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**The impact of shade management on presence of heteropterous
pests of cocoa (*Theobroma cacao* L.) in San Alejandro, Peruvian
Amazon**

M.Sc. Thesis

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DECLARATION

I, Stanislav Křížek hereby declare that this thesis independently, submitted in partial fulfilment of requirements for the master degree in Faculty of Tropical AgriSciences of the Czech University of Life Sciences Prague, is wholly my own work written exclusively with the use of the quoted sources.

In Prague, 2015

.....

Stanislav Křížek

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ABSTRACT

Cocoa tree, *Theobroma cacao* L. (Malvaceae), is traditionally cultivated in agroforestry system with cover canopy trees. Recent trend is to eliminate cover canopy trees in order to get better yields. Change of climatic conditions within cocoa plantation affects occurrence of pest and diseases. We have selected three similar cocoa plantations around San Alejandro city in Peruvian Amazon in order to assess the impact of changing light conditions on occurrence of important pest species *Monalonion dissimulatum* Distant 1883 (Heteroptera: Miridae) and *Parajalysus andinus* Horvath 1905 (Heteroptera: Berytidae). There were randomly established four study plots with five sample trees under canopy cover and in open cultivation on each plantation; in total evaluating 60 trees on occurrence of both insects. On every tree were counted the number of punctures made by *M. dissimulatum* on all pods and number of individuals of *P. andinus* on 10 young leaves. Morphometric parameters of the pods and leaves and occurrence of insects were noted. Previous studies on relatively known *M. dissimulatum* give different results and no study on behavior of *P. andinus* was carried out before. Statistical analysis was done in R software using logit model. Our results clearly support fact that the occurrence of both insects is significantly stimulated by shade conditions. There was not discovered any preferred pod or leaf length respectively. The result of our investigation of *M. dissimulatum* is not correspondent to works carried out before which suggests that this insect has site-specified behavior. No investigation on behavior of *P. andinus* was carried out before. Our results should not be considered as incentive to change cocoa plantation to monoculture, because economic importance of these two pests in the region is low and shade trees play important environmental and economical services in agroforestry system. Shade management should be a part of pest management in cocoa plantation.

Key words: agroforestry, cocoa pest, Peruvian Amazon, cocoa tree, *Theobroma cacao* L., *Monalonion dissimulatum* Dist., *Parajalysus andinus* Horvath, Berytidae, Miridae, stilt bugs, plant bugs, shade management, diseases.

ABSTRAKT

Kakaovník pravý, *Theobroma cacao* L. (Malvaceae), je tradičně pěstován v agrolesnických systémech v zástinu tvořeným krycími stromy. Současným trendem v mnoha regionech pěstujících kakao je eliminovat krycí stromy pro zvýšení výnosu. Změna klimatických podmínek uvnitř kakaové plantáže ovlivňuje výskyt chorob a škůdců. Zkoumali jsme výskyt škůdců na třech kakaových plantážích v okolí městečka San Alejandro v peruánské Amazonii v závislosti na různých světelných podmínkách. Studovanými škůdci byl *Monalonion dissimulatum* Distant 1883 (Heteroptera: Miridae), významný škůdce kakaových bobů a *Parajalysus andinus* Horvath 1905 (Heteroptera: Berytidae), napadající listy kakaa. Na každé plantáži byly založeny 4 zkusmé plochy po pěti stromech v zástinu a v otevřeném pěstování, celkově jsme tedy vyhodnotili oba druhy na 60 stromech. Na každém stromě se sečetly všechny dostupné plody a deset mladých listů, zaznamenala se jejich délka a výskyt škůdců. Analýza dat byla provedena pomocí logistické regrese v programu R. Naše výsledky jasně ukazují, že zástin stimuluje výskyt obou škůdců. Nebyla zjištěna žádná přednostně napadaná délka plodů, respektive listů. Výsledek zkoumání *M. dissimulatum* není v souladu s předešlými pracemi, což zřejmě značí, že výskyt tohoto škůdce je značně závislý na místních podmínkách. Na výzkum chování *P. andinus* nebyl vypracován doposud žádný výzkum. Naše výsledky by neměly být brány za bernou minci v procesu eliminace krycích stromů v kakaových plantážích, jelikož významnost obou škůdců v regionu je malá a krycí stromy plní mnoho environmentálních a ekonomických funkcí. Úprava zástinu by měla být částí integrované ochrany na plantážích kakaa.

Klíčová slova: agrolesnictví, škůdce na kakau, peruánská Amazonie, kakaovník pravý, *Theobroma cacao* L., klopušky, Miridae, *Monalonion dissimulatum* Dist., štíhlenkovití, Berytidae, *Parajalysus andinus* Horvath, zástin, choroby.

RESUMEN

El cacao, *Theobroma cacao* L., (Malvaceae) se cultiva tradicionalmente en los sistemas agroforestales bajo árboles de sombra. En muchas regiones de producción del cacao hay una tendencia de eliminar los árboles de sombra para obtener mayor cosecha. El cambio microclimático dentro de los cacaoteros influye en la aparición de plagas y enfermedades. En nuestro estudio investigamos la presencia de las plagas según las condiciones luminosas en 3 plantaciones en los alrededores de la ciudad de San Alejandro en la Amazonía Peruana. Los insectos del estudio son *Monalonion dissimulatum* Distant 1883 o “el chinche mosquilla” (Heteroptera: Miridae), que es una plaga importante en las mazorcas y *Parajalysus andinus* o “el chinche zancudo” Horváth 1905 (Heteroptera: Berytidae), que ataca las hojas tiernas del cacao. En cada plantación fueron establecidas 4 áreas experimentales de cinco árboles en sombra o en sol, en total hemos examinado 60 árboles. En cada árbol fueron contadas todas las mazorcas y sus picaduras. Asimismo, en el mismo árbol se evaluaron 10 hojas tiernas y la presencia del *P. andinus* en ellas. El análisis estadístico fue hecho en el programa R. Nuestros resultados claramente señalan que la sombra favorece la aparición de ambas plagas. No se encontró ninguna preferencia por el tamaño de las mazorcas o las hojas. El resultado de nuestra investigación sobre el *M. dissimulatum* no es paralelo con algunas investigaciones previas. Esto significa que el “chinche mosquilla” tiene un comportamiento variado de acuerdo a las condiciones regionales. En el comportamiento del *P. andinus* no fue elaborada ninguna investigación previa. Nuestros resultados no deben ser el motivo para la eliminación de los árboles de sombra, ya que los árboles de sombra tienen un alto valor ecológico y económico en los sistemas agroforestales. La manipulación de la sombra debería ser un parte del manejo integrado de las plagas en los cacaoteros.

Palabras clave: agoroforestería, plaga del cacao, Amazonía peruana, cacao, *Theobroma cacao* L., Miridae, *Monalonion dissimulatum* Dist., chinche mosquilla, Berytidae, *Parajalysus andinus*, chinche zancudo, sombra, enfermedades.

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1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) is an important pantropical crop. It forms major source of income for smallholders in many developing countries as well as main cash crop for several West African economies (Motamayor et al., 2008). Cocoa, cultivated in agroforestry-based agriculture systems (Nair, 1993) is an environment friendly crop, as it can provide a reservoir for biodiversity during forest disturbance (Lojka et al., 2010). It belongs among crops cultivated traditionally in shade conditions, as it occurs naturally in undergrowth in its place of origin, Amazonia. Well-known crops such as black pepper (*Piper nigrum*) and vanilla (*Vanilla fragrans*) and lesser-known crops such as Yerba mate (*Ilex paraguariensis*) (Evans et al., 1984) and cupuazú (*Theobroma grandiflorum*) – close relative of cocoa, could be found in this group (Beer et al., 1998). The necessity of shade is widely discussed. Farmers tend to reduce canopy closure in order to intensify the production and get better yields (Juhrbandt et al., 2010).

The cocoa cultivation had spread rapidly from the Amazon throughout the tropics of Old and New World, assuming that isolation from its co-evolved native pathogens will ensure high and safer yields. However in this case the assumption did not meet the reality, as cocoa tree was adapted as a host plant for many local pathogens, from which some present main limitation factor in the production (Keane, 1992). Therefore, big threat for the cocoa producing countries is represented by accidental introduction of crop related diseases. This threat was demonstrated by important drops of yield in the history of cocoa cultivation (Pereira et al., 1996; Leiter, 2004). Most recently, the introduction of fungi *Moniliophthora perniciosa* (Stahel) Aime & Phillips-Mora to Brazil caused the drop of cocoa cultivation from the second world largest producer and caused 75% reduction of yields (Hebbar, 2007). Attention should be paid also on pests and particularly mirids, as they were responsible for temporal abandonment of West African cocoa plantations in 1920's, which lasted until the beginning of 1950's when widespread use of pesticides took place (Wood, 1985; Schaefer et al., 2000). As the most important issue worldwide for cocoa production are diseases (Hebbar, 2007), then it is logic that huge effort was put on the protection against accidental disease introduction to untainted areas and on investigation evolution and development of diseases. As cocoa is a product cultivated in very simple agronomy (by smallholders with almost absence of mechanization) and processed in industrialized countries, strong effort had been

carried out on the suggestion of new sustainable and low income integrated disease management adaptable for smallholders (Meléndez, 1993, Hebbar 2007). These incentives included also eradication of shade trees. It seems that lowering of humidity and higher air movement would decrease the level of disease attack, however, the effect of adverse conditions on the pests remains to be discussed (Keane, 1992, Beer et al., 1998). Keane (1992) first mentioned that the effect of shade is questionable in the case of mirids (*Heteroptera: Miridae*). They are considered as most important cocoa pests worldwide (Muhamad et al., 1995). A contradictory claiming was observed, as both suppressing and stimulating effects of shade on their presence were mentioned (Coto, 2003; Donis, 1988; Wille, 1944). The possible reason of this could be the variance in insect behavior under different climate, as the works were carried out in different regions of Latin America.

