being considered.

The Bodi District is one of 22 districts in the Western Region of Ghana (see Figure 3). It is located between latitude 60 6 `N and 70 0` N, and longitude 20 40 `W and 30 15 `W. The district is in the northern part of the region, has Sefwi Bodi as its district capital and shares borders with Juaboso District to the north, Sefwi Wiaiso District to the west, and Sefwi Akontombra to the south. The total land size of the district is estimated to be about 662 km^2.

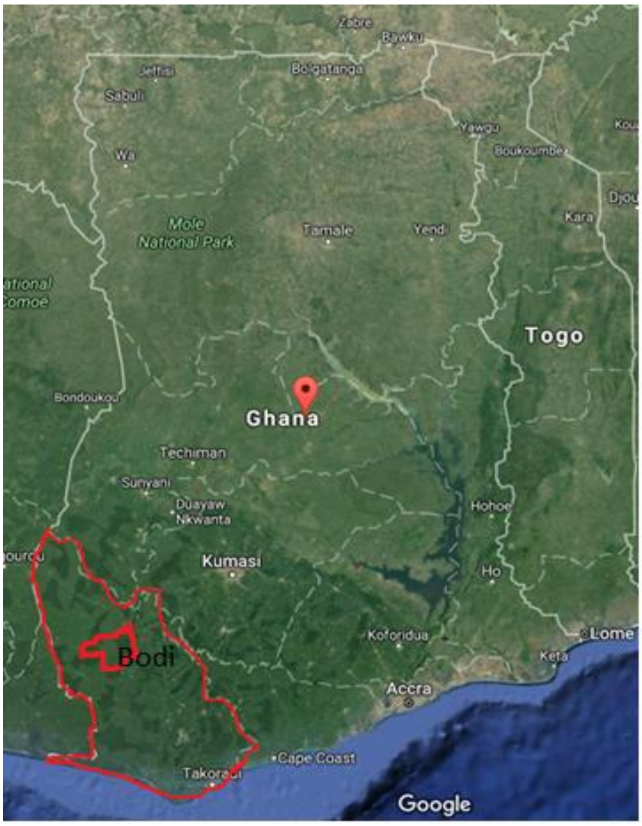

Figure 3 Map of Ghana with red highlighted area representing the western region; Source: Google earth 2017

2.1.1 Climate

The Bodi district falls within the country's wet semi-equatorial climatic zone with high temperatures throughout the year between 25˚ C, and 30˚ C. Rainfall is between 1250 mm – 2000 mm per annum with double maxima peaks in May – June and September – October. The climate of this area is characterised by two main seasons; a short relatively dry season followed by two wet seasons. The rainy season falls between April and October, this relatively long wet season with abundant rains provides the conditions adequate for food and cash crop cultivation. The relative humidity recorded in this region is 90% at night and 75% during the day. Relatively low humidity is characteristic of the dry season which is roughly between November and March.

2.1.2 Topography

The district constitutes the country's dissected plateau which has isolated hills ranging between 300 and 390 metres above sea level. Low lying areas accompany this topographic feature, mainly valleys which accommodate the main rivers and streams. The district is endowed with several rivers and streams (e.g. Bia and Sui rivers). The Bia basin is made up of many tributaries which depict a dendritic pattern.

2.1.3 Vegetation

The vegetative cover of the district is a moist semi-deciduous forest type with a three-canopy layer. The vegetation in the district has a high species richness. Some of the most important species include; Esa (*Celtis mildbraedii*), Wawa (*Triplochiton scleroxylon*), Ofram (*Terminalia superba*), Edinam (*Entandrophragma angolense*), Onyina (*Ceiba pentandra*), kyenkyen (*Antiaris toxicaria*), and Odum (*Milicia excelsa*).

2.2 Data collection

2.2.1Sample selection

The study population was small-holder cocoa farmers of the Bodi district. Through interaction with the Agricultural Extension Service department of the Ministry of Food and Agriculture (MOFA) and the regional directorate of the Cocoa Health Extension Division (CHED) of the Ghana Cocoa Board (COCOBOD), information pertaining to the most important cocoa growing areas in the district was obtained. This information provided guidance in preparing the sampling plan. A number of suggestions were made, however, three communities were selected based on (1) closeness to forest reserves, (2) proximity to water bodies in the catchment and (3) level of engagement in cocoa production by inhabitants. Hence, a purposive sampling approach was used to pick the three communities (Community 1, community 2 and community 3) (see Figure 4) to be studied. Radom sampling was employed in making farm household selections. Seventy-five individuals from all selected communities were administered with questionnaires in a structured interview design, which were conducted between July and August 2016. It is worth mentioning that there was no non-response bias, as all farmers approached consented to be part of the research work.

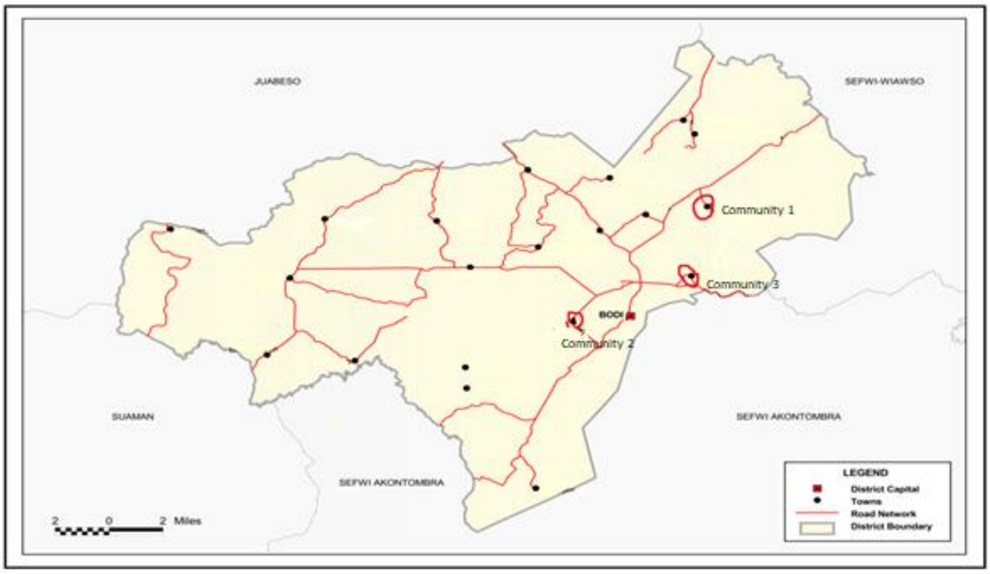

Figure 4 District map of Bodi; Source: Ghana statistical service, GIS

Two research assistants were recruited and trained to help interview the respondents and administer the questionnaires. These assistants were both males, who are employed by the Agricultural Extension Service department of the Ministry of Food and Agriculture and the Cocoa Health Extension Division (CHED) of the Ghana Cocoa Board (COCOBOD). They both held degrees in Agricultural Sciences and had a good knowledge of the geography and culture of the area having worked there for an extended period. Respondents who could read and write were provided with the document and allowed to fill out, while those who were illiterate or had difficulty in completing were assisted through an interview. Interviews were mostly conducted in the local dialect (Twi) at weighing centres, with a few of them held in farmer's homes or on their farms to make certain observations. Each interview lasted approximately 45 minutes, on average. The incidence of biased responses was reduced by interviewers making sure they avoided leading the interviewees or signalling preferred answers (Alemagi et al. 2015).

2.2.2 Questionnaire design

A structured questionnaire modified after Ayano-Negawo (2016) was pretested in the three communities (see Figure 4) studied in the Bodi district and used as the instrument for the study. The structure of the questionnaire used during data collection constituted close- ended, open-ended and partially closed ended questions. The design of questionnaire consisted of 5 main parts. Part A considered the demographics and form related characteristics namely sex, age, occupation, education level, household size, the number of household members below the age of 18, the age of farm and size of the farm. Part B consisted of information related to knowledge of pesticides, names of pesticides known, forbidden pesticides known, knowledge of routes of exposure and transfer in the environment. Part C involved information on the pesticide use patterns (a table containing pesticide name, active ingredient, amount per application per area, application interval and application equipment; this information was complemented with information on pesticide properties and reference values from databases associated with models), the reason for using pesticides, the source of pesticides used, common crop pests and diseases, types of pesticides used, the source of knowledge of the application, factors that influence application times. The fourth section Part D involved close-ended questions on the Likert scale considering their attitudes towards pesticide use and whether they agreed or disagreed with the some issues. These included; having adequate knowledge before handling chemicals is necessary, health risks associated with chemical use are minimal, precautions must be adhered to during pesticide application, chemicals help secure good crops, chemical use should be limited to safeguard the environment.

Finally, Part E involved protective measures adopted during pesticide application. Observations were also made on selected farmer fields for pests and disease incidence and severity. Again, the quantities of pesticides they administered and the intervals were recorded, reasons why the applied chemicals on farms as well as what influenced spraying periods were collected.

2.2.3 EIQ (The Environmental Impact Quotient)

The Environmental Impact Quotient (EIQ) (Kovach et al. 1992) was used to assess the environmental impact of pesticides used by cocoa farmers in a growing season. Individual farmer application information collected in the questionnaires in tandem with required information on pesticide data sheets were used in calculations.

The Environmental Impact Quotient value is the average of the farm worker, consumer, and ecological components. The equations of the different components are given as (variables explained in Table 3 *Symbols for variables in equations*):

$EI_{farmworker} = C[(DT * 5) + (DT * P)$ …………………………..…(equation 1)

$EI_{consumer} = (C * ((S + P)/2 * SY) + (L)$ …………………….…….(equation 2)

$EI_{ecology} = (F * R) + (D * ((S + P/2) * 3 + (B * P * 5)$ ………(equation 3)

The whole equation is written as shown in equation 4 (refer to Table 3 Symbols for variables in equations):

$$EIQ = \{[C(DT * 5) + (DT * P)] + [(C * ((S + P)/2 * SY) + (L)] + [(F * R) + (D * ((S + P/2) * 3 + (B * P * 5)]\}/3$$ ………………..(equation 4)

Table 3 Symbols for variables in equations

DT = dermal toxicity	D = bird toxicity
C = chronic toxicity	S = soil half-life
SY = Mode of action	Z = bee toxicity
F = fish toxicity	B = beneficial arthropod toxicity
L = leaching potential	P = plant surface half-life
R = surface loss potential	

EIQ Field use rating is employed to provide an accurate comparison of pesticides and pest management strategies. To be able to arrive at this end point, information on the dose, formulation or percentage of active ingredient and the frequency of application need to be delimited. Difficulties often arise when different formulations of the same active ingredient are being considered. Kovach et al. (1992) developed the EIQ Field use rating (EIQ F. U.) to account for any differences. This equation is given as shown in equation 5:

EIQ F. U. = $EIQ * \%\text{ active ingredient (AI)} * \text{application rate (R) kg/ha}$ …..(equation 5)

Total impacts from all pesticides applied in a growing season can be estimated by summing up the product of individual EIQ Field use rating and application frequency, using the equation below in equations 6 and 7:

Field Total EI = $\sum[\text{EIQ F.U.} * Application\ frequency]$ ………..…………..(equation 6)

Field Total EI = $\sum[\text{EIQ} * \%\text{active ingredient (AI)} * \text{application rate } (R) * Application\ frequency]$ ……………………………………………….…....(equation 7)

In this thesis, all calculations of the Environmental Impact Quotient model were done using Cornell University’s online EIQ calculator (Eshenaur et al. 2015). Input needed to run this calculator include. %AI, application rate and application intervals. All reference values required for EIQ calculations are listed in Appendix 2.

Calculations of Field Total Environmental impact (Field Total EI) makes it possible to rapidly make projections of the likely impact pest management programs will have in a system or the environment culminating in the selection of sustainable programs which are environmentally friendly (Kovach et al. 1992). These calculations provide lasting solutions which do not completely put a stop to the use of these chemicals but eventually lead to a reduction in environmental footprint.

2.2.4 PRIMET (Pesticide Risks in the Tropics to Man, Environment, and Trade)

PRIMET (Pesticide Risks in the Tropics to Man, Environment, and Trade) is a decision support system developed for use initially in the South-eastern part of Asia (Ansara-Ross et al. 2008; Bos, M. G. et al. 2007; Van den Brink et al. 2005). The first version was used in Sri Lanka and Thailand to estimate risks of pesticide application to terrestrial life, aquatic life dietary exposure and groundwater used as drinking water. The latest version (PRIMET version 3) was used for ETR calculations in this thesis. The PRIMET Decision support system uses defined scenarios based on a combination of pesticide exposure assessment and risk assessment. Its main aim is to serve as a tool that can aid agriculturalists to make informed decisions on their chemical usage patterns. Often with the result of helping choose an application regime which has the lowest negative environmental load.

This model has a temperature-dependent assessment of exposure incorporated into it which allows users to tune temperature to local conditions (Peeters et al. 2008). This makes it applicable in warmer climates, especially developing countries. A worst-case scenario risk assessment is calculated based on minimum input data. The input variables needed to run this model include; basic pesticide properties and parameters that describe pesticide use on pesticide application information from farms being investigated. Application scheme information relevant for calculations include; number of applications, the individual dosage/ concentration, and the time interval between applications. Material safety data sheets (MSDS) and label assays provided information on percentage of active ingredients in the pesticides used by farmers. The pesticide characteristics data required to run this model were extracted from Pesticide Properties DataBase (PPDB) of the University of Hertfordshire.

The output generated by this model is expressed in an Exposure Toxicity Ratio (ETR). It can be explained as a ratio of the Predicted Environmental Concentration (PEC), which represents the estimated environmental concentration (Padovani et al. 2004), and the Predicted No Environmental Concentration (PNEC), which represents the estimated safe concentration based on laboratory and field tests (Ansara-Ross et al. 2008). The fate of pesticides in all environmental compartments are considered (Padovani et al. 2004).

The important indicator values for the different compartments are calculated as:

$ETRwater = PECwater/PNECwater$…………………………………… (equation 1)

$ETRsoil = PECsoil/PNECsoil$…………………………………………. (equation 2)

$ETRgroundwater = PECgroundwater/PNECgrounwater$…………... (equation 3)

$ETRbees = PECbees/PNECbees$…………………………………….. (equation 5)

$ETRnta = PEConfield/AECnta$……………………………………… (equation 6)

Where:

ETR – Exposure toxicity ratio

PEC – Predicted effect concentration

PNEC – Predicted effect concentration

DWS – Drinking water standard

AEC- Acceptable effect concentration for *Typhlodromus pyri* and *Aphidius rhopalosiphi (g/ai)*

The highest of the three calculated ETR values will be used as an assessment of the sustainability of a current strategy employed by a farmer. An ETR value greater than or equal to 100 is an indication of high risk while a value less than or equal to 1 represents no risk.

2.3 Data analysis and interpretation

Descriptive statistics were used to compute the frequencies of respondents who adhered to PPE safety standards, clearly understand the demographics within the communities and determine the proportion of respondents who had faced side effects of chemical applications. Pie charts and bar charts were specifically employed to visualize the proportions of different sources of pesticides and storage strategies employed by respondents. Scatter plot diagrams were generated to observe patterns or trends in similar parameters computed from the two models under investigation (for example ETR value for bees is comparable with EIQ value for the environment of the farm under consideration).

One-way ANOVA was used to determine if EIQ values and ETR values can be explained by the level of education or community of origin of a respondent.

All analysis were done using SPSS statistical package version 20.

3 Results

3.1 Questionnaire responses

3.1.1 Gender profile, educational background, and age of respondents (Part A of questionnaire)

About 77 % of the farmers were males whiles 23 % were females (N=75). A community level gender profile assessment revealed that all, except community 3 had a male dominance. About 52 % of farmers in this community were made up of females (N=25). In the other communities, males generally constituted about 65 % (community 1 – 76 % and community 2 – 68 %) of the respondents (N=25).

Most of the household heads were male (70 %), within the age bracket of 21-30 years. Age of farmers varied from 20 to 98 years, and the cohort from 21-30 years included as many as 40% of respondents. The average age of farmers was 38 years. A breakdown of the different communities revealed average ages of community 1; 35 years, community 2; 32 years, and community 3; 47 years. An ANOVA statistical test reveals that the mean ages of all communities are indeed not the same (refer to table 4).

The largest group of respondents have had some level of secondary education (27 % Junior high school (JHS), 25 % Senior high school (SHS), vocational and technical school), and 5 % had obtained Tertiary education (University, Teacher training and Polytechnic) (Figure 7).

3.1.2 Pesticide Knowledge (Part B of questionnaire)

A test of farmer knowledge on the routes of entry of pesticides into the human body, organisms and the environment churned out the results in the table below (Table 5). Majority of farmers answered positively to the question whether or not pesticides could enter the body through the mouth and via inhalation (90% and 84% respectively). This idea was translated into a 90% acceptance of pesticide entry through the mouth. All farmers but 4 admitted to knowing how dangerous pesticides can be to their health (95%).

Table 4 Anova table for age of communities 1,2,3.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between groups	2150,82667	2	1075,41333	3,98568587	0,02282056
Within groups	19426,96	72	269,818889		
Total	21577,7867	74			

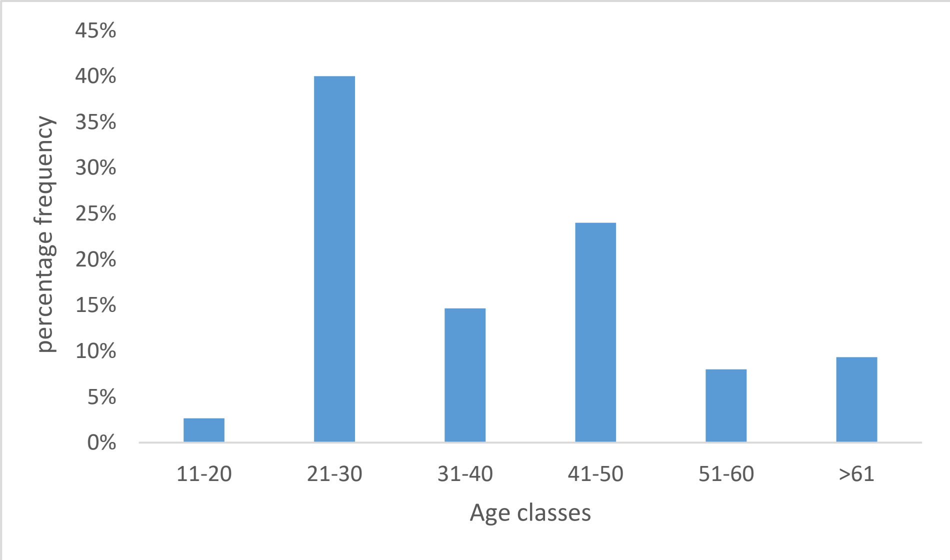

Figure 5 Age of farmers

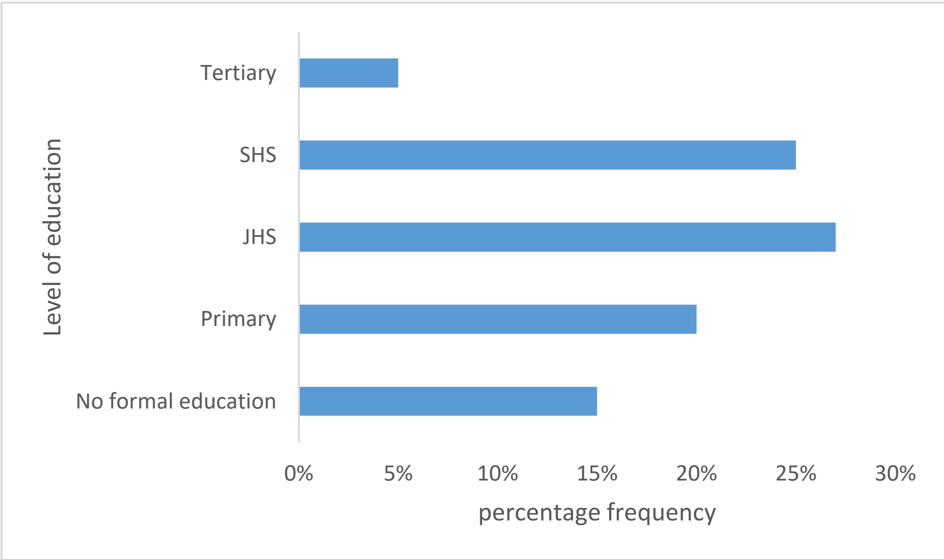

Figure 6 Educational background of farmers

Table 5 Knowledge on pesticide toxicology's

Question asked	% response (N) Yes	No	Don't know
Can pesticides be dangerous to use?	95(71)	4(3)	1(1)
Can pesticides enter the body through inhalation?	84(63)	15(11)	1(1)
Can pesticides enter the body through skin?	78(59)	19(14)	3(2)
Can pesticides enter the body through mouth?	90(68)	9(6)	1(1)
Can pesticide residues be left in the air?	92(69)	3(2)	5(4)
Can pesticide residues be left in the soil?	72(54)	22(17)	6(4)
Can pesticide residues be left in the groundwater?	68(51)	30(22)	2(2)
Can pesticide residues be left in the fruits?	92(65)	7(5)	1(1)

3.1.3 Pesticide use (acquisition, reason for application, and knowledge of application) and economically important pests and diseases (Part C of questionnaire)

The government supplied pesticides represented the main source of pesticides among all farmers interviewed (Figure 7). About one fourth of the farmers indicated local agrochemical stores as their source of pesticides. The remaining 1 % received chemicals from Amajaro cocoa produce buying company. Upon acquiring chemicals, storage options explored by the farmers are represented in figure 8. About half of respondents stored chemicals within their living household which is reminiscent of a safe place, whiles a little over one fourth stored it in their toilets (refer to figure 8).

Interviews revealed Akate master, Confidor, Ridomil and Nodox as the commonly used pesticides. During focus group discussions, all farmers consented to using motorised sprayers for insecticide application whiles the knapsack sprayer was the preferred equipment for fungicide application. Application strategies employed by majority of the farmers involved the application of different chemicals individually, however, the remaining group indulged in the improper farming practice of mixing different chemicals to have rapid knockdown effects of pests (Table 6). Farmers again mentioned economic constraints of renting spraying equipment's as a reason for this improper agricultural practice. About three fourth of farmers identified the presence of pests as the driving factor of their decision to apply chemicals (Table 6). Others also followed recommended calendar spraying schedules no matter the observations made in the field.

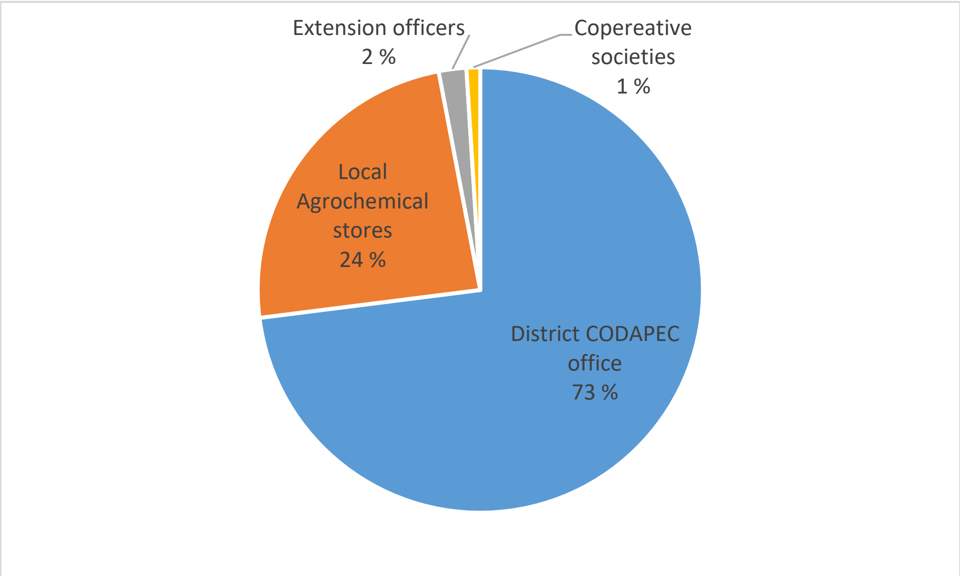

Figure 7 Source of Agrochemical by respondents

The study further revealed that more than three forth of farmers observed the seven day no-entry period after application and thus harvested only after chemicals on the pod of fruits had dried off (refer to table 6). Some farmers harvested produce within this seven-day period and is likely to have detrimental effects on the farmer as well as consumers. A minority of respondents were reported to have never received training on best pesticide application practices (refer to table 6). The remaining group who have received some form of training listed NGO's, agrochemical shops, extension officers and fellow farmers as their source of knowledge (refer to table 6).