Heteroptera (true bugs) consists of a large number of phytophagous pests. Both *Berytidae* (stilt bugs) and primarily *Miridae* (plant bugs) include predominantly phytophagous species (Cassis et al., 2002). However, stilt bugs are discussed also as predatory or pollinating species, which is giving them possibility to play some role in integrated plant protection (Beingolea, 1959; Henry, 2000; Rogg, 2000). As was mentioned above, especially *Miridae* are considered as important cocoa pest worldwide (Muhamad et al., 1995).

The aim of this study was to assess the impact of shade management on the level of attack of two important cocoa pest species (*Theobroma cacao* L), *Monalonion dissimulatum* Distant 1883 (*Hemiptera; Miridae*) and *Parajalysus andinus* Horvath 1905 (*Hemiptera; Berytidae*) in Peruvian Amazon.

2. LITERATURE REVIEW

2.1. COCOA

2.1.1. BOTANY

Cocoa brings pleasure for human since ancient time, as this important crop was national drink already for old Aztecs and Mayas. Taxonomic nomenclature outcomes from Greek word Theo-broma, which is a name for “Food of the Gods” (Knapp, 1920). It is cultivated in Central America for more than 1500 years (Motamayor et al., 2002). The cocoa tree *Theobroma cacao* L. is a crop belonging to the family Malvaceae, native to humid regions. There are more than 20 species within the genus *Theobroma*, but only cocoa is cultivated widely (Wood, 1985a).

Majority of cocoa roots is superficial and it is present in the upper 30 cm layer of soil. Root development is affected by soil structure and, in particular, by conditions of soil moisture and aeration. The majority of the roots does not go deeper than 45 cm in waterlogged conditions; anyway in optimal moisture the roots go much deeper. Cocoa tree is cauliflorous, that means, the flowers and fruits develop on the trunk and main old branches (figure 1) and there is a complicated process of pollination, provided by flying female of insect *Forcipomyia* sp. Meigen, 1818 (*Diptera: Ceratopogonidae*). However, also pest *P. andinus* studied in this thesis was also considered as a possible cacao pollinator (Pruett, 1996). This system provides self-pollination incompatibility for majority of the varieties, except Amelonado (West African variety of Forastero group, see next chapter). From 10,000 flowers developed per year only 10 to 50 will develop as mature fruits depending on the season and number of flowers opening at the time (Murray, 1975). The fruit development lasts usually from 5 to 6 months. Important factor called “cherelle wilt” takes place at that time. It is abortion of young developing fruits called “cherelle” induced by tree itself as a result of competition between older developing fruits themselves and vegetation growth. The fruit remains on the trunk as the frequent breakdown of the abscission layer does not occur at cocoa tree. The fruit is indehiscent (non-splitting) drupe, usually called a pod. The length may vary from 10 cm to 30 cm (Murray, 1975). It shows a great variation in the pod size, shape and color (Kalousová, 2013).



Figure 1: *Theobroma cacao*, L. (Polivka, 1908).

2.1.2. ORIGIN AND DISTRIBUTION

One could get confused by many approaches to classification of populations of cocoa, taking into consideration many transfers of planting material throughout the world and specific way of cocoa pollination preventing self-pollination. Most of the groups are recognized according to its geomorphological characteristics. The basis of widely accepted division forms 2 groups: Criollo with almost rounded and white seeds occurring mainly in Central America and purple seeded Forastero, which has a lot of diverse populations in river valleys occurring throughout the Amazon basin on the Andean foothills (Cheesman, 1944; Murray, 1975; Wood, 1985a). A third group, Trinitario, consisting of more disease resistant hybrids of both mentioned groups is recognized. Sometimes, another group of cocoa is recognized – Nacional in Ecuador. West African homogenous cocoa population resulting from introduction of small group of Amazonian Forastero, is called Amelonado and makes largest production throughout the world.

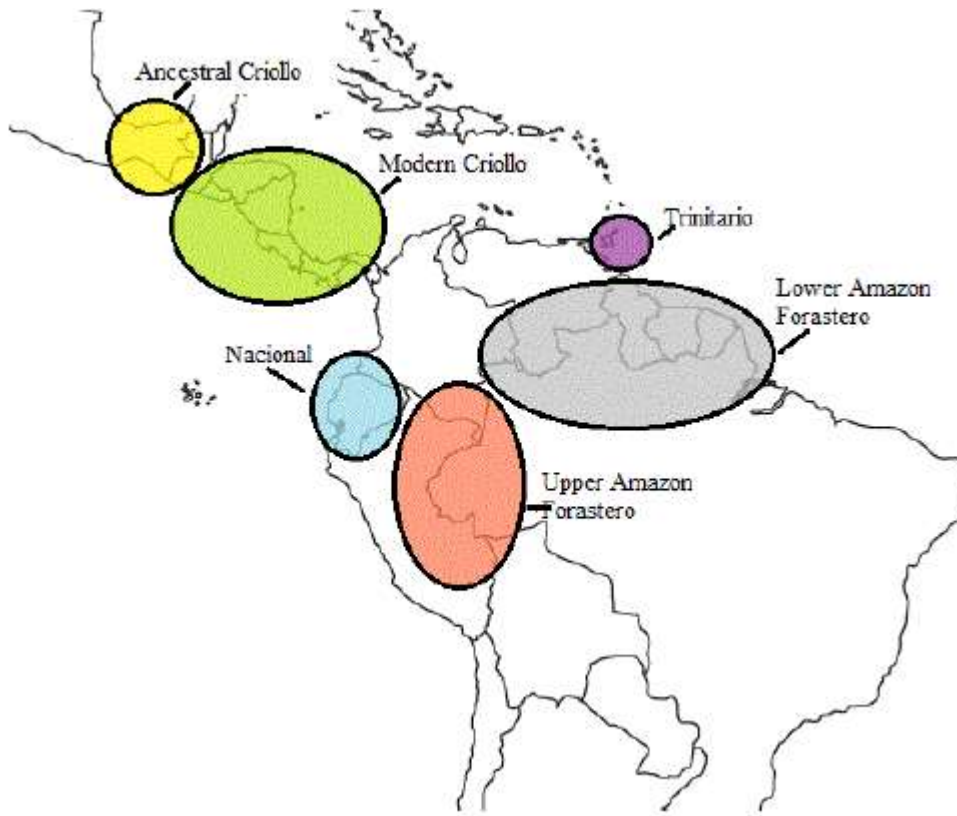


Figure 2: Map of the distribution of the main genetic groups of cocoa in Latin America (Kalousová, 2013).

According to morphological differences, it was accepted that there were two centers of origin, one lying in Central America and another in Amazon valleys, although there are no natural populations of cocoa in Central America. Investigation of genetic composition of Criollo population revealed small genetic difference between Criollo from Central America and Forastero from the Amazon, when higher degree of similarity between Criollo and Forastero than between populations within Forastero group was recognized. On the basis of this investigation, the Criollo population in Central America is nowadays known as a man-introduced population (Motamayor et al., 2002). Thus, origin of cocoa is being placed into the Amazon region (Alverson et al., 1998). Search for genetic differentiation of cocoa alters traditional grouping by proposing new division to ten groups according to genetic clustering (Motamayor et al., 2008) (figure 2).

2.1.3. ECOLOGY

Altitudinal range of cocoa cultivation is driven by temperature. Therefore, it varies from sea level until high altitudes where the climate is friendly. Cultivation in 1,400 m. a. s. l. was recorded in Colombia (Wood, 1985b). As the cultivation range occupies lower altitudes in higher latitudes, the upper level of cocoa cultivation in Peru does not exceed 800 m. a. s. l. As a crop typical to tropical humid climate, the cocoa is being cultivated mainly between 15° N to 15° S. The latitude of 23° 25' S is reached in the Brazil state of Sao Paulo, but here the plants can suffer in cold years (Hernández et al., 1992).

The recommended annual average temperature should optimally range about 25°C. Cocoa is able to withstand high temperatures with a maximum annual average of 30°C. Constant temperature of 31°C had provoked damage to plants in experiments in Trinidad. Significantly higher temperatures for small period of time could be reached in field conditions, as is common in West Africa, where average monthly temperature is above 32°C (Wood, 1985b). On the other side, it was investigated that annual average temperature below 23°C reduces flowering (Hernández et al., 1992). Here could be found one from the reasons for harvest seasonality in some regions, as the flowering is reduced during months with average temperature lower than 23°C. Monthly average temperatures higher than 15°C are required for successful cocoa cultivation. The absolute minimal temperature below 10°C produces damage to crop. Low temperature affects vegetative growth, pod development and rate of flowering (Wood, 1985b; Hernández et al., 1992).