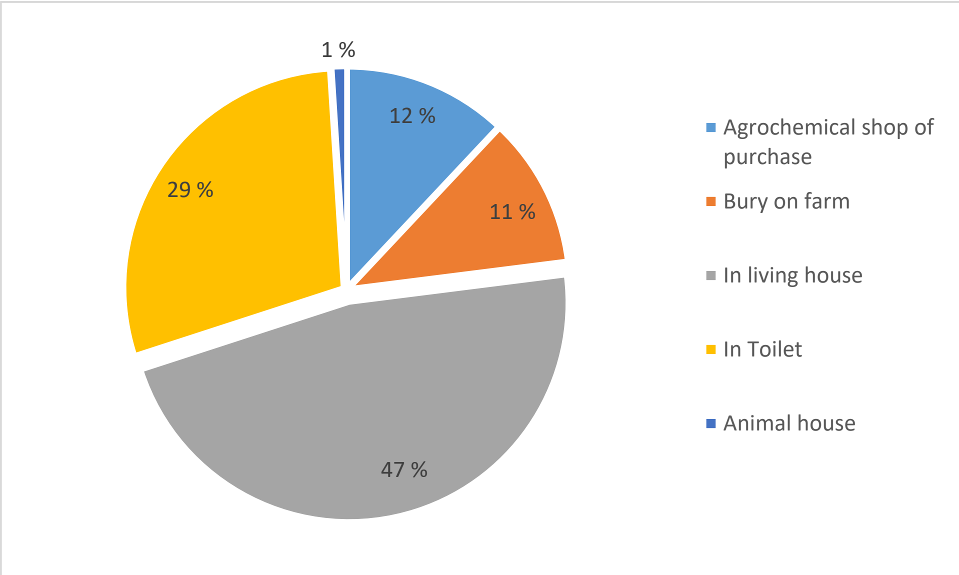

Figure 8 Pesticide storage strategy in use

The commonest way of disposing off empty pesticide containers and remnants from spraying equipment was throwing them out on the field. Empty pesticide containers and sachets were found disposed of indiscriminately on farms where observations conducted (refer to plate 1). Five of the respondents (7 %) revealed they put empty pesticide containers to other use once they were emptied of content. Some farmers (31 %, N=23) also mentioned digging holes on farm and burying containers as their favoured disposal method. And the smallest percentage (3 %, N=2) returned containers into designated bins provided by Amajaro cocoa purchasing company for proper disposal. After a spraying session is over, 53 % (N=40) of respondents discharged the remnants of mixed chemical on the farm, whiles 27 % (N=20) returned any leftover chemical into storage place. The least favoured disposal option was burying in the ground. Once the equipment is empty, 59 % (N=44) of farmers returned home with it to carry out cleaning, with 32 % cleaning sprayers on their farms. A small proportion of respondents (9 %, N=7) washed directly into streams and rivers.

3.1.4 Attitudes towards pesticide use (Part D of questionnaire)

Farmers' perception on the effectiveness of spraying was sought by expecting respondents to agree or disagree with certain statements. Among these statements were; pesticide use is important to secure good crops, pesticide use should be limited, adequate knowledge on pesticide handling is necessary when using pesticides, there are minimal health risks associated with pesticide use, and precaution should be taken when handling and applying pesticides. Prominent among these responses were 90% of respondents strongly agreeing to the statement 'pesticide use is important to secure good crops', whiles the rest of the 10% simply agreed with the statement. Majority of the respondents answered in agreement with precaution being taken in the administration of chemicals (30% strongly agreed, 50% agreed). A plethora of health effects are associated with pesticide use, respondents made this point with 60% strongly disagreeing with the statement 'there are minimal health risks associated with pesticide use'.

3.1.5 Importance of Personal protective equipment PPE's (Part E of questionnaire)

Spraying of farms with pesticides was claimed by farmers as one of the most important activities carried out during the growing season. This statement was buttressed by all respondents (100 %) agreeing that pesticides use is important for good crop yield. About 80 % of respondents could attest to the improvement in application techniques after receiving training. They accepted proper knowledge is necessary for appropriate application. The notion within the scientific community with regards to reducing the amounts of pesticide applied and cleaving towards ecologically friendly approaches did not go down well with many. 68 % of them disagreed with the statement "pesticide use must be limited".

Applicators were not observed to have fully donned all personal protective equipment during the study period (appendix 5). About 13% revealed they use the full working gear during applications while 67 % partially protect themselves before administering chemicals on farms. The most common component of the PPE used by this partial group was the wellington boots (not reported). And yet 20 % failed to put on any of these human safety equipment. Despite not adhering to regulations of personal protection before application, all but 1 farmer responded that he/she ate, drunk or chewed gum during chemical application. Common symptoms associated with pesticide poisoning were reported to have been observed by the farmers, about three fourth of them reported to have experienced a headache, a burning sensation on the face, and weakness in the body. Fever, watering of the eyes, and dizziness were experienced by about half of respondents. Diarrhoea and vomiting were the least experienced symptoms with recording about one fourth each (refer to Table 7).

Figure 9 shows diseases and pests important within the studied communities. Majority of the farmers reported mirids and stink bugs as the most important insects (constituted about one third), whiles black pod was identified as the most important disease. The others category (2 %) constitutes Termites, caterpillars, and stem borers.

Table 6 Pesticide application information by cocoa farmers

Questions and predefined answers	Respondents	
	N	%
Source of farmers' knowledge on pesticide application rates		
Agrochemical dealers	15	20
Extension officers	45	60
Fellow farmers	4	5
Own experience	8	11
NGO's training	3	4
Timing of pesticide application		
When first symptoms of pests/ diseases are observed	60	80
Based on severity of pest or disease infection	4	5
Based on calendar spray schedules	9	12
Based in advice of Agricultural extension officers	2	3
Pesticide application strategy?		
Mix more than one type of chemical	19	25
Apply different pesticides individually	56	75
How many days of the waiting period do you observe?		
Less than stipulated seven days re-entry interval	7	9
Seven days or more after application	68	91

Plate 1 Fungicide sachets (blue coloured material in litter) and insecticide containers (white coloured material in litter) found in a cocoa farm in the Western Region of Ghana

Table 7 Common symptoms associated with frequent pesticide poisoning

Question asked	Percent response (N) Yes	No
Have you experienced any of the following symptoms after chemical application?		
Headache	80(60)	20(15)
Burning sensation	80(60)	20(15)
Weakness	76(57)	24(18)
Fever	51(38)	49(37)
Eye watering	52(39)	48(36)
Skin rash and itching	39(29)	61(46)
Dizziness	62(47)	38(28)
Body Pains	67(50)	33(25)
Vomiting	26(19)	74(56)
Diarrhoea	28(21)	72(54)
Forgetfulness	36(27)	64(48)

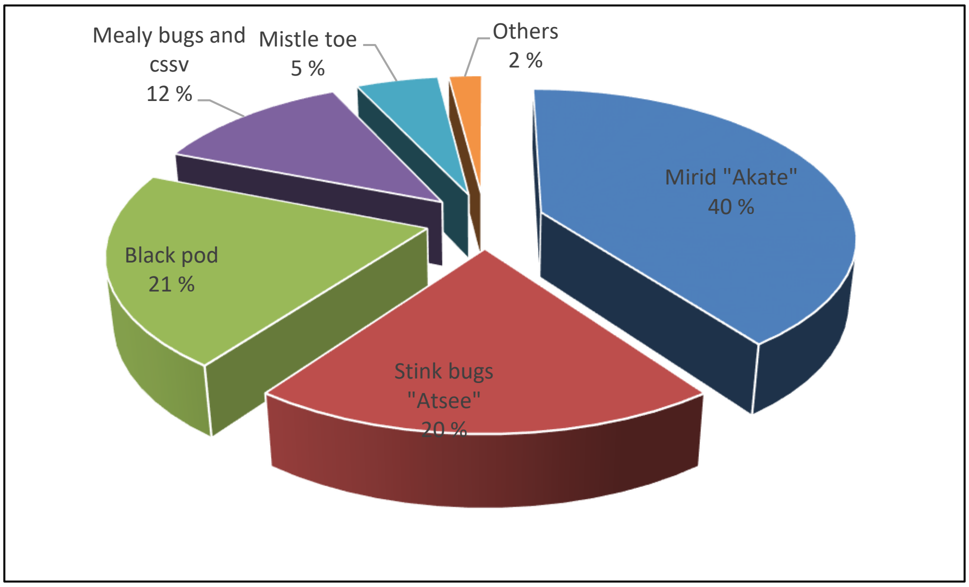

Figure 9 Farmers perception of the most economically important pests and diseases

3.2 The EIQ model application

Factors that directly impact the EIQ values for the environment, consumers, and farm workers were identified as; application rate, percentage of active ingredients and lastly the formulation of chemicals. The detailed list of chemicals used and contributions to the final EIQ scores for the farmers who recorded highest chemical scores in each of the three communities are shown in table 9. For all three farmers insecticides were observed to record high EIQ values as compared to fungicides used. Akate power recorded the highest field use EIQ value than the other chemicals used by these farmers (refer to table 9). This can be attributed to the high application rate of the farmer in question with ID number 16. Again fungicides were almost in all instances used according to the recommended doses, which may account for the lower values recorded. Akate power with thiamethoxam as active ingredient recorded the highest ecological EIQ among all pesticides used (120 and 200 respectively for farmer ID 16 and 30).

Table 8 Anova table for EIQ values comparing the three communities

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between groups	15112,2851	2	7556,14253	8,40034853	0,00052599
Within groups	64764,2488	72	899,503456		
Total	79876,5339	74			

3.3 The PRIMET model application

This model proved to be more sophisticated in its calculation of risk, the input variables required in this case were much more. Climatic factors influencing movement and transfer of pesticides were selected specifically to mirror tropical conditions in the area.

High negative values recorded for the exposure toxicity ratios of groundwater (ETR GW) and water (ETR water) could be attributed to the high octanol water partitioning coefficient of the insects used mostly. As described briefly in the background, soils in this agro ecological zone tend to be rich in organic content. The chemicals therefore bind strongly to the organic structure, this result from indicator model is corroborated by soil analysis performed in certain areas where theses pesticides are used. Soil analysis revealed high content of pesticides in the top portion of the soil, even though there is a high amount of precipitation annually there is minimal leaching. Another explanation may be the high temperatures during the year which speeds up the breakdown process by microorganisms. Insect pests were reported as the most important pests in the three communities, results for Exposure toxicity ratios of non-target arthropods (ETR NTA) and bees for almost all farms follows this trend. Chemicals tend to affect all insects irrespective of whether or not they are the target organisms. Again departures from the recommended doses by manufacturers were observed to be more likely to be with the insecticides since farmers looked at the insects as a destructive entity in the landscape.

Table 9 Farmers EIQ calculation detailing different chemicals used during the growing season

ID number	**Trade name**	**Active ingredient name**	**Dose**	**Applications**		**EIQ field use rating**	**Consumer**	**Worker**	**Ecological**
16	Akate master	Bifenthrin	150 ml/acre	1		36,6	9,0	18,1	51,2
	Akate power	Thiamethoxam	150 ml/acre	2		74,2	21,0	38,8	120,5
					Total	**110,8**	**30,0**	**56,9**	**171,7**
30	Akate power	Thiamethoxam	120 ml/acre	2		70,3	9,6	8,4	200,2
	Akate master	Bifenthrin	90 ml/acre	2		37,9	6,4	5,6	140,4
	redomil	copper hydroxide	60 ml/acre	1		20,9	5,2	3,9	30,6
	kocide	copper hydroxide	60 ml/acre	1		20,9	5,2	3,9	30,6
					Total	**150,0**	**26,4**	**21,8**	**401,8**
51	Akate master	Bifenthrin	75 ml/acre	2		44,3	12,0	22,8	68,7
	Akate power	Thiamethoxam	90 ml/acre	2		66,5	18,0	34,1	103,0
					Total	110,8	30,0	56,9	171,7

Fungicides were less likely to be overdosed basically because of the packaging, 1 sachet was for a tank of 15l of water in the knapsack sprayer. The degree of importance of funguses as destructive elements also meant they were not very particular about them. It is worth mentioning that this was a notion of the farmers in this area and there was no scientific explanation at the time of this study.

3.4 Comparison between the two models

Based on EIQ and PRIMET values the insecticides had a higher propensity to cause risk than the fungicides used by farmers. All fungicides used are granular formulations whiles the insecticides were made of liquid formulations. Scatter diagrams below show both models recording similar values for the different compartments that are understudy. Figure 11 for community 1 shows a trend line which indicates one value does not increase or decrease with the other. Both variables on the x and y axis measure similar parameters in both models which explains the reason for this trend. EIQ consumer as a compartment in the EIQ model has groundwater as a part of the calculation as shown in equation 2 in section 2 above. The same reasons account for the trends in figures 14 and 17. Figures 12 and 19 represent the risk which insects and other organisms that inhabit the farms are likely to face. ETR values from PRIMET calculate risk to bees because they are one of the important pollinators in many landscapes. An estimation of the level of risk they face can be transposed to many other insect species. They are often used as indicator species due to the sensitivity in any landscape. ETR values for Non Target Arthropods (NTA) in appendix 6 reveals the levels of risk faced by other beneficial insects.

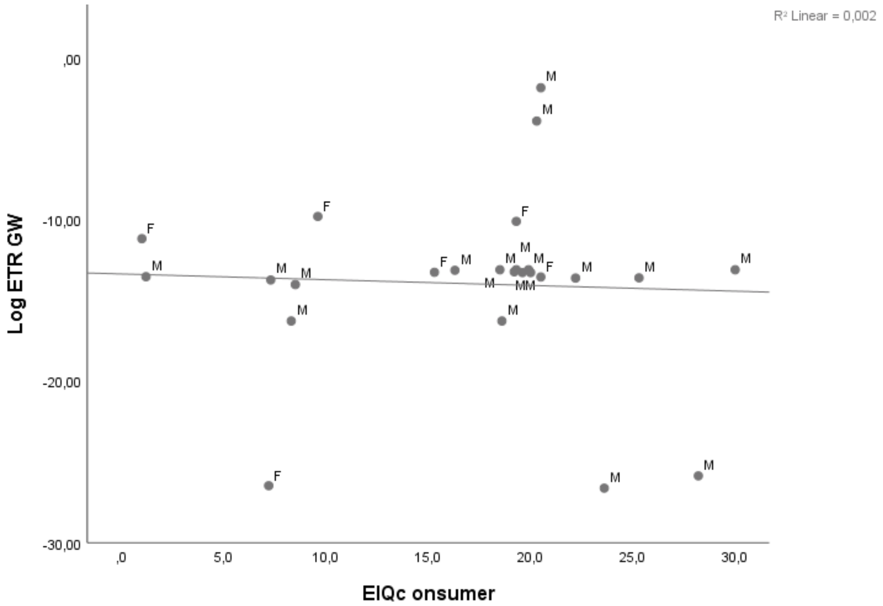

Figure 11 scatter plot of log ETR groundwater vs EIQ consumer for community 1

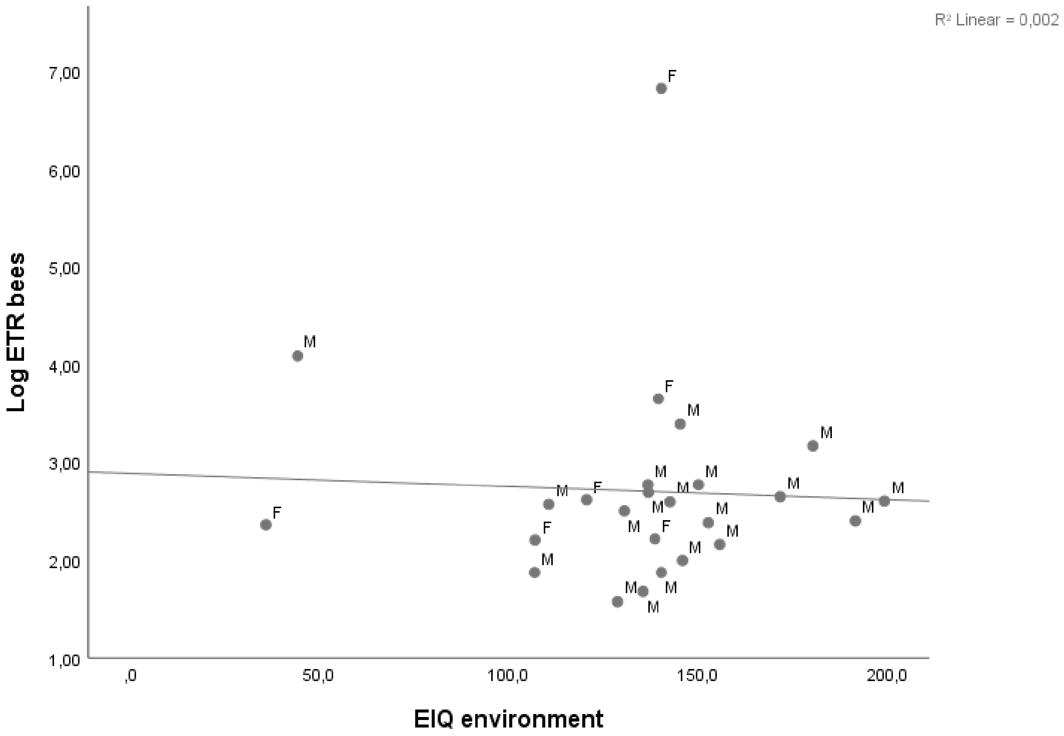

Figure 12 scatter plot of log ETR bees vs EIQ environment for community 1

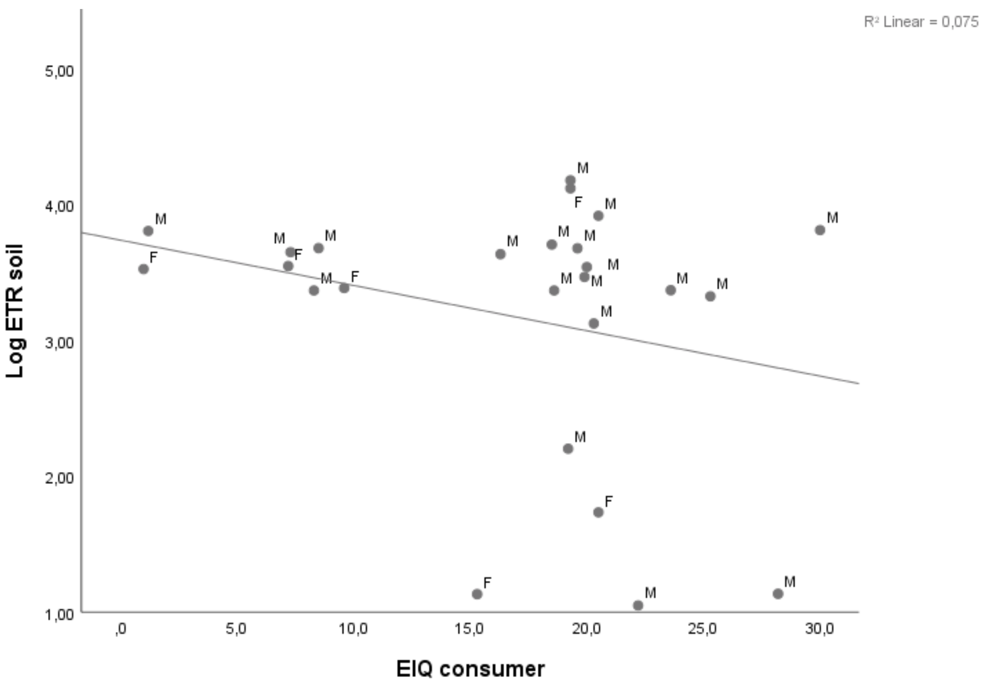

Figure 13 scatter plot of log ETR soil vs EIQ consumer for community 1

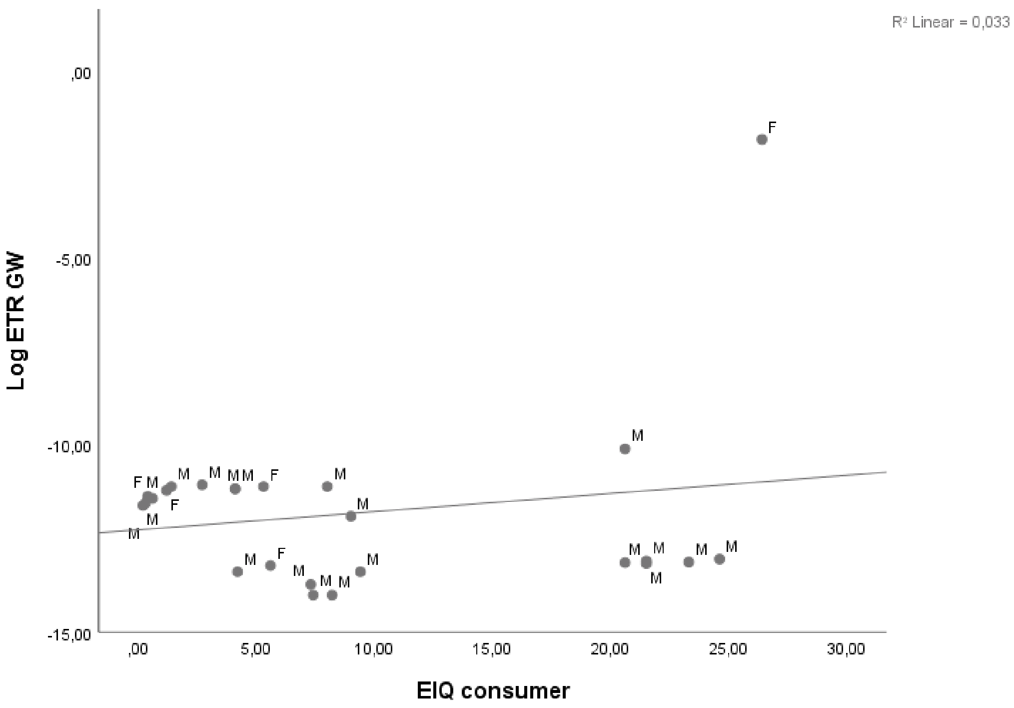

Figure 14 scatter plot of log ETR groundwater vs EIQ consumer for community 2

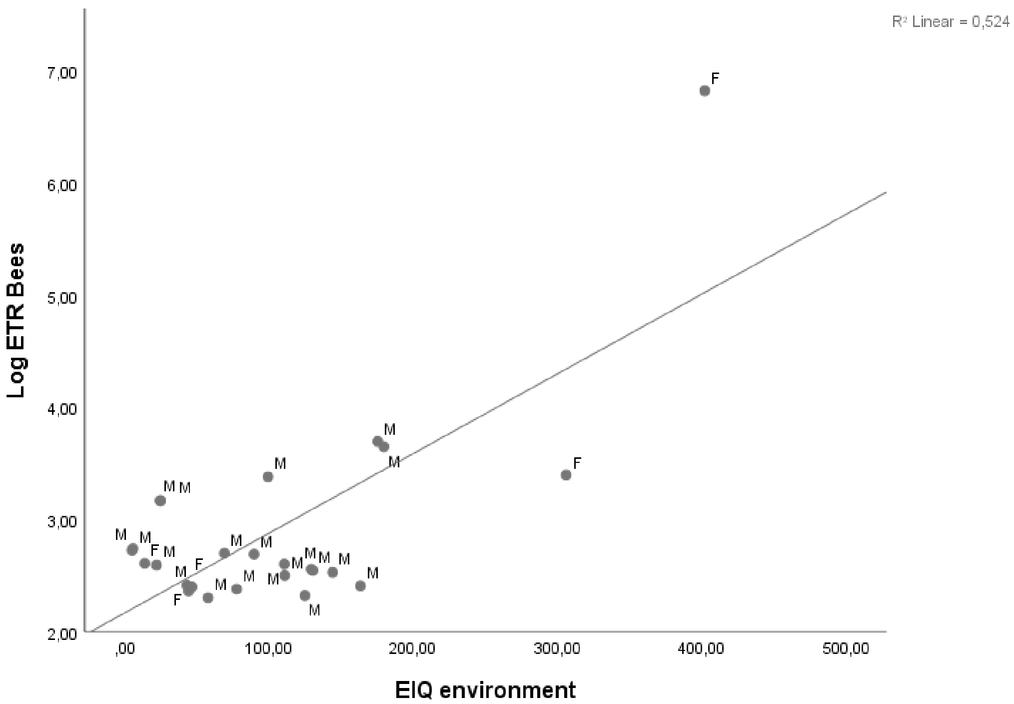

Figure 15 scatter plot of log ETR bees vs EIQ environment for community 2

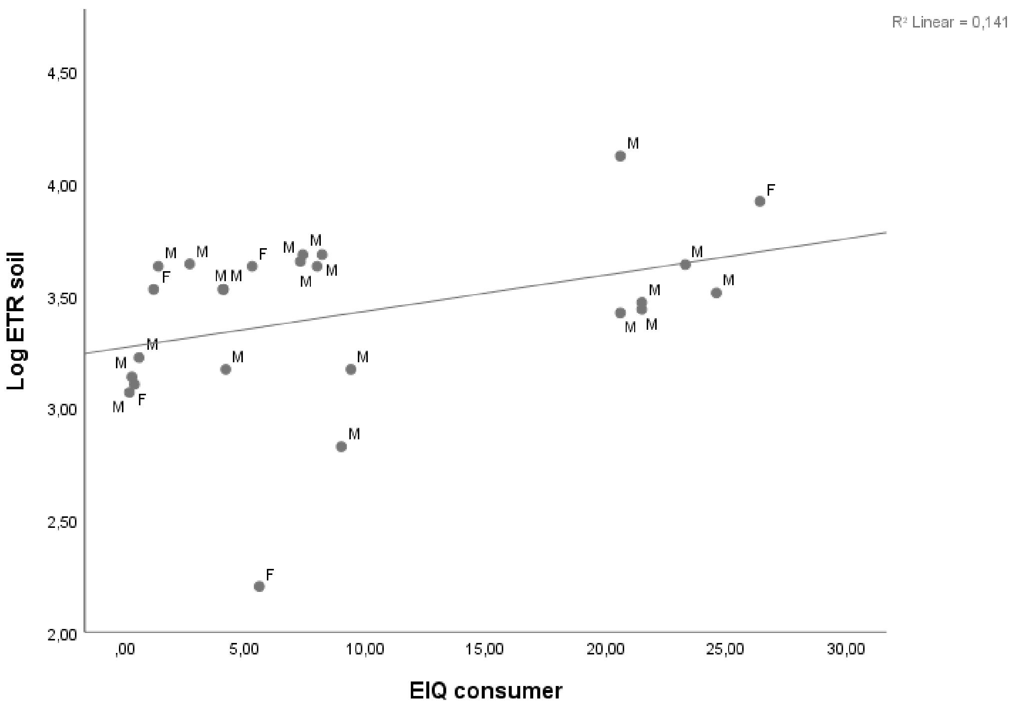

Figure 16 scatter plot of log ETR soil vs EIQ consumer for community 2

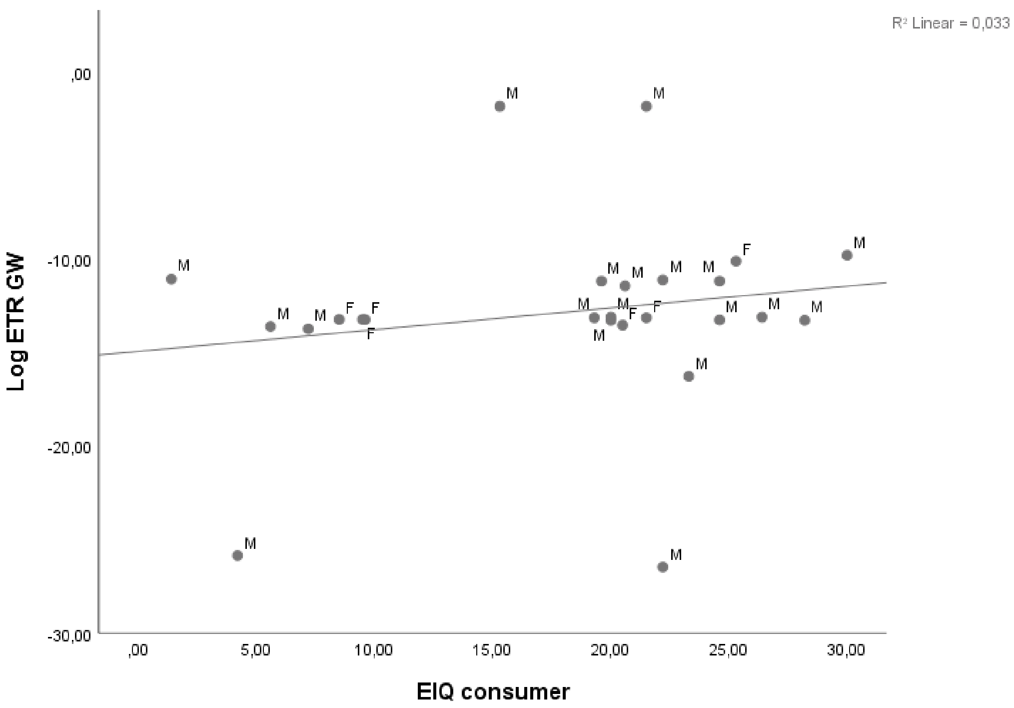

Figure 17 scatter plot of log ETR groundwater vs EIQ consumer for community 3

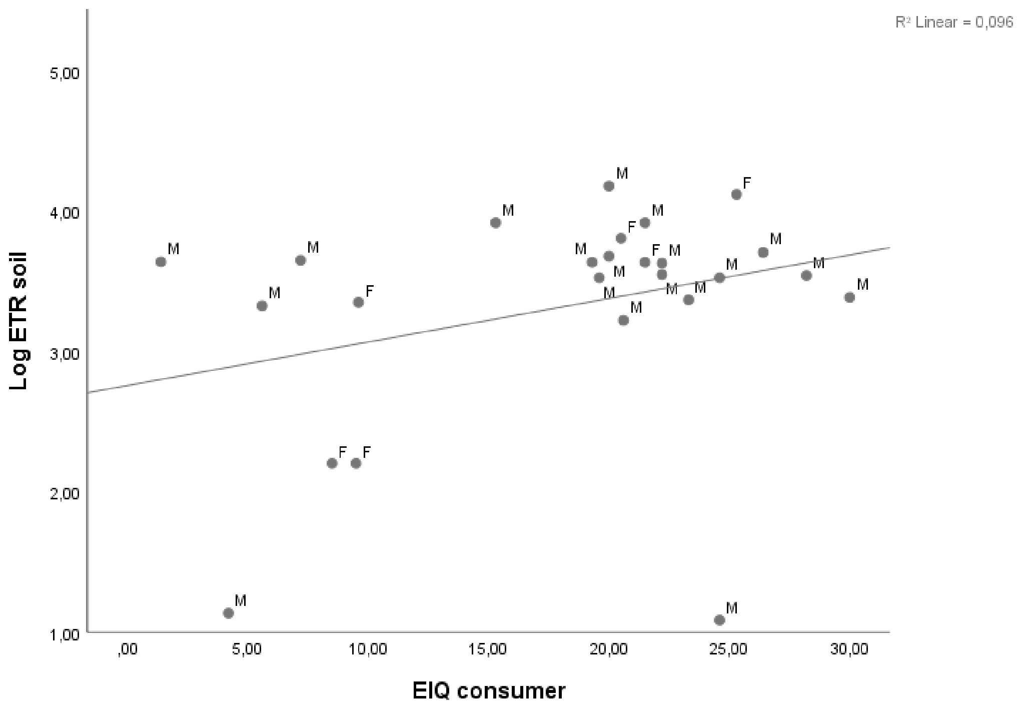

Figure 18 scatter plot of log ETR soil vs EIQ consumer for community 3

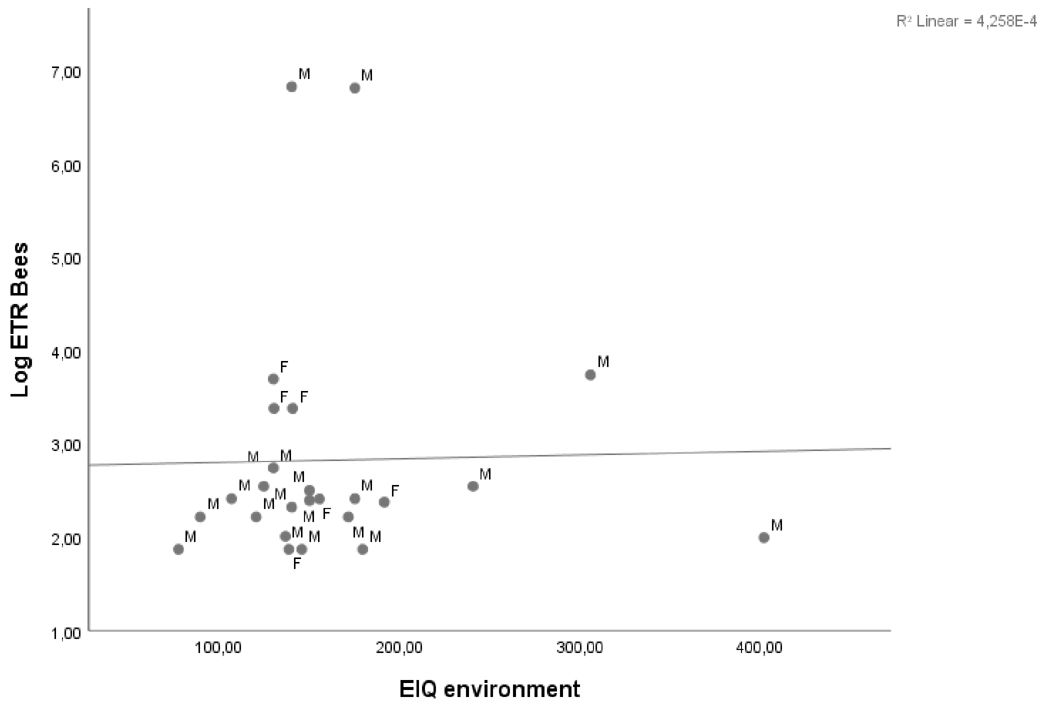

Figure 19 scatter plot of log ETR bees vs EIQ environment for community 3

4 Discussion

Basic statistics of means, modes and percentage frequencies were used to answer the first part of research questions. Socioeconomic characteristics of the communities studied showed the typical farmer is a male averaging 20-years with a basic level of education, using mostly pesticides distributed for free by the government (through the Cocoa health extension division CHED of the Ghana cocoa board COCOBOD). It is worth mentioning that unregistered pesticides were also used in these communities. Almost all farmers failed to perform an assessment of pest status of farm before chemical application, and waste from this application was generally not handled in line with WHO's "safe use of pesticides" manual (WHO 1973). This improper disposal could be as a result of low pesticide toxicity knowledge. Inferring from above, it is clear that a change in perceptions of farmers on pesticide toxicity coupled with the use of these indicator models to select the best combination of chemicals with least negative impact will improve current situation.

Demographic analysis suggest that cocoa farming is a male dominated venture. This could be attributed to the physical strain all its farm activities put on the body. Antwi-Agyakwa (2013); Osei Boadu (2014); Zhu (2015) and, Tijani (2006) corroborated this observation in their studies. The mean age of farmers in these communities reflects a shift from the old guard (average age of 55). Cocoa farming (and farming in general in most parts of Africa) is known to be a job indulged by the elderly. This study reflects the efforts of the Government of Ghana to get the youth involved in agriculture since it contributes a lot to the country's GDP. Antwi-Agyakwa (2013), Osei Boadu (2014) and, Kumi and Daymond (2015) reported higher mean ages than that observed in this thesis. All these studies reported that a high proportion of individuals were within the economically active range (18 – 64 years).

Educational background of respondents demonstrated a good number of farmers had received basic level education. This is suggestive of being open minded and ready to learn new techniques of good farming practices. The proportion of illiterates is low (section 3.3.1), however, majority of the farmers did not further studies beyond the high school level. This is coherent with a studies by Antwi-Agyakwa (2013) and Zhu (2015) and may fuel the notion that a high level of education is not necessary to carry out farming. The main age class which makes up the largest component of the active labour force can be classified as semi-literate, since they often drop out of school after the Junior high level, similar to a trend found in a study in Nigeria (Alabi et al. 2014). Oluwole and Cheke (2009) reported a similar proportion of respondents their survey had no formal education. It is there safe to conclude from the above paragraph that, poor educational facilities in rural Africa will affect adherence to good agricultural practices.