Optimal rainfall for cocoa takes place in the belt 8° from equator, where 75% of cocoa production is placed. It demands high precipitative climate with evenly distributed rainfall. But the cocoa is susceptible to variation in soil moisture: it is not able to withstand prolonged period of waterlogging, as well as it is exceptionally susceptible to shortages in soil moisture. In the place of origin of cocoa, in headwater of Amazon River, high rainfall above 2,000 mm is evenly distributed throughout the year. This is quite different climate from Ecuador, where whole rainfall of 2,000 mm is concentrated in 5 months of wet period. Pronounced dry period lasting 7 months (with precipitation > 100 mm) is present there. In Africa, total rainfall in cocoa producing regions varies from 1,200 mm to 3,000 mm. Generally, cocoa should be irrigated, if the average annual rainfall is lower than 1,250 mm (Wood, 1985b). As well as temperature the accessibility of rainfall drives the seasonality of the harvest, as it occurs in West Africa, where about 80% of production is being concentrated in wet period (Hernández et al., 1992).

Cocoa is a crop sensitive to strong winds, which creates a factor able to limit cocoa cultivation, unless windrows are employed. The principal effect of strong wind is defoliation or premature leaf fall, which can result in mechanical damage. The problem severity rises with elimination of canopy cover within the plantation. Threshold wind speed value for observing defoliation was considered as 4 m/sec (Hernández et al., 1992).

2.1.4. CULTIVATION

Natural habitat for cocoa is the lower tree storey of the rainforest. In this environment it is adapted to high mean annual temperature without large variation and to high precipitation values. High relative humidity and low irradiation values are leading factors in cocoa natural habitat. It often grows in the floodplains, when it can stand in moving flood waters of rivers for several months of year. Although cocoa is able to survive in this condition, it does not provide high yields. The cocoa tree reaches from 8 to 10 meters in height and it tends to grow less high when cultivated without shade (Murray, 1975; Wood, 1985). These conditions are imitated by agroforestry practices, very rich in species, where cocoa is traditionally cultivated (Nair, 1993).

Average yields per hectare are 500 kg, but it can reach also 3,000 kg on experimental fields (FAOSTAT; Yin, 2004). The necessity of shade remains to be discussed. The demand of the crop resulting from the conditions in its natural environment and additional benefits produced by mixed shade trees favor traditional shade cultivation. However, when favorable conditions like sufficient humidity and adequate nutrients are available, higher yields could be expected from open cultivation (Adomako, 1983; Wood, 1985). Young plantings of cocoa are always recommended to grow in shady conditions.

There are two general methods of plantation establishment. It can be carried out by thinning of forest cover or by clearcut – firstly totally cleared and then replanted forest site, when both methods could be done in primary and secondary forest, when the later site demands for lesser work. Clear cut method involve establishment of shade crops, when there can be temporal or permanent shade established. Approximate density of shade should be around 50% to ensure good conditions for growth of the plantings (Hernández et al., 1992b). There were experimental plots with establishment of cocoa seedlings without shade, but this required advanced management practices (Wood, 1975).

Establishment of canopy trees has to be carried out several months before planting of cocoa seedlings to ensure sufficient shade. There are two types of shade management: temporal and permanent shade. Temporal shade is often provided by banana or plantain (*Musa* sp.), because of additional food and cash benefits. But it has to be noted that there is a high risk of competition for nutrients and moisture between banana and cacao (Hernández et al., 1992b). Permanent shade practices employ broad variety of trees, predominantly leguminous according to local variety. Although demanding for additional labor, shade trees provide good source of nutrients in pruning residues and litterfall when it is able to supply up to 340 kg nitrogen per ha (Beer et al., 1998). Many *Erythrina* species are cultivated in Central America and Southeast Asia and large variety of *Inga* species is used in South America. In Trinidad, *E. fusca* Lour. suffered from witches' broom disease. Suppressive effect of three shade tree species (*E. poeppigiana* (Walp.) O.F.Cook, *Gliricidia sepium* (Jacq.) Kunth ex Walp. and *Inga edulis* C. Martius) on progress of frosty pod rot disease was investigated by Meléndez (1993), whereas the most efficient was evaluated *I. edulis*, which is a tree also widely planted in surroundings of San Alejandro (Kalousová, 2013). Other shade trees cultivated widely with cocoa involve for example *Leucaena glauca* Benth, *Albizia* sp. and *Parkia javanica* Hassk. (Wood, 1975).

Cocoa can be reproduced both by seedlings and by vegetative propagation (cuttings or grafts), but in traditional and most widely used (Hernández et al., 1992) seed propagation it is recommended to use certified seeds with controlled pollination, as the crop has complicated process of pollination with high risk of progeny of varying quality. It can be sown directly on the plot, or planted seedlings from nursery could be used. Hard control of genetic quality and necessity of great number of seeds makes these practices costly. Therefore, intentions to establish vegetative propagation has arisen (Wood, 1975; Abdoulaye et al., 2002). Vegetative propagation techniques were developed in first half of 20th century mainly on Trinitario hybrids, because its progeny is highly variable in performance. These practices are known very well throughout cocoa producing regions. It includes rooted cuttings, where plagiotropic growth and weak, drought susceptible roots of established plants create disadvantages of this method. Grafting, budding and recently investigated in vitro techniques eliminate many of these problems (Abdoulaye et al., 2002).

Cocoa trees in plantation are spaced according to crop growth and conditions of shade, when narrow spacing experimentally had greater yield, but just for first years of harvest. Generally trees are planted at spacing of 4 x 4 m. Application of fertilizers to planting hole shortly before planting is possible. First years of plantation are marked by control of weeds, replacement of dead plantings and pruning (Brilho et al., 1992).

2.2. PATHOGENS OF COCOA

When transferring some crop from its center of origin to new area of cultivation, isolated by far, it is expected, that the crop should be relieved from its pathogens. But, it is not the case of cocoa, on which many local pathogens have adapted, including fungi, viruses (such as African cocoa swollen shoot virus-CSSV) and insects (especially mirids). This process of adaptation seems to be still in progress, as many new-encounter species were described mainly in 20th century (Keane et al., 1992).

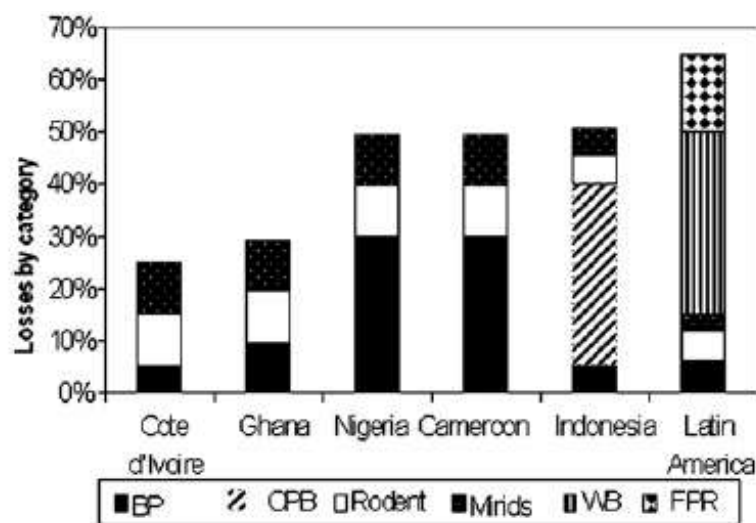


Figure 3: The proportion of cocoa crop losses worldwide: BP = black pod, CPB = cocoa pod borer, WB = witches' broom, FPR = frosty pod rot (Hebbar, 2007).

In compliance with figure 3, Evans (1988) mentioned that many harmful co-evolved cocoa pathogens are limiting its production in area of its origin, South America, and they are presenting potential threat to major cocoa producing countries. This destructive potential (notable from the table 1) was demonstrated on the historical declines in cocoa production in Trinidad and Brazil, caused by introduction of diseases *P. palmivora* and *M. pernicioso*,

respectively (Pereira et al., 1996; Leiter, 2004). Fortunately, until now no intercontinental spread of cocoa pathogens was noticed and all co-evolved pathogens remains in American tropics (Schaefer et al., 2000; Dropdata, 2014). Quarantine methods will be major measure against possible intercontinental pathogen spread (Keane et al., 1992).

Table 1: Important pathogens of cocoa (Gotsch, 1997; Aime, 2005).