The high focus of the Ghanaian government on cocoa farming is evident by majority of the farming reporting their primary source of pesticides were the free distributed ones (section 3.3.2). The added advantage of providing farmers with only industry tested and registered chemicals has kept this practice in place for the past 17 years. The second majority acquired chemicals through local agrochemical shops, this is not surprising because a great proportion of the respondents can be considered semi-literates. This often translates into inability to distinguish between different pests and disease pathogens and appropriate control measure, they therefore rely on information and advice provided by chemical sellers. This trend was observed in vegetable farming within the cocoa belts in the western region of Ghana (Zhu 2015). Antwi-Agyakwa (2013) reported some farmers apply pesticides just at the presence of the pests ignoring the economic threshold of (6 mirids per tree). This finding lends support to the observations made in this thesis, with respondents not considering the degree of infestation before application.

Pesticide storage was another well debated topic at the focus group discussions. Majority of the farmers keep chemicals within living home or close to the home than the farm. Another interesting dynamic in these rural community setting was the storage of chemicals in the toilet. Here the toilet is stated separate from living house because it is often detached from house in a stand-alone unit. Zhu (2015) documented a similar trend in vegetable farmers within the cocoa belts, whiles Oluwole and Cheke (2009) lent support to this assertion with data form rice farmers. Tijani (2006) uncovered a different pattern to all studies mentioned here, with majority of the farmers stowing pesticides in designated stores and a minority keeping them in their bedrooms. Advice was however given at focus group meeting to find a better storage option since keeping near living house has been reported to be one of the main causes of food poisoning.

Agricultural extension officers act as conduits between the ministry of agriculture and farmers and farm workers. They are the first point of call for farmers in the event the require assistance with farm practices implementation. This observation was in line with results recorded by Tijani (2006) and (Zhu 2015). They both presented data showing most farmers receive application techniques knowledge from Extension agents, however, Oluwole and Cheke (2009) recorded farmers personal experience as the major source of knowledge in another region. There is always the fear of distortion of information during dissemination by contemporaries, all studies clearly showed it was the least used option. The most prominent container and sachet disposal strategies currently employed were burying in a hole and throwing on field (section 3.3.2). This trend is coherent with data reported by Tijani (2006) and Oluwole and Cheke (2009).

The CSSV disease was reported by the minority of the farmers, this is likely due to the low populations of mealy bugs on their farms. The vectors of this disease were mentioned as one of the least important. Mistletoe growth in the canopy was mentioned by 5 % as important. Cocoa mirids were reported as the most important corroborated by Sosan and Akingbohungbe (2009).