Common name	Scientific name	Geographic distribution	Estimated annual loss in affected regions
Black pod, <i>Phytophthora</i> pod rot	<i>Phytophthora</i> spp.	Worldwide	5-90%
Witches' broom	<i>Moniliophthora perniciosa</i>	Northern South America (Brazil, Columbia, Ecuador, Venezuela, Peru), Panama, Granada, Trinidad and Tobago	10-90%
Soft rot, <i>Moniliophthora</i> pod rot	<i>Moniliophthora rozeri</i>	Northwestern South America (Columbia, Ecuador, Peru), southern Central America (up to Coasta Rica), western Amazon	10-65%
Vascular streak dieback	<i>Oncobasidium theobromae</i>	Papua New Guinea, Malaysia, Indonesia, India, Philippines	10-50%
Anthracnose of cocoa	<i>Colletotrichum gleosporoides</i>	Indonesia, Malaysia, India, Ghana	Up to 70%, reduces tree life up to 15 years
Swollen shoot	Cocoa swollen shoot virus (CSSV)	Nigeria, Ghana, Côte d'Ivoire, Sierra Leone, Togo	100% of infected trees killed
Cocoa moth, cocoa pod borer	<i>Ephestia elutella</i> , <i>Conopomorpha crammerella</i>	Philippines, Malaysia, Indonesia	Up to 50%
Mirids, capsids	<i>Helopeltis</i> spp., <i>Monalonion</i> spp.	Worldwide, especially in West and Central Africa (Cameroon, Nigeria, Ghana, Côte d'Ivoire, Togo)	5-20%

2.2.1. DISEASES

Diseases cause major cocoa yield loss in many cocoa producing countries (Nigeria, Cameroon and several regions of Latin America). They can reduce potential world pod production by 35% (Hebbar, 2007, figure 4). The variety of fungi pathogens is especially broad in Latin America. Here, in the center of origin of cocoa, all of the important diseases are present. Possible threat presented by accidental introduction of some disease together with difficulties of successful control of disease progress led to establishment of quarantine measures in movement of plant material and strict eradication of diseased trees, as took place during introduction of devastating witches' broom disease to Brazil and in control of highly virulent strains of cocoa swollen shoot virus in Africa (Wood, 1985). Inadequate management and lack of control destroys efforts to eradicate the pathogen, as it happened in previously mentioned Brazil, where costly and difficult measures took place after its first observed occurrence; however, second and much larger center of infestation remained unknown for

long time (Pereira et al., 1996). During my survey of plantations there were observed many plantations where infected plant material was left on tree or plantation, which presents source of inoculation for many diseases for a long time, as stated Evans, (1998). This all also calls for educative effort in the struggle of disease control. The damage caused by diseases may affect generative and also vegetative tissue, when the later can debilitate the tree by wilting and die back of many shoots and eventually kill the whole tree. As the most important fungal diseases are recognized **witches' broom** *Moniliophthora perniciosa* (Stahel) Aime & Phillips-Mora, (= *Crinipellis perniciosa*), **frosty pod rot** *Moniliphthora roreri* (Cif.) H.C. Evans, Stalpers, Samson & Benny and **black pod disease**, which is caused by various species of oomycete *Phytophthora* sp. (Fulton, 1989; Aime et al., 2005). Significant damage is also caused by viruses, from which especially CSSV creates problems in Nigeria and Ghana (Wood, 1985).

Witches' broom *Moniliophthora perniciosa* (= *Crinipellis perniciosa*)

M. perniciosa, called in Spanish "escoba de bruja" is endemic to the region of origin of *T. cacao* (Fulton, 1989; Hebbar, 2007). Evans (1998) mentioned, that this fungus, together with *M. roreri*, creates major limiting factor in the cocoa production in Latin America, since this fungus accounts for 35% of potential crop loss induced by all pathogens (Hebbar, 2007). Recently, in the revealing work of Aime (2005) *Crinipellis perniciosa* was identified as a close relative of *M. roreri* and they were considered in the same genus as *Moniliophthora* (*Agaricomycetes*; *Marasmiaceae*). This fungus caused 95% decline in production since its introduction in 1989 to region of Bahia, Brazil (Pereira et al., 1996). Subsequent Brazilian fall from the second world largest cocoa producer demonstrates potential threat to the countries free of this infection, particularly for world major cocoa producing countries in West Africa. The fungus has a strong effect on the vigorously growing and early producing hybrids of cacao (Evans, 1981). It is able to attack all types of the meristematic tissue, which results in hypertrophy. It provokes brooms when the buds are attacked. Stem cankers result from the infection of the leaves, pulvini and petioles. Flower infection produce cherimoya-like pod. Basidiospores, which are responsible for the infection, are killed by direct sunlight. (FAO/IPGRI, 1999).

Frosty pod rot *Moniliophthora roreri*

Although not accounting for highest loss on the possible crop the fungus *M. roreri* is considered to be potentially invasive species, with possible severe impact on the cocoa production (Phillips-Mora et al., 2005). Any other host plants than cocoa were not recognized. This pathogen seems to originate from the Andean foothills of the western Ecuador. It attacks the pods when the infection is internal and hard to recognize because of minimal external manifestation, when first external symptoms are spots of mature coloration on pod surface. These spots turn rapidly brown and in favorable conditions they become covered with white mycelia (Wood, 1985; Evans, 1988). Under natural conditions, the pathogen affects only the pods, although artificial inoculation on the seeds produced infected seedlings. Infection through the seeds in the wild has not been observed (Wood, 1985). The disease is reproduced by conidia which are viable for several weeks and can withstand direct sunlight (FAO/IPGRI, 1999). Different shade trees were evaluated in search of possible impact on number of released spores and *Inga edulis* Mart. was evaluated as having most suppressive effect (Meléndez, 1993).

Black pod rot *Phytophthora* sp.

This disease is caused mainly by *P. palmivora*, which belongs to the empire of *Chromalveolata* and to the class of *Perenosporomycetes* (alternatively *Oomycete*). It is present throughout all world cocoa regions (*fig*). It is estimated to be responsible for the highest losses on the pod production worldwide. Disease progress is stimulated by high humidity when in some regions the fungus with humid conditions determines profitability of cocoa cultivation, such as in wetter parts of Cameroon. It can attack every part of plant body, including roots. Infested area on pods rapidly turns black and when the fungi begin to sporulate it turns to white or yellowish color. Stem canker induced by infection from diseased pods was detrimental at susceptible Criollo hybrids at the beginning of 20th century. When pathogen attacks old almost ripe pods, there is still a possibility to harvest the crop, as it attacks only pod wall and seeds remain unaffected (Wood, 1985). Variety of local *Phytophthora* species adapted to cocoa; in West Africa there occurs *Phytophthora megakarya* and in Brazil there is *P. capsici*. It is even likely that pantropical pathogen *P. palmivora* was encountered anew (Keane, 1992).

Viruses

Viruses were discovered on cocoa in 1938 in Africa and since then they were found in several West African countries and other parts of the world. Major importance is primarily given to CSSV because it creates serious problems in Ghana and Nigeria. The virus disease was found in Western Nigeria, Ivory Coast and Sierra Leone, but also in Trinidad and Sri Lanka. Virulent strains of CSSV virus cause death of susceptible cocoa hybrids and trees, such as Amelonado type. There are several strains of this virus, differing in the symptoms. Most virulent isolate of CSSV produce swellings on the young shoots, leaves and also on the roots. Transmission of CSSV from tree to tree is facilitated with many species of mealybugs, primarily by *Planococcus citri* and *Planococcoides njalensis* (Hemiptera: Pseudococcidae) Laing (Wood, 1975).

2.2.2. PESTS

Figure 4 shows the relative proportion of cocoa pathogens on potential yield. Except of Latin America, all cocoa producing regions suffer predominantly from pests, including not only a wide variety of insects, but also rodents. Muhamad et al. (2005) marked mirids, alternatively capsids (*Heteroptera: Miridae*) as most important cocoa pest worldwide; however, there are differences between the regions, as it can be seen from figure 3. There are several other insect pests throughout the World. Namely, moths (*Insecta: Lepidoptera*), which cause Indonesian most severe damage on cocoa yield conducted by cocoa pod borer moth *Conopomorpha (=Acrocercops) crammerella* (Snellen, 1904) (Keane et al., 1992; Hebbbar, 2007; Dropdata, 2014), leaf-cutting ants (first of all *Atta cephalotes* L. in New World – *Insecta: Hymenoptera*), beetles (*Insecta: Coleoptera*), where genera *Adoretus* sp. cause defoliating in Malaysia (Keane et al., 1992) and mealybugs, (*Insecta: Hemiptera*) from which several species, especially *Planococcus citri* (Risso, 1813), have become indirect pests, as they are vectors of CSSV (Entwistle, 1985).

2.2.2.1. MIRIDS (HETEROPTERA: MIRIDAE HAHN, 1833)

Entwistle (1975) besides many other mentioned that mirids (known also as plant bugs) in West Africa are able to cause losses from 20 to 30% on cocoa yields. The lesions on both vegetative and reproductive tissue made by mirid feeding on the plant tissue result in small water-soaked areas of tissue, which rapidly turns black by action of phytotoxic bug's saliva (Coto, 2003). The shape of the lesion is circular on the pods. On the stems the lesion shape is usually oval and of greater size (see Appendix A). Both hardened and unhardened stem tissue could be attacked, but feeding on pod provides better nutrition. Lesions on woody tissues present an entryway for fungi, which could have detrimental effect on the whole tree. Thus, more important problems could cause feeding on shoots and branches, where many of mirids move after the harvest of pods, as also Wheeler (2001) confirm. He also stated that pod-feeding populations do not have to be related with those feeding on branches. Damage on vegetative part is indirect in the comparison to pod-feeding. As it enables the fungi to enter the plant, many fungal agents could act, regarding to local fungal variety (Entwistle, 1975). For example, in West Africa most important mirid related fungi is *Calonectria rigidiuscula* (Berk. & Br.), causing dieback in 50% of infected trees. This fungus is naturally occurring as a saprophyte on cocoa pods (Crowdy, 1947). However, tough looking pod affected by feeding, rarely accounts for high production losses, if it takes place on older pods. Young "cherelles" are more susceptible, and following infestation can produce wilting. Older pods not affected by any fungal pathogen normally develop, although the weight of seeds may be reduced (Wheeler, 2001).

Within large, mainly phytophagous family of mirids (Cassis et al., 2002), there are several subfamilies. The subfamily Bryocorinae Carvalho, 1957 comprises important pests of tropical crops. This subfamily has several tribes (Bryocorini Carvalho, 1957, Dicyphini Carvalho, 1958 and Eccritotarsini Carvalho, 1957) when most of the important bryocorine plant pests belong to Dicyphini Carvalho, 1958. Lower taxa for this tribe are subtribes Dicyphina Reuter, 1883, Monaloniina Schuh 1979 and Odoniellina Schuch 1979, from which only Monaloniina and Odoniellina have particular importance for the purpose of this thesis. Odoniellina subtribe includes important cocoa pest, like *Distantiella theobroma* (Distant), an important low-density pest on cocoa in West Africa, whose severity of the damage caused does not correspond to the number of individuals (Schaefer et al., 2000). Another important,

more widespread West African pest from same subtribe is *Sahlbergella singularis* Haglund 1895, more common on older cocoa. Wheeler (2001) noted, that both species mentioned above generally feed more on stems and flushes than do Monaloniina mirids, although its development is faster on pods. Schaefer et al. (2000) reviewed the literature aiming to describe possible control of these closely related mirids by management practices, including shade alteration.

Second mentioned subtribe Monaloniina includes apart of many others, genus *Helopeltis* V. Signoret, 1858 and *Monalonion* Herrich-Schaeffer, 1850, important cocoa mirids of Old and New World, respectively. The genus *Helopeltis* was alternatively divided by inspection of museum samples and geographical distribution made by Schmitz (1968) to genus *Helopeltis* and *Afropeltis*, representing Asian and West African species, respectively. However, today the name *Afropeltis* is being known as a synonym for *Helopeltis* (Schaefer et al., 2000; Schuh, 2002). Any cocoa pest belonging to *Helopeltis* genus is present on cocoa in Africa; however, importance of this genus rises contrastingly on cocoa in Southeast Asia. Here, polyphagous *Helopeltis antonii* V. Signoret, 1858, can be found as a pest on cocoa and tea there, anyway particular importance gets on cashew (*Anacardium occidentale* L.) and guava (*Psidium guajava* L.). *Helopeltis theivora* Waterhouse, 1886 (= *H. theobromae*) is a key pest of cocoa and many other crops in Southeast Asia, Indonesia, Malaysia, India and Sri Lanka. This pest feeds on pods and new shoots, similarly as *H. antonii* (Schaefer et al., 2000). *Helopeltis bradyi* Waterhouse, 1886 is an important cocoa pest in Sri Lanka. It tends to feed more on the pods than on stem and branches (Wheeler, 2001).

There are several others mirids on cocoa, mainly in Southeast Asian region, but it is not crucial to describe them here. Relevant information could be found in literature (Entwistle, 1975; Schaefer et al., 2000; Wheeler, 2001).

Monalonion dissimulatum

The diverse mirids species on cocoa in tropics of Old World do not appear in New World; all cocoa mirids species in South America belong to genus *Monalonion* (about 7 species) (Entwistle, 1975), being considered generally less important pests compared to Bryocorinae in Old World. *M. dissimulatum* belonging to Dyciphini tribe is considered as most important cocoa pest in Peru (Wille, 1944). This New World mirid was recorded as a pest firstly in the late 19th and early 20th century, nowadays it occupies large area throughout the countries of Latin America, such as Brazil, Colombia, Costa Rica, Ecuador, Panama, Peru and Venezuela (Schaefer et al., 2000). The insect attacks both, pods and young shoots, but it seems that there is a preference to feed on pods and particularly on young and soft ones, which are more likely to wilt. Thus, the damage of major importance of this pest is being made by feeding on “cherelles” (Donis, 1988; Wheeler, 2001, see appendix A).

The life cycle of all mirids is similar. For example, *M. dissimulatum* lays since 18 to 40 eggs in the epidermal layer of pods, pod stalks, small branches. They hatch after 6 to 10 days. As simple metamorphosis is general trait for the whole suborder of *Heteroptera*, there are five juvenile stages – nymphs after, each of them lasting 10 – 21 days (appendix A). All nymphs have bright orange color and soft body. The last nymph moults to 8-10 mm long winged adult, which is able to reproduce within 7 days. The adult has a prolonged orange body, with black head and black stripes on long legs, antennae and on smoky wings (Entwistle, 1975; Donis, 1988; Coto, 2003; pers. obs., appendix A). The *Monalonion* and *Helopeltis* genera have similar morphological characteristics (Donis, 1988).

In Brazil, there are few more possible host plants for *Monalonion* sp. than cocoa, namely *Cecropia adenopus* Mart. ex Miq., *Hamelia patens* Jacq., *Begonia convolvulacea* A. DC. and *Begonia reniformis* Dry and genus *Crotalaria* L (Donis, 1988). However, Hernandez et al. (1950) stated, that in Venezuela no other host plants except *T. cacao* nor feeding on woody tissue of *T. cacao* was observed. The feeding on pods there caused about 75% loss on yield. Coto (2003) estimated the vulnerable size and age of pods to 7 to 12 weeks and to 10-12 cm. Donis (1988) stated, that the “cherelle” smaller than 5 cm is not able to withstand any mirid lesion. Ferrari et al. (2014) observed low impact of high infestation on wet bean yield if the almost ripening pod was attacked. Up to 70% of damaged cocoa surface did not have significant impact on wet bean yield. However, if the attack was higher than 70 %, the reduction of the yield was up to 50%.

The management of the mirids in cocoa is performed mainly in Western African and South Asian countries, where they present major problem (Entwistle, 1975; Sounigo et al., 2003). Intensive application of gamma-HCH insecticides in Africa resulted in expansion of resistance of *D. theobroma* and *S. singularis* (Clayphon, 1969). Therefore, cocoa protection against pests evolved rapidly in West Africa as there are employed biological methods in the principles of integrated pest management. There were introduced black ants (*Dolichoderus bituberculatus*) and associated mealybugs to control of *Helopeltis* sp. (Keane, 1992). The importance of pest regulation by natural enemies could be seen on the example of cocoa in Africa and coffee in Latin America, which as non-native crops are seriously attacked by pests from local regions, but in their place of origin the importance of pests is quite lower. This is explained by lack of natural enemies in a new ecosystem (Avelino et al., 2011). Here could be seen the importance of complex and more diverse agroecosystem provided by agroforestry. The management of pests on cocoa in South America is quite different. Protective treatments are employed only on very elevated pest outbreaks. For example, no integrated management is proposed in Ecuador, which results in excessive use of pesticides with harmful side effects on natural entomofauna. Promising results were conducted in attempts to establish enthomopathogenic fungus *Beauveria bassiana* (Balsamo.-Criv.) Vuillemin (Hypocreales: Cordycipitaceae) on cocoa pods by spraying of flowers (Posada et al. 2010). The mortality of *M. dissimulatum* varied between 63 to 90% (Ferrari et al., 2014; Montealegre and Rodriguez 1989). One of the efficient methods in maintaining low population of *M. dissimulatum* is improved shade management and collection of the nymphs (Ferrari et al., 2014, Riera et al., 2012). Coto (2003) recommended about 28 insecticides to control of *M. dissimulatum*. He advised diverse chemical substances, majorly from organophosphates, nicotinoids and pyrethroids. Organophosphates have selective effectivity which allows us to protect natural enemies of the pests. There was recorded high effectivity of botanical insecticides. The most efficient pesticide was based on sap from tree *Hura crepitans* (Euphorbiaceae), with mortality close to 100%. Significant impact on the population of *M. dissimulatum* had also pesticides prepared from *Gallecia integrifolia* and from *Nicotiana tabacum* (Callisaya, 2012). Integrated cocoa pest management could help in the solution of the problems associated with the usage of pesticides. These problems are for example connected with European restrictions on the content of pesticides residuals in exported cocoa beans and total ban of the use of same insecticides, as was reported from Nigeria (Asogwa and Dongo, 2009).

There were established traits to evaluate resistance of cocoa clones to pests. Most promising clones in resistance against *D. theobromae* and *S. singularis* in Africa were from forastero group. Contrary, least resistant clones were from trinitario group (Sounigo et al., 2003). The replacement of susceptible by resistant cocoa clones was carried out on Papua New Guinea (Keane et al., 1992). During field survey involved in our thesis was observed only one mirid infested tree with characteristics of criollo clone. Work of del Aguila (1996) on total insect occurrence on particular cocoa clones was elaborated in Pucallpa, a capital city of Ucayali department. The lowest phytophagous insect occurrence was observed on forastero clones (SCA-6), however higher values were observed on cocoa hybrids (EET-400). It is appropriate to note, that in the work of del Aguila (1996) it is not recorded occurrence of *M. dissimulatum*.