Dosage and application rates are determinants of impact levels faced by the three compartments. Cuprous hydroxides which are the active ingredients in the fungicides used by farmers in these communities have high half-life values in the environment and their use in quantities above the required doses result in high persistence in the environment. As seen in the results the ecology of the area is likely to be at a high risk due to the levels of chemical use in these areas. All three communities recorded high values for bees and arthropods. Dietary risk recorded was the lowest value recorded in PRIMET and this is in line with the groundwater values recorded. The EIQ consumer values recorded were also below the risk zone which could be looked at as a good sign.

5 Conclusion

In conclusion, the level of education of majority farmer of the farmers is quite low. Personal protective equipment for the chemical applications can be another area the Cocoa health extension division may need to consider. This recommendation may be difficult to implement given the number of farmers who fail to receive chemicals under the program due to the low stock at district offices. However, the Ghana cocoa board needs to look into the possibility of carrying this out under the program. More education on pesticide handling is required at the community level which in effect will need effort at the district and regional levels. This looks even more possible since results from the thesis and other studies show a shift from the old guard (average age of 55) to the younger generation (average age of 20 years) in cocoa farming and in some instances agriculture in general.

Both models under consideration in this thesis provide a prediction of the effect of the current pesticide regime of a farmer, they do quite a good job at that. Comparing both models reveals they provide similar results for the different compartments, however, the temperature dependent algorithm in PRIMET makes it a better option. It is worth mentioning however that EIQ uses very basic determinants in prediction risk and the online calculator makes its use easier comparatively. PRIMET on the other hand requires data on water bodies in the area, rainfall patterns and yearly temperature averages. This results in a calculation which is often tailored to a specific landscape, region or farm. In this thesis all farms used the default value of the region which is a better representation than the EIQ which uses the same default value no matter the region under study. Among all compartments under study the environment or ecology of the area was the one at risk the most. Further monitoring of the environment by collection of soil samples and fruits for tests need to be carried out to confirm this.

Chemicals currently under use in these farms recorded high values primarily due to the use by farmers in quantities above the recommended doses. These as well as the application frequencies need to be drummed home a bit more during the farmer business school sessions within the communities.

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7 Appendix

Appendix 1 Questionnaire administered during study

ASSESSMENT OF PESTICIDE USE IN BODI DISTRICT OF THE WESTERN REGION, GHANA

Village: _____________

Date: _____________ Questionnaire no: _____________

a) BACKGROUND

1. Are you
   - ☐ Male
   - ☐ Female

2. What is your age?

....

3. What is your ethnical tribe?
   - ☐ Asante
   - ☐ Fante
   - ☐ Akwapim
   - ☐ Akyem
   - ☐ Akwamu
   - ☐ Bono
   - ☐ Nzema
   - ☐ Kwahu
   - ☐ Safwi
   - ☐ Other (specify) …………………..

4. What is your occupation?

....

5. What is your religion?
   - ☐ Roman catholic
   - ☐ Lutheran
   - ☐ Pentecostal
   - ☐ Islam
   - ☐ Other (specify)

…………………………………..

6. What formal education do you have?
   - ☐ No formal education
   - ☐ Primary education
   - ☐ Secondary education Level
   - ☐ Certificate/diploma
   - ☐ Degree level
   - ☐ Other (specify) …………………..

7. What is your position in the family?
   - ☐ Father
   - ☐ Mother
   - ☐ Daughter
   - ☐ Son
   - ☐ Other (Specify) …………………………..

8. What is the main economic activity in your household?
   - ☐ Farming
   - ☐ Day worker
   - ☐ Small business
   - ☐ Other (Specify) …………………………..

9. How many people live in your household?

....

10. How many of the household members are below 18 years old?

……………………

11. What is the approximate a: size of your farm b: age of farm :

…………………/……………………

12. Which of the following crops do you grow for own use and sale?

Tick (√) against		Crops	Tick (√) against		Crops
For own use	For sale		For own use	For sale	
		Tomatoes			Cowpeas
		Onion			Maize
		Cabbages			Rice
		Spinach			Banana
		Green pepper			Sugarcane
		Carrot			Oranges
		Swiss chard			Mangoes
		Chinese			Pawpaws
		Egg plant			Millets
		Okra			Sweet potatoes
		Melon			Cucumber
		Beans			Others: (i)…………………………
		Sunflower			(ii)…………………………………….
		Cotton			(iii)………………………………….

b) PESTICIDE KNOWLEDGE

13. Which pesticides do you know by name?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

14. Which forbidden pesticides do you know?

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

15 Can pesticides cause negative health effects?

☐ Yes
☐ No
☐ I don't know

16. Do all pesticides have the same health effect?

☐ Yes
☐ No
☐ I don't know

17. Can pesticides be dangerous to use?

☐ Yes
☐ No
☐ I don't know

18. Can pesticides enter the body through inhalation?

☐ Yes
☐ No
☐ I don't know

19. Can pesticides enter the body through the skin?

☐ Yes

☐ No
☐ I don't know

20. Can pesticides enter the body through the mouth?

☐ Yes
☐ No
☐ I don't know

21. Can pesticide residues be left in the air?

☐ Yes
☐ No
☐ I don't know

22. Can pesticide residues be left in the soil?

☐ Yes
☐ No
☐ I don't know

23. Can pesticide residues be found in groundwater?

☐ Yes
☐ No
☐ I don't know

24. Can pesticide residues be found in fruits?

☐ Yes
☐ No
☐ I don't know

25. Can pesticide residues be found in vegetables?

☐ Yes
☐ No
☐ I don't know

26. Do you read manufacturer notifications?

☐ Yes
☐ No
☐ I don't know

27. Do you respect manufacturer notifications?

☐ Yes
☐ No
☐ I don't know

C) PESTICIDE USE

28. Have you ever used pesticides?

☐ Yes, I currently do (go to no. 29)
☐ Yes, in the past (go to no. 30)
☐ No (go to no. 33)

29. Why do you use pesticides?

☐ To protect crops against insects
☐ To make crops grow better
☐ Because others use pesticides
☐ Because I was advised to use pesticides
☐ Others……………………………..
☐ I don't know

30. Why did you stop using pesticides?

☐ Did not show good response
☐ Scarce availability of pesticides
☐ High buying costs
☐ Others………………………………….
☐ I don't know

31. Where do get/buy the pesticides that you use?

☐ District CODAPEC office
☐ Local agrochemical shops in the village
☐ Extension officers
☐ General shops
☐ Cooperative societies
☐ Others………………………………….

32. If you currently use other pesticides (answered "Yes" on no 28),

mention the insecticides, fungicides and herbicides you use.

Type of pesticides	Crops used on	Season of use	Amount per each application (application pr.area)	Interval of use(last spraying before harvest could be interesting to know or post harvest)	Application methods, e.g. knapsack sprayers
Insecticides:					
Fungicides:					
Herbicides:					

33. What are the common crop pests you encounter in your farm?

List them in order of importance.

(i) ……………………………………………………………

(ii)…………………………………………………………………

(iii)…………………………………………………………

(iv)…………………………………………………………

(v)……………………………………………………………

34. What are the common crop diseases you encounter in your farm?

List them in order of importance.

(i) ……………………………………………………………

(ii)…………………………………………………………………

(iii)…………………………………………………………

(iv)…………………………………………………………

(v)……………………………………………………………

35. What makes you decide the time to apply pesticides on your farm?

☐ Presence of pests
☐ Degree of pest infestation
☐ On calendar spray schedules
☐ On economic thresholds
☐ On the advice of an extension officer
☐ Others…………………………………

36. Where did you get the knowledge on pesticides application methods and rate?

☐ Agrochemical shops
☐ Extension officers
☐ Pesticides labels on packages
☐ Fellow farmers
☐ Own experience
☐ Others…………………
☐ I don't know

37. How do you dilute/mix the pesticide before application?

☐ Mix more than one type of pesticides with water in one container
☐ Mix one type of pesticide with water in a container
☐ Depending with instructions on the label
☐ Don't know
☐ Others…………………………………

D) ATTITUDES TOWARDS PESTICIDE USE

To what degree do you agree or disagree with following statements:

38. Adequate knowledge on pesticide handling is necessary when using pesticides.

☐ Strongly agree
☐ Agree
☐ Neither agree or disagree
☐ Disagree
☐ Strongly disagree

39. There are minimal health risks associated with pesticide use.

☐ Strongly agree
☐ Agree
☐ Neither agree or disagree
☐ Disagree
☐ Strongly disagree

40. Precaution should be taken when handling and applying pesticides.

☐ Strongly agree
☐ Agree
☐ Neither agree or disagree
☐ Disagree
☐ Strongly disagree

41. Pesticide use is important to secure good crops.

☐ Strongly agree
☐ Agree
☐ Neither agree or disagree
☐ Disagree
☐ Strongly disagree

42. Pesticides use should be limited.

☐ Strongly agree
☐ Agree
☐ Neither agree or disagree
☐ Disagree
☐ Strongly disagree

E) PROTECTIVE MEASURES

43. During the last three months, when you applied pesticides …

a) …did you wear gloves?

☐ Yes ☐ No

b) … did you wear goggles?

☐ Yes ☐ No

c) … did you wear something on your head?

☐ Yes ☐ No

d) … did you wear oral/nose mask?

☐ Yes ☐ No

e) … did you wear special boots?

☐ Yes ☐ No

f) … did you wear an overall?

☐ Yes ☐ No

g) … did you smoke during application?

☐ Yes ☐ No

h) … did you eat during application?

☐ Yes ☐ No

i) … did you drink during application?

☐ Yes ☐ No

j) … did you chew gum during application?

☐ Yes ☐ No

44 . Have you ever used protective gears during handling (mixing, spraying) of pesticides?

☐ Yes
☐ No

45. If answered "yes", mention the gears you have ever used

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

46. In your opinion, is the trend of pesticide use increasing, constant or decreasing?

☐ Increasing
☐ Constant
☐ Decreasing

47. In your opinion, what are the reasons for the increase, constant or decrease?:

(a) Increase

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

(b)Decrease

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

(c) Constant

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

48. Where do you store the pesticides?

☐ In the agrochemical store
☐ Animal houses
☐ In the food store
☐ Living house
☐ In the kitchen
☐ In the bush
☐ In the toilet
☐ Others…………………………………
☐ I don't know

49. Where do you dispose off empty pesticide containers?

☐ Sell to others
☐ Put in other uses/give to others
☐ Throw away on farm
☐ Throw away in town or village garbage
☐ Bury in ground on farm
☐ Burn on farm
☐ Others…………………………………

50. Where do you dispose remnants of pesticides after end of application?

☐ On field
☐ Throw in rivers, lakes or irrigation canal
☐ Bury in the ground on farm
☐ Others…………..

51. Where do you wash the sprayers after application of pesticides?

☐ In rivers, lakes or irrigation canal
☐ At home using tap or bucket water
☐ I don't wash
☐ Wipe with piece of cloth or paper and throw it away
☐ Other…………………………………..

52. How long do you wait from last spraying to selling produce?

☐ I sell just after pesticide spraying
☐ 1 – 2 days
☐ 3 – 6 days
☐ One week
☐ More than one week
☐ Depending on manufacturer's instructions
☐ Others…………………………………

53. Do you use the crops you spray with pesticides as food in your family?

☐ Yes
☐ No

54. After application of pesticides to crops, have you <u>ever</u> experienced…

a) …headache?

☐ Yes ☐ No

b) … burning sensations in eyes/face?

☐ Yes ☐ No

c) … weakness?

☐ Yes ☐ No

d) … fever?

☐ Yes ☐ No

e) … watering eyes?

☐ Yes ☐ No

f)… skin rash?

☐ Yes ☐ No

g) …itching and skin irritation?

☐ Yes ☐ No

h) … dizzieness?

☐ Yes ☐ No

i) … chest pain?

☐ Yes ☐ No

j)…forgetfulness?

☐ Yes ☐ No

……………………………………………………………………………………

k)… vomiting?

☐ Yes ☐ No

l) … diarrhoea?

☐ Yes ☐ No

55. What common diseases (health problems) affect members of your household?

………………………………………………………………………………….

………………………………………………………………………………….

………………………………………………………………………………….

………………………………………………………………………………….

56. What are the common medications you normally use?

………………………………………………………………………………….

………………………………………………………………………………….

………………………………………………………………………………….

………………………………………………………………………………….

57. Do you know any other methods of pests control apart from using pesticides?

☐ Yes
☐ No

58. If answered "Yes" on question 57, mention the alternative methods of pest control

(i)…………………………………………………………………………….

………………………………………………………………………………….

(ii)……………………………………………………………………………

………………………………………………………………………………….