2.2.2.2. STILT BUGS (HETEROPTERA: BERYTIDAE FIEBER, 1851)

The long legs, antennae and elongated body have caused berytids to get common name stilt bugs. This small and morphologically diverse family is present throughout the world and it includes both phytophagous (where only one serious pest is recognized) and predatory species, although literature records of phytophagy of several species are not supported by appropriate evidence. Both phytophagy and predatory feeding habits were observed in the case of *Berytinus minor* (Herrich-Schäffer, 1835). This implies a possibility that future investigations will notice predatory behavior instead of phytophagy, which is making this family possible valuable in integrated pest management. Compared to other heteropteran families such as *Miridae*, relatively few stilt bugs cause serious problems on crops. Only one important pest was considered in North America – *Jalysus wickhami* Van Duzee, causing losses on commercial tomatoes, *Lycopersicon esculentum* Mill. Our studied insect, *P. andinus*, is frequently collected berytid found on cocoa in South America, considered to be pest on cocoa, although it was considered also as possible pollinator (Henry, 2000; Rogg, 2000). *Berytidae* are separated into three subfamilies (and six tribes), the Berytinae Fieber, 1851 (Berytini Fieber, 1851 and Berytinini Southwood & Leston, 1959), Gampsocorinae Southwood & Leston, 1959 (Gampsocorini Southwood & Leston, 1959 and Hoplinini Henry, 1997), and Metacanthinae Douglas & Scott, 1865 (Metacanthini Douglas & Scott, 1865 and Metatropini Henry, 1997). 35 genera and 170 species are recognized around the world (Henry et al., 1998).

The literature about *Parajalysus* genus is scarce, especially about bionomics of its species. It is distinguished from all other genera by four, large, erect spines present on thorax. The body dimensions vary from 4.75 to 7.75 mm. The identification of genus *Parajalysus* is considered difficult and the possibility of misidentification seems to be the greatest among all the stilt bugs genera of New World. There are 12 species within, which is making it the largest berytid genus in the New World (Henry, 1997). As a pests on cocoa only *P. andinus* and *P. spinosus* Dist. are considered. However the later was then considered as being also predator of many pests such eggs and young larvae of *Heliothis virescens* F., a moth on tobacco, and larvae of *Buculatrix thurberiella*, a moth on cotton (Busck) (Beingolea, 1959). This indicates that the some observations could be incomplete or in error.

Parajalysus andinus

It is considered to be member of *Parajalysus* genus with the easiest identification. It ca be confused with *P. grandis* and *P. angulatus*, which were reported only from Iquitos (Peru) and Mato Grosso do Sul (Brazil), until now. *P. andinus* has a broad distributional range; possibly the largest from the genus. This species was recorded in Bolivia, Brazil, Colombia, Peru and Venezuela. The length of yellowish brown body is approximately 6 mm (appendix B; Henry, 1997). *P. andinus* is common on cocoa plantations (table 4) and it is one of the most common berytids in entomologist collections. It can be found feeding on cocoa leaves of all dimensions (appendix B). The damage induced by *P. andinus* is deformation of leaf structure and wilting of top part of the leaf (appendix B). Adults (appendix B) fly rapidly away when disturbed. It is not stated whether both nymphs and adults feed on leaves. Rogg (2000) presents *P. andinus* as a pollinator in the nymph stage and as a pest of young leaves in the adult stage. He doesn't support his statement with appropriate evidence though, however, from our observations it is possible that *P. andinus* is pest on the cocoa (Appendix B). Pruett (1996) cited by Henry (1997) considers *P. andinus* as one of the most important pollinators of *T. cacao*, enabling cross-pollination of some important cocoa hybrids. He observed both nymphs and adults with significant amounts of pollen bearing on their bodies. The population peak coincides with peak of flowering of *T. cacao*.

2.2.2.3. THE IMPACT OF SHADE MANAGEMENT

The management of shade alters microclimatic and macroclimatic conditions within cocoa plantations. This has a significant impact on important processes, which influence the ability of the plantation to produce yield. This includes not only, let's say, general processes such as nutrient uptake competition, litter fall, the rate of decomposition, soil fertility and cocoa pod development (Bos et al., 2006; Ofori-Frimpong et al., 2007) but also highly specified interaction between crops and pathogens. Large varieties of plant species which are involved in agroforestry systems suppress pest's occurrence by offer of higher biodiversity and subsequent higher occurrence of natural enemies (Lojka et al., 2010). Therefore, shade management is also considered as protective treatment in the management of cocoa mirids (Wille, 1944; Babin et al., 2010). Influence of environmental factors on the presence of diseases (Bos et al., 2006; Leandro Muñoz, 2011) and pests (Villacorta, 1973; Donis, 1988; Vargas et al., 2005; Bos et al., 2006) in different shade managements in cocoa was investigated. Whether the positive effect of the shade on the disease progress, which was confirmed in the case of the most important pathogens like *P. palmivora* (Dakwa, 1976; Beer et al., 1998) and *M. roreri* (Bos et al., 2006; Leandro Muñoz, 2011), the key driver of pest presence influenced by shade management is more variable in existing investigations (Villacorta, 1973; Donis, 1988; Wheeler, 2001; Vargas et al., 2005; Bos et al., 2006). For example, minimal daily relative humidity, daily mean temperature was recorded to have stimulative effect on female fecundity of African cocoa mirid *S. singularis* by comprehensive work of Babin et al. (2011). Positive effect on mirids occurrence could have also increased flushing of cocoa under sunny conditions (Boyer, 1970), because some mirids prefer to lay the eggs on young shoots (Villacorta, 1967). Pruning of shade trees during year should be therefore adapted to climate variation in the region to avoid increased humidity.

2.3. STUDY AREA

The study was performed in the surrounding of small city San Alejandro, which was named after the river passing through. The city lies in Irazola district, Padre Abad province, department of Ucayali, Peru ($8^{\circ} 49.5840$ S, $75^{\circ} 13.9230$ W and 257 m.a.s.l.) (figure 4). San Alejandro, capital city of Irazola district, began to develop in 1940's during the construction of Federico Basadre road (Smith et al., 1999). The city lies on the road about 110 km from the city of Pucallpa. The road is important as it is connecting capital Lima and all three regions of Peru (coast, rainforest and mountains) and it can be used for international transport across the Amazon River. Construction of the road caused start of a strong immigration into the rainforest zone. Annual rate of the immigration in Ucayali department has reached 5.9% in the 1960's and during 16 years from 1993 to 2007 the number of population has grown by nearly one quarter (INEI 2012). The same source says that the population density for Padre Abad district is 6.33 inhabitants/km² and that its population is 55, 866 persons (in 2011). The Padre Abad province has 8, 822.50 km². The immigration phenomenon is very well seen in the case of the city of Pucallpa, capital of department, which was the village constituted only by few houses before the construction of the Federico Basadre road (Municipalidad provincial de Padre Abad, 2014).

The cocoa production in Peru is strongly rising. Although Peruvian cocoa bean production presented in 2012 only 1.58% of world production (FAOSTAT, 2014), the country is in the process of transition from the world second largest coca (*Erythroxylon coca*) producer to one of the world largest organic cacao producers (Emmenius, 2012). By Peruvian Ministry of agriculture or Ministerio de Agricultura y Riego (2012), Peru was recorded as the world largest organic cocoa producer after Bolivia in 2011 (Imaña, 2011). Between 2001 and 2007 the cocoa production had raised four times (Ministry of Foreign Trade and Tourism, 2008). Cocoa production was installed to replace the coca production, which, brought to the region many severe problems connected to narcotraffics (Ministry of Foreign Trade and Tourism, 2008; Chauvin, 2010; Ristau, 2013). Only in the province of Padre Abad in year 1993 the coca production covered about 2,300 ha, which presented 63.4% of all fields cultivating perennial crops (INEI 1993).

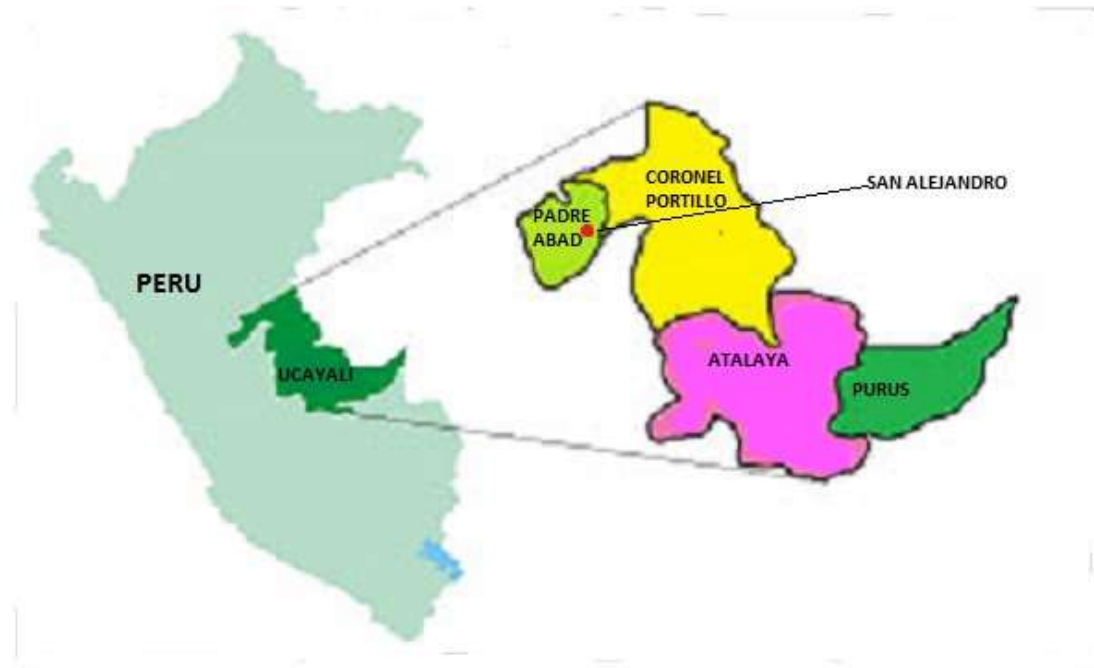


Figure 4: The map of the study area. A map modified from UNICEF (2014).