(iii)……………………………………………………………………………

Appendix 2 A List of values of individual effects of each pesticide used as reference values in the online EIQ calculator database

(Farm Worker+ Consumer+ Ecological)/ 3				**C(DT*5)**	**C(DT*P)**	**C(DT*5) +C(DT*P)**	**C* ((S+P)/2) *SY)**	**L**	**C*((S+P)/2) *SY)+L**	**(F*R)**	**(D*((S+P) /2*3)**	**(Z*P*3)**	**(B*P*5) (Beneficial) + (Plant 1/2L)**	**(D+B) (Bird)+ (Beneficial)**	**(Fish)+(Bird) +(Bee)+ (Beneficial)**
EIQ total	**EIQ Rev Date**	**Old EIQ Rating**	**Missing Data**	**Applicator Effects**	**Picker Effects**	**Farm Worker**	**Consumer Effects**	**Grd H2O Leaching**	**Consumer + Leaching**	**Fish**	**Birds**	**Bee**	**Beneficials**	**Terrestrial**	**Ecology**
44,35	mar.04	87,83	P	10,00	3,80	13,80	6,90	1,00	7,90	25,00	10,35	28,50	47,50	86,35	111,35
44,03	apr.99	43,40	P	5,00	1,90	6,90	1,45	1,00	2,45	25,00	21,75	28,50	47,50	97,75	122,75
36,71	dec.04	34,90	P	5,00	1,90	6,90	7,35	3,00	10,35	3,00	22,05	28,50	39,33	89,88	92,88
33,30	dec.96	33,30	P	7,50	2,85	10,35	11,03	1,00	12,03	5,00	7,35	28,50	36,67	72,52	77,52
33,20	feb.03	33,30	P	15,00	9,30	24,30	4,05	5,00	9,05	5,00	36,45	9,30	15,50	61,25	66,25

Appendix 3 Photo of pesticides mostly used by cocoa farmers

Appendix 4 Pesticide handling practices in use by farmers

Questions and predefined answers	Respondents N	%
Disposal of empty pesticide containers		
Burning	11	15
Burying	23	31
Throw away on farm	27	36
Throw away in community garbage	7	9
Put to other uses	5	7
Return to Armajaro office for safe disposal	2	3
Where do you wash sprayers after use?		
On farm	24	32
In nearby streams and rivers	7	9
Wash with tap water within premises of household	44	59
Disposal of remnants in equipment		
On the field	40	53
Bury in a hole	15	20
Return to storage room for future usage	20	27

Appendix 5 Two pesticide applicators dressed in their personal protective equipment

Appendix 6 EIQ and PRIMET values for farmers in communities 1, 2 and, 3

Community	**ID_number**	EIQ_FR	EIQ_consumer	EIQ_applicator	EIQ_environment	ETR_water	ETR_GW	ETR_soil	ETR_bees	ETR_NTA	ETR_Dietary	Log_ETR_GW	Log_ETR_water	Log_ETR_soil	Log_ETR_Bees	Log_ETR_NTA
1	1	**72.7**	**20.3**	**45.2**	**152.7**	1.13E-04	1.31E-04	1.34E+03	2.40E+02	8.03E+03	0.00E+00	-3.882728704	-3.9476909	3.126629602	2.379863848	3.904715545
1	2	93.6	23.6	57.8	199.2	2.64E-04	2.39E-27	2.35E+03	3.98E+02	8.29E+04	0.00E+00	-26.62123882	-3.578396073	3.371806459	2.599602545	4.918774503
1	3	41.3	7.3	6.0	110.5	2.01E-04	1.87E-14	4.49E+03	3.69E+02	7.86E+03	0.00E+00	-13.72815839	-3.696803943	3.652439748	2.567132832	3.895477796
1	4	16.3	1.2	3.7	44.2	2.44E-04	2.98E-14	6.44E+03	1.22E+04	6.33E+03	0.00E+00	-13.52578374	-3.612610174	3.808548551	4.086359831	3.801678059
1	5	52.7	8.5	7.2	130.5	2.15E-02	9.73E-15	4.81E+03	3.16E+02	4.98E+03	0.00E+00	-14.01188716	-1.66756154	3.682235357	2.500067693	3.697177015
1	6	15.6	1.0	2.9	35.8	1.50E-04	6.74E-12	3.37E+03	2.29E+02	3.51E+03	0.00E+00	-11.17146899	-3.823908741	3.527758753	2.359384986	3.544787137
1	7	70.3	19.3	44.3	140.3	4.43E-04	7.96E-11	1.33E+04	6.66E+06	2.31E+08	0.00E+00	-10.09919607	-3.353596274	4.122445256	6.823333811	8.364072631
1	8	95.3	25.3	47.6	155.7	9.48E-03	2.53E-14	2.12E+03	1.44E+02	8.30E+03	0.00E+00	-13.59773862	-2.023191663	3.327154512	2.159031303	3.91911995
1	9	59.2	9.6	8.0	138.6	2.99E-03	1.60E-10	2.44E+03	1.64E+02	5.76E+03	0.00E+00	-9.79658632	-2.524328812	3.38774566	2.215961776	3.760067967
1	10	41.2	7.2	5.8	106.9	2.10E-04	3.39E-27	3.55E+03	1.60E+02	1.47E+03	0.00E+00	-26.4698003	-3.676954265	3.549983611	2.204119983	3.16592655
1	11	90.9	20.5	53.2	191.6	4.30E-04	1.51E-02	8.32E+03	2.50E+02	5.88E+03	0.00E+00	-1.821023053	-3.366531544	3.920279895	2.398437842	3.769121697
1	12	60.0	15.3	40.2	120.6	2.27E-02	5.60E-14	1.35E+01	4.11E+02	2.09E+04	0.00E+00	-13.25219991	-1.643343248	1.131875188	2.613860419	4.319855274

1	13	70.7	19.2	40.5	145.3	3.57E-03	5.99E-14	1.60E+02	2.45E+03	3.00E+07	0.00E+00	-13.22257318	-2.447331784	2.20341368	3.388839709	7.477121255
1	14	77.3	20.5	41.6	139.5	8.07E-04	2.86E-14	5.43E+01	4.45E+03	2.17E+04	0.00E+00	-13.54408976	-3.093180285	1.735158794	3.648451252	4.335578243
1	15	81.3	16.3	45.7	180.3	1.51E-02	7.43E-14	4.34E+03	1.47E+03	3.53E+04	0.00E+00	-13.1291281	-1.821438276	3.637589786	3.16674351	4.547233038
1	16	110.8	30.0	56.9	171.7	3.21E-04	8.04E-14	6.53E+03	4.41E+02	2.34E+07	0.00E+00	-13.094852	-3.493494968	3.81517913	2.644359799	7.368363318
1	17	96.0	22.2	45.9	150.1	4.29E-04	2.45E-14	1.12E+01	5.87E+02	1.09E+04	0.00E+00	-13.61154355	-3.368049174	1.048270849	2.769007132	4.03841747
1	18	89.5	19.6	40.2	140.3	5.31E-03	5.36E-14	4.79E+03	7.43E+01	1.56E+07	0.00E+00	-13.27083521	-2.274905479	3.680607429	1.871164133	7.192583211
1	19	68.9	20.0	45.0	145.9	6.52E-03	5.36E-14	3.49E+03	9.90E+01	1.55E+07	0.00E+00	-13.27083521	-2.18608558	3.542776893	1.995635195	7.190352827
1	20	97.5	28.2	50.6	136.8	4.29E-04	1.38E-26	1.36E+01	4.89E+02	4.73E+03	0.00E+00	-25.86012091	-3.367542708	1.134495856	2.688953463	3.674401813
1	21	48.3	8.3	6.7	106.8	5.31E-03	5.36E-17	2.34E+03	7.43E+01	1.56E+07	0.00E+00	-16.27083521	-2.274905479	3.369934484	1.871164133	7.192579111
1	22	75.6	19.3	35.6	142.6	7.21E-03	8.04E-14	1.52E+04	3.91E+02	2.34E+07	0.00E+00	-13.09474395	-2.142064735	4.181872159	2.592398624	7.368353763
1	23	66.7	18.5	41.6	135.4	6.15E-03	8.04E-14	5.11E+03	4.74E+01	2.34E+07	0.00E+00	-13.09474395	-2.210913085	3.708165858	1.676043968	7.368299238
1	24	81.7	18.6	32.5	128.7	3.50E-03	5.36E-17	2.34E+03	3.73E+01	1.56E+08	0.00E+00	-16.27083521	-2.455931956	3.369920087	1.571359393	8.192576733
1	25	76.0	19.9	35.2	136.7	8.07E-03	8.16E-14	2.95E+03	5.88E+02	2.37E+07	0.00E+00	-13.08830984	-2.093126465	3.469423607	2.769180076	7.375001536

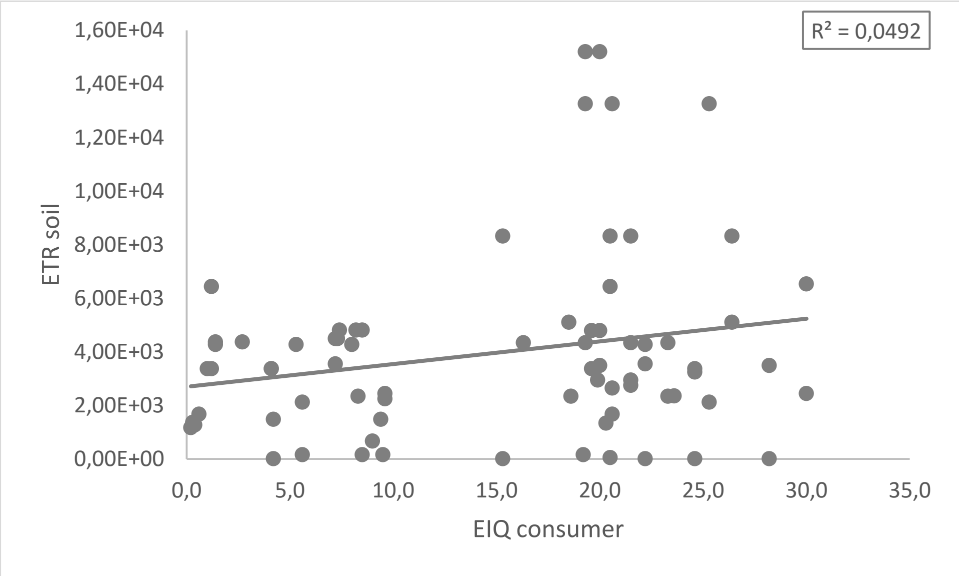
2	1	78.9	**20.6**	**52.7**	**163.3**	4.43E-04	7.96E-11	1.33E+04	2.55E+02	5.90E+03	0.00E+00	-10.09919607	-3.353596274	4.122445256	2.407028257	3.770597249
2	2	54.0	8.2	9.9	144.0	2.15E-02	9.73E-15	4.81E+03	3.36E+02	5.00E+03	0.00E+00	-14.01188716	-1.66756154	3.682235357	2.526697242	3.698917886
2	3	41.3	7.3	6.0	110.5	2.01E-04	1.87E-14	4.49E+03	3.99E+02	7.89E+03	0.00E+00	-13.72815839	-3.696803943	3.652439748	2.601071357	3.897132043
2	4	16.3	1.2	3.7	44.2	1.40E-04	6.14E-12	3.37E+03	2.29E+02	3.51E+03	0.00E+00	-11.21197312	-3.853871964	3.527758753	2.359384986	3.544787137
2	5	150.0	26.4	21.8	401.8	4.30E-04	1.51E-02	8.32E+03	6.66E+06	2.31E+08	0.00E+00	-1.821023053	-3.366531544	3.920279895	6.823333811	8.364072631
2	6	87.3	23.3	59.3	179.5	8.07E-04	7.43E-14	4.34E+03	4.45E+03	2.17E+04	0.00E+00	-13.1291281	-3.093180285	3.637589786	3.648451252	4.335578243
2	7	13.0	4.1	10.3	24.7	1.50E-04	6.74E-12	3.37E+03	1.47E+03	3.53E+04	0.00E+00	-11.17146899	-3.823908741	3.527758753	3.16674351	4.547233038
2	8	35.1	4.2	11.5	89.6	4.03E-03	4.08E-14	1.48E+03	4.89E+02	4.73E+03	0.00E+00	-13.38933984	-2.394694954	3.170934644	2.688953463	3.674401813
2	9	8.2	0.6	1.8	22.1	7.00E-05	3.74E-12	1.67E+03	3.91E+02	2.34E+07	0.00E+00	-11.4273607	-4.15490196	3.22297645	2.592398624	7.368353763
2	10	24.4	8.0	18.9	46.4	2.50E-04	7.84E-12	4.27E+03	2.50E+02	5.88E+03	0.00E+00	-11.10579474	-3.602059991	3.630529571	2.398437842	3.769121697
2	11	13.0	4.1	10.3	24.7	1.50E-04	6.74E-12	3.37E+03	1.47E+03	3.53E+04	0.00E+00	-11.17146899	-3.823908741	3.527758753	3.16674351	4.547233038
2	12	35.1	9.4	26.7	69.1	4.03E-03	4.08E-14	1.48E+03	5.00E+02	4.80E+03	0.00E+00	-13.38933984	-2.394694954	3.170934644	2.69862243	3.680788612
2	13	2.1	0.2	0.8	5.1	4.10E-05	2.44E-12	1.17E+03	5.31E+02	4.90E+03	0.00E+00	-11.6129663	-4.387216143	3.068556895	2.724767246	3.689752696