San Alejandro is located in the humid rainforest zone where stable temperatures without high oscillations are common. Mean annual temperature in San Alejandro is 26.2 °C. The difference between coldest and hottest month is lower than 2° C, so the temperature is stable throughout the year. Mean annual relative humidity value is 85%. Annual precipitation value is around 2,510 mm. Monthly precipitation values, which are dividing the year into high and low precipitation period, could be seen from table 2 (DOMUS, 2008).

Table 2: Monthly precipitation in San Alejandro (data from DOMUS, 2008, Servicio Nacional de Meteorología e hidrología, 2015).

Monthly precipitation in San Alejandro													
Average 2000-2008 and values from 2014 (mm)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Σ
Avrg	300.7	337.8	283.7	234.6	123.9	97.6	90.2	77.2	166	221.7	237.9	338.7	2510
2014	224.8	170.2	198.3	118.1	140.9	82.6	51.3	137.6	96.6	197.9	295.6	250.5	1964.4

Main ecological problems of Padre Abad province are torrential rains, soil erosion, deforestation and inadequate forest management, which lead to loss of biodiversity. The maximum amount of 24 hours rainfall in summer months is regularly reaching over 60 mm, with extreme value of 240 mm per 24 hours in January 2004 (DOMUS, 2008).

3. OBJECTIVES

The main objective of this study was to evaluate the influence of shade in cocoa plantation on the infestation with pest species from the family *Heteroptera*. Specific objective was to investigate behavior and preference between shade and full sun environment of relatively unknown cocoa pest *P. andinus* that attack leaves. Similarly, investigation of the same preference of relatively better known cocoa pest *M. dissimulatum* that attacks pods was done. We aimed to re-examine diverse works carried out on this insect previously and relate this preference to the conditions of the study area, where process of large shift of coca plantation to cocoa plantation is giving place to possible cocoa pathogens expansion.

Based on the collected acquired data we were also able to assess the size of pods or leaves that was preferred by the pests and assess the assumption that the insect will attack the younger pods and leaves.

4. MATERIAL AND METHODS

4.1. STUDY SITES

Three plantations of organic cocoa (prohibiting use of insecticides) were selected in the surroundings of San Alejandro city. All plantations were in the production age, and the owners were members of farmers association ACATPA (Asociación de Cacaoteros Tecnificados de Padre Abad), a cooperative organization of cocoa growers. All farmers included in this thesis cultivate cocoa in agroforestry plantation system combined with many other species, including trees, palms and crops. Diversity of tree and palm species used in cocoa agroforestry around San Alejandro was studied by Vebrova (2012). The most employed species were *Inga edulis*, *Calycophyllum spruceanum* (Bentham) Hooker f. ex Schumman, *Phytelephas macrocarpa* Ruiz & Pavon, *Guazumua crinita* Martius, *Bactris gasipaeas* and *Croton draconoides* Mueller Arg. The age and clone of cocoa trees were recognized. First studied cocoa plantation of Mr. Yonel Yanac Cierta was established in year 2009 and it is located at 8° 48.903' S, 75° 13.942' W. Second plantation Mr. Lubén Mejía Murga is located at 8° 48.902' S, 75° 13.914' W and it consists of cocoa trees established in year 2008. Third plantation was owned by Mr. Carlos del Aguila Encinas, it was established in 2009 and it lies on 8° 50.727' S, 75° 15.415' W (Figure 5). Cocoa trees were planted in 4 x 4 m density, with scattered pattern of canopy trees.

This work does not deal with the evaluation of individual cacao clone resistance, but in the test only trees with the characteristics of hybrid CCN-51 cacao cultivar were included, the most planted cultivar in the region of interest. Between 3rd of July 2014 to 17th of July 2014 I have done survey of the plantations in Padre Abad and Coronel Portillo province. I was seeking for plantations with marks of presence of the studied pests, both *M. dissimulatum* and *P. andinus*. On the basis of this survey I have included only the plantations with the presence of both pests.

4.2. DATA COLLECTION

On each plantation two groups of cocoa trees were studied, either growing in full-sun or shade conditions, respectively. The level of shade was approximately 30% of transmitted light. The full-sun sites might be influenced in the early morning or late afternoon by shade trees of neighboring shade trees, but the minimal level of transmitted light was approximately 70%. Each group consisted of 10 studied trees. To acquire more randomized data, the groups were divided to two study sites, each one consisting of five trees and isolated from neighboring group by at least 50 m distance. In total 60 trees were examined, 20 trees on each plantation. The test was identical on every plantation. Only trees with no visible signs of the biotic or abiotic stress were assessed. Every tree was labeled with plastic etiquette marking the number of site, type of management and number of tree.

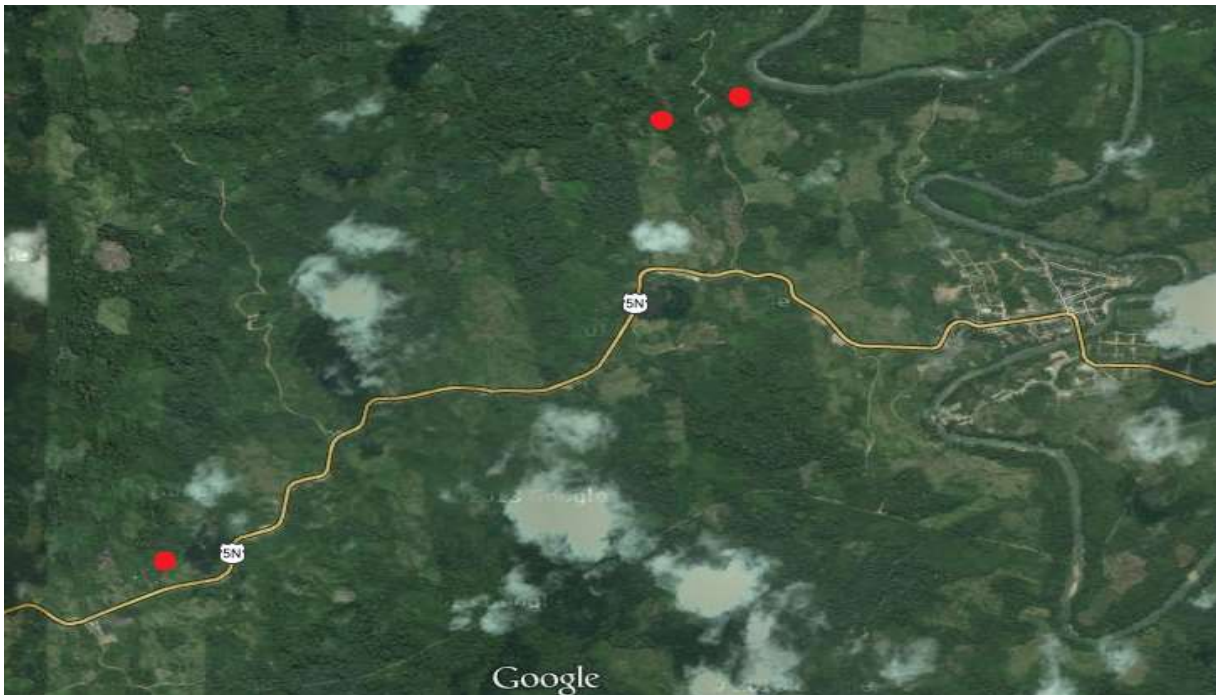


Figure 5: The map of study sites (red dots). Source www.maps.google.com.

The level of attack of *M. dissimulatum* was assessed on the cocoa pods, when the data were taken from all visible fruits of each tree. The length of every fruit was measured. The determining feature for assessing this pest was number of punctures on the pods. Both old and fresh punctures were counted. Any signs of damage made on the shoots were observed, which supports hypothesis of Wheeler (2001) that mirid populations on the pods do not have to be related with those feeding on shoots. Thus, determining feature for this pest was only the number of punctures. This was carried out one day before counting the number of individuals

of *P. andinus*, because of the possible disturbing of rapidly escaping adults of *P. andinus*. At that time I have marked the leaves for assessing *P. andinus* too. In total there were assessed 408 pods.