2	14	2.3	0.3	0.9	5.7	4.30E-05	2.84E-12	1.37E+03	5.51E+02	4.96E+03	0.00E+00	-11.54698761	-4.366531544	3.137037455	2.740836207	3.695043659
2	15	51.4	7.4	36.0	110.8	2.15E-02	9.73E-15	4.81E+03	3.16E+02	4.98E+03	0.00E+00	-14.01188716	-1.66756154	3.682235357	2.500067693	3.697177015
2	16	108.6	5.6	14.8	305.8	3.57E-03	5.99E-14	1.60E+02	2.49E+03	2.90E+07	0.00E+00	-13.22257318	-2.447331784	2.20341368	3.396401535	7.462397998
2	17	5.6	0.4	2.6	13.8	7.30E-05	4.24E-12	1.27E+03	4.05E+02	2.84E+07	0.00E+00	-11.37283905	-4.13667714	3.104145551	2.607669222	7.452608147
2	18	21.6	5.3	16.3	43.2	2.50E-04	7.84E-12	4.27E+03	2.58E+02	5.90E+03	0.00E+00	-11.10579474	-3.602059991	3.630529571	2.412102111	3.770597249
2	19	68.0	21.5	53.6	129.1	6.67E-03	6.76E-14	2.75E+03	3.60E+02	2.04E+07	0.00E+00	-13.1700533	-2.175874166	3.438905296	2.556543467	7.30864115
2	20	68.4	21.5	53.8	130.2	7.07E-03	7.96E-14	2.95E+03	3.50E+02	2.13E+07	0.00E+00	-13.09908693	-2.150580586	3.469423607	2.544315894	7.327432421
2	21	89.4	24.6	68.6	175.2	8.67E-03	8.96E-14	3.25E+03	4.95E+03	2.57E+04	0.00E+00	-13.04769199	-2.061980903	3.511521744	3.694687225	4.409188947
2	22	27.6	1.4	3.9	77.5	2.50E-04	7.84E-12	4.27E+03	2.39E+02	5.81E+03	0.00E+00	-11.10579474	-3.602059991	3.630529571	2.378918633	3.763917422
2	23	65.6	20.6	51.6	124.8	6.07E-03	7.16E-14	2.65E+03	2.09E+02	5.21E+03	0.00E+00	-13.14508698	-2.216811309	3.422802339	2.320741713	3.716549209
2	24	30.8	9.0	25.7	57.7	2.00E-05	1.24E-12	6.71E+02	2.00E+02	5.04E+03	0.00E+00	-11.90727936	-4.698970004	2.82672252	2.301652198	3.702132287
2	25	36.9	2.7	8.1	99.3	3.50E-04	8.74E-12	4.37E+03	2.40E+03	2.80E+07	0.00E+00	-11.05858796	-3.455931956	3.640580806	3.38042101	7.447158031
3	1	108.6	5.6	14.8	305.8	9.48E-03	2.53E-14	2.12E+03	5.45E+03	3.17E+04	0.00E+00	-13.59773862	-2.023191663	3.327154512	3.736471003	4.500456037

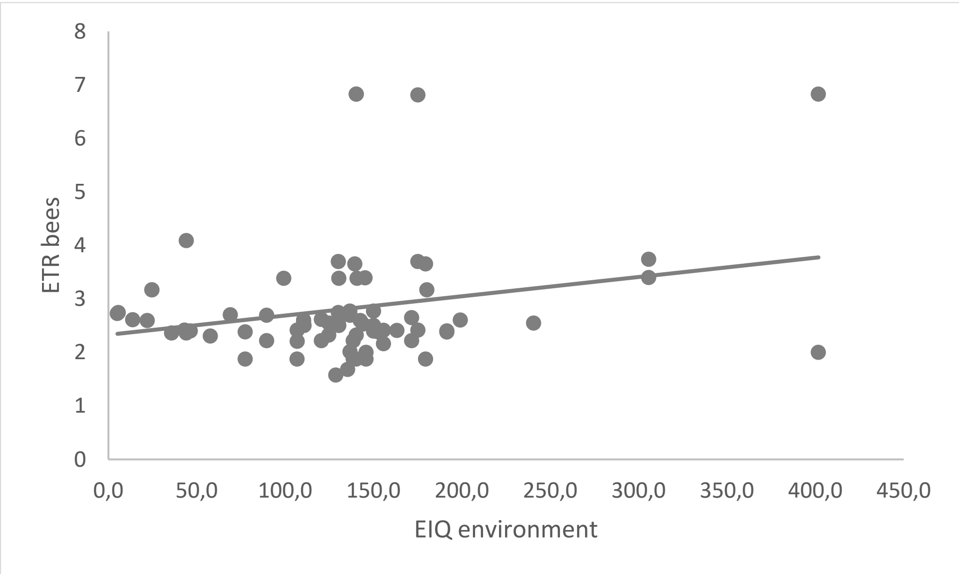
3	2	110.8	30.0	56.9	171.7	2.99E-03	1.60E-10	2.44E+03	1.64E+02	5.76E+03	0.00E+00	-9.79658632	-2.524328812	3.38774566	2.215961776	3.760067967
3	3	96.0	22.2	45.9	150.1	2.10E-04	3.39E-27	3.55E+03	3.16E+02	4.98E+03	0.00E+00	-26.4698003	-3.676954265	3.549983611	2.500067693	3.697177015
3	4	68.4	21.5	53.8	130.2	4.30E-04	1.51E-02	8.32E+03	5.51E+02	4.96E+03	0.00E+00	-1.821023053	-3.366531544	3.920279895	2.740836207	3.695043659
3	5	89.4	24.6	68.6	175.2	2.27E-02	5.60E-14	1.21E+01	2.58E+02	5.90E+03	0.00E+00	-13.25219991	-1.643343248	1.084218687	2.412102111	3.770597249
3	6	52.7	8.5	7.2	130.5	3.57E-03	5.99E-14	1.60E+02	2.40E+03	2.80E+07	0.00E+00	-13.22257318	-2.447331784	2.20341368	3.38042101	7.447158031
3	7	52.8	9.5	8.3	140.8	3.57E-03	5.99E-14	1.60E+02	2.40E+03	2.80E+07	0.00E+00	-13.22257318	-2.447331784	2.20341368	3.38042101	7.447158031
3	8	70.3	19.3	44.3	140.3	8.07E-04	7.43E-14	4.34E+03	2.09E+02	5.31E+03	0.00E+00	-13.1291281	-3.093180285	3.637589786	2.320741713	3.724811442
3	9	95.3	25.3	47.6	155.7	4.43E-04	7.96E-11	1.33E+04	2.56E+02	5.94E+03	0.00E+00	-10.09919607	-3.353596274	4.122445256	2.408726137	3.773533398
3	19	59.2	9.6	8.0	138.6	5.09E-03	5.86E-14	2.25E+03	7.43E+01	1.56E+07	0.00E+00	-13.23210238	-2.293282218	3.351660086	1.871164133	7.192579111
3	11	41.2	7.2	5.8	106.9	2.01E-04	1.87E-14	4.49E+03	2.58E+02	5.90E+03	0.00E+00	-13.72815839	-3.696803943	3.652439748	2.412102111	3.770597249
3	12	90.9	20.5	53.2	191.6	2.44E-04	2.98E-14	6.44E+03	2.38E+02	5.61E+03	0.00E+00	-13.52578374	-3.612610174	3.808548551	2.377099876	3.748694925
3	13	60.0	15.3	40.2	120.6	4.30E-04	1.51E-02	8.32E+03	1.64E+02	5.76E+03	0.00E+00	-1.821023053	-3.366531544	3.920279895	2.215961776	3.760067967
3	14	68.4	21.5	53.8	130.2	8.07E-04	7.43E-14	4.34E+03	4.95E+03	2.57E+04	0.00E+00	-13.1291281	-3.093180285	3.637589786	3.694687225	4.409188947

3	15	89.4	24.6	68.6	175.2	1.50E-04	6.74E-12	3.37E+03	6.46E+06	2.11E+08	0.00E+00	-11.17146899	-3.823908741	3.527758753	6.810087751	8.324786745
3	16	27.6	1.4	3.9	77.5	3.50E-04	8.74E-12	4.37E+03	7.43E+01	1.56E+07	0.00E+00	-11.05858796	-3.455931956	3.640580806	1.871164133	7.192579111
3	17	65.6	20.6	51.6	124.8	7.00E-05	3.74E-12	1.67E+03	3.50E+02	2.13E+07	0.00E+00	-11.4273607	-4.15490196	3.22297645	2.544315894	7.327432421
3	18	96.0	22.2	45.9	150.1	2.50E-04	7.84E-12	4.27E+03	2.48E+02	5.89E+05	0.00E+00	-11.10579474	-3.602059991	3.630529571	2.394953526	5.770333891
3	19	89.5	19.6	40.2	140.3	1.50E-04	6.74E-12	3.37E+03	6.66E+06	2.31E+08	0.00E+00	-11.17146899	-3.823908741	3.527758753	6.823333811	8.364072631
3	20	68.9	20.0	45.0	145.9	5.31E-03	5.36E-14	4.79E+03	7.43E+01	1.56E+07	0.00E+00	-13.27083521	-2.274905479	3.680607429	1.871164133	7.192583211
3	21	97.5	28.2	50.6	136.8	6.52E-03	5.36E-14	3.49E+03	1.02E+02	1.30E+07	0.00E+00	-13.27083521	-2.18608558	3.542776893	2.008600172	7.113968544
3	22	35.1	4.2	11.5	89.6	4.29E-04	1.38E-26	1.36E+01	1.64E+02	5.76E+03	0.00E+00	-25.86012091	-3.367542708	1.134495856	2.215961776	3.760067967
3	23	87.3	23.3	59.3	179.5	5.31E-03	5.36E-17	2.34E+03	7.43E+01	1.56E+07	0.00E+00	-16.27083521	-2.274905479	3.369934484	1.871164133	7.192583211
3	24	103.7	20.0	50.3	240.7	7.21E-03	8.04E-14	1.52E+04	3.50E+02	2.13E+07	0.00E+00	-13.09474395	-2.142064735	4.181872159	2.544315894	7.327432421
3	25	150.0	26.4	21.8	401.8	6.15E-03	8.04E-14	5.11E+03	9.90E+01	1.55E+07	0.00E+00	-13.09474395	-2.210913085	3.708165858	1.995635195	7.190352827

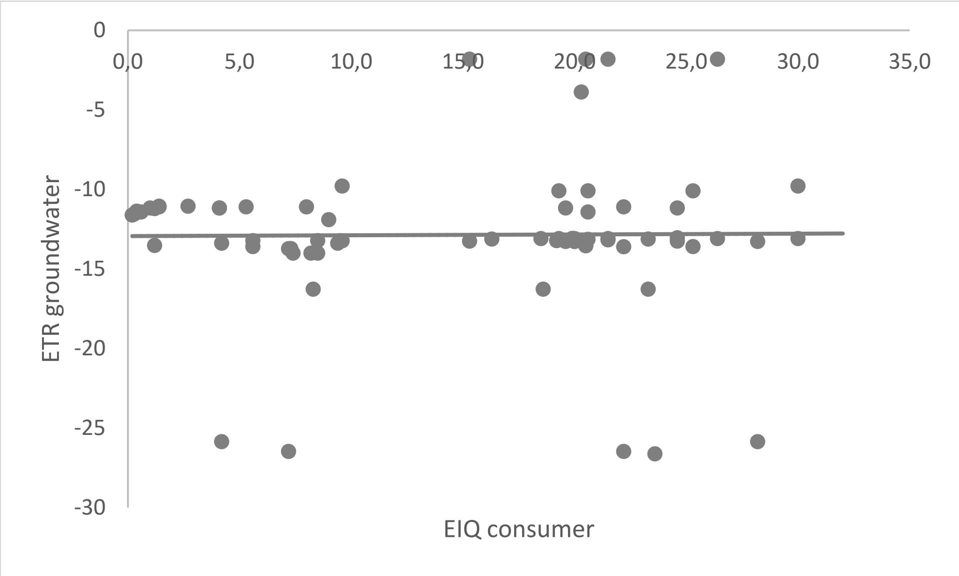
Appendix 7 Scatter plot of ETR soil and EIQ consumer for all 75 farmers



Appendix 8 Scatter plot of ETR bees and EIQ environment for all 75 farmers



Appendix 9 Scatter plot of ETR groundwater and EIQ consumer for all 75 farmers



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