The determining feature for *P. andinus* was the number of individuals (both nymphs and adults) on young, tender leaves. On every tree I have chosen 10 young leaves, without any damage from the leaf-eating insects and equally distributed on the crown (if possible). The studied leaf had to be easily accessible and with well visible whole leaf surface without necessity of leaf manipulation. The length of the leaves was measured and they were marked by water-resistant marker in the ascending order from the youngest to the oldest on the shoot. I have marked change of the shoot to the notebook to have an idea about the number of leaves on shoot and number of shoots on tree during insect assessing. This enabled me to do counting of insects also when the leave numbering were depreciated (leaf-consuming insects etc.). Data collection was carried out during one week in July 2014, on days with partly cloudy skies without rain between 7:30 am and 10:30 am, when all individuals occurring on the sample leaves were counted. Total number of evaluated leaves was 600.

To ensure our species identification of the pests I have sent 20 individuals from both pests to the Peruvian National Service of the Agricultural Protection-Servicio Nacional de Sanidad Agraria (SENASA) to Lima. 10 individuals of both species were captured at two neighboring plantations and 10 individuals were captured at the plantation of Mr. Carlos del Águila Encinas. In the case of *P. andinus* I have ensured the capturing of uniform number of female and male by capturing only copulating individuals. Similarly, the insects were captured to elaborate species identification at CULS in Prague.

4.3. STATISTICAL ANALYSIS

Data analysis was carried out using statistical software R (R Core Team, 2014). First, I have tested the normality of the data using Shapiro-Wilk test. The normality was rejected in both datasets. Therefore I employed logit regression model to investigate which factors influence the level of infestation or occurrence of both pests. The dependent variable Y, converted to binomial values “yes = 1” or “not = 0”, was level of infestation (or number of individuals in the case of *P. andinus*).

The probability of success of the dependent variable Y ($p = 1$) in binomial distribution is determined by model m (1):

$$\log\left(\frac{p}{1-p}\right) = \text{Intercept} + \beta_1 \times x_1 + \beta_2 \times x_2 + \beta_3 \times x_3 = m \quad (1)$$

The independent variables x_i (or factors alternatively) were length (x_1), shade (x_2) and plantation (x_3), driven by its deviance coefficient β_i . If formula (1) is converted in order to isolate p it will give formula (2):

$$p = \frac{e^m}{1+e^m} \quad (2)$$

There are also used contingency tables (or crosstabs alternatively) in order to assess if there is some effect on pod length in different light condition and to assess methodology used by Donis (1988). Frequencies n_{rs} of two variables, X and Y are assembled in contingency tables (table 3 and table 5). All levels of first variable construct rows, second variable construct columns. Random variable X can range levels $1, \dots, r$ and random value Y can range values $1, \dots, s$. The columns and rows are summed in the margins, when these values are called marginal frequencies. The sum of all values in rows or in columns is placed in the lower right hand corner, when both must be equal to overall sum (n). The minimal number of records per cell is 5 (Anděl, 2007).

Table 3: Contingency table.

X\Y	1	2	...	s	
1	n_{11}	n_{12}	...	n_{1s}	n_{1*}
2	n_{21}	n_{22}	...	n_{2s}	n_{2*}
...
r	n_{r1}	n_{r2}	...	n_{rs}	n_{r*}
	n_{*1}	n_{*2}	...	n_{*s}	n

Tests of relationships between the variables within the contingency tables are based on a statistic called Chi-square (χ^2) (3).

$$\chi^2 = \sum_{r,s} \frac{(n_{r,s} - \frac{n_{r*}n_{*s}}{n})^2}{\frac{n_{r*}n_{*s}}{n}} = n \sum_{r,s} \frac{n_{r,s}^2}{n_{r*}n_{*s}} - n \quad (3)$$

The hypothesis H_0 says that variables are not dependent. The hypothesis is rejected when the value of χ^2 (figure 6) exceeds the critical value for given chi-square distribution.

$$\chi^2_{(r-1)(s-1)}(1 - \alpha) \quad (4)$$

Critical value formula χ^2 is indexed with degrees of freedom (d_f), where r =number of rows, s =number of columns; α =significance level (4).

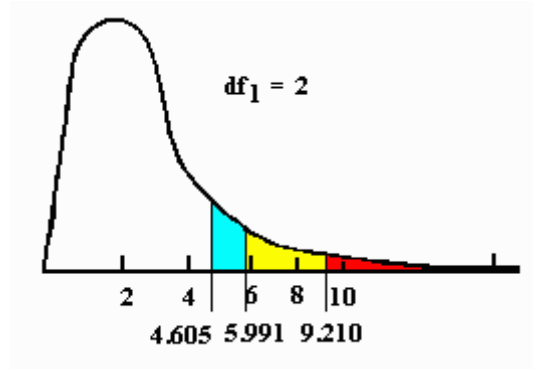


Figure 6: Example of chi-square distribution with marked critical values

(4.605 for $\alpha = 0.1$, 5.991 for $\alpha = 0.05$ and 9.21 for $\alpha = 0.01$) (Stockburger, 1996).

Chi-square distribution is characterized by parameter called the degrees of freedom (d_f), which determines the shape of distribution.

Critical value is unique for each significance level α , which determines the probability that real value calculated from every value within the variables will fit calculated value from the sample. The α lays in most cases between 0.1 and 0.01 (figure 6).

Methodology of works carried out on similar topic, such as Villacorta (1973), Donis (1988), and Vargas et al. (2005) was studied for our data analysis. My idea was to establish similar methodology for data analysis of both pests (*M. dissimulatum* and *P. andinus*). However, all the studied works were designed to investigate different phenomenon, such as whole insect population throughout certain period (year or harvest period), which means that

the data were taken periodically or the difference between altitudes was assessed in addition. This makes these works different from this thesis, which is designed as a testing without repetition. In comprehensive and most similar work carried on *M. dissimulatum* by Donis (1988) the level of attack on pods was evaluated using modified data. The idea there was to obtain the data showing level of attack without respect to the total number of pods available (unaffected) by absolute (*AI*) and relative (*RI*) indices demonstrated by these formulas (5):

$$AI_i = \sum(x_{ij} \times j) \quad (5)$$

$$RI_i = \frac{\sum(x_{ij} \times j)}{n_i}$$

$$AI_N = \sum[\sum(x_{ij} \times j)]$$

$$RI_N = \frac{\sum[\sum(x_{ij} \times j)]}{N}$$

Where X_{ij} = the number of pod/leaf of particular size i and level of infestation j , j =level of infestation (0 – 4), n_i =number of pods of size i and N =number of pods of all sizes. Absolute (AI_i) and relative indices (RI_i) were established to enable the comparison between particular sizes of pods and total (AI_N and RI_N) indices were designed to enable the comparison between shade and sunny cultivation regardless to the size of pods and its level of infestation. Relative indices could help to evaluate the severity of the attack with regards to that any attacks of *M. dissimulatum* on cherelles up to 5 cm of length make them to decay. However indices brought largely different results, possibly because they are not dealing with the impact of light conditions on the growth of cocoa. If the level of infestation was zero, it eliminated zero values from the data analysis. This means mainly total number of available pods, where greater number of pods offer broader possibility of attack of pests. This phenomenon was on our insect observed by Donis (1988) and Vargas et al., (2005). It is breaking the requirement of independency of the testing, possible more importantly for smaller amount of analyzed data such as in our discontinuous testing. Overall smaller number of investigated pods in our testing was caused by advanced stage of harvest. The inequality in the number of the pods available on the sun and shade plantation was proved by statistical testing on 1% significance level in our work (table 4) and others also stated that the cocoa yields differently in shade and sun (Adomako, 1983; Wood, 1985 and Donis, 1988). Therefore, modification of the data proposed by Donis (1988) is not used.

5. RESULTS

5.1. *MONALONION DISSIMULATUM*

First, the effect of different light conditions on the pod number and length was evaluated by contingency tables in order to assess if the methodology using indices proposed by Donis (1988) is suitable for our analysis. Pod length was divided to 5 groups (1=0-5 cm; 2=6-10 cm; 3=11-15; 4=16-20 cm; 5=20 cm<) similarly to the work of Donis (1988) (table 4).

Table 4: Contingency table evaluating impact of light conditions on pod number.

Conditions/Length categories	Sun	Shade	Row sum
0-5cm	8	22	30
6-10 cm	28	39	67
11-15 cm	41	27	68
16-20 cm	107	66	173
20 cm<	43	27	70
Column sum	227	181	408

Calculated value $\chi^2 = 19.66$ exceeds critical value $\chi_1^2(0.99)=13.28$ and thus, it is possible to reject H_0 hypothesis with the risk of error lesser than 1%.

Table 5: Relative occurrence of *M. dissimulatum* on pods of different sizes under different light conditions.

Relative occurrence (%)	Shade						Sun					
	<5cm	6-10 cm	11-15 cm	16-20 cm	20 cm<	Σ	<5cm	6-10 cm	11-15 cm	16-20 cm	20 cm<	Σ
<i>Monalonia dissimulatum</i>	9.1	12.8	25.9	19.7	11.1	16.6	0	3.6	4.9	0.9	0	1.7

Although the overall occurrence was often low, as only 2 % of pods were infested in sunny conditions. From figure 7 can be seen, that the number of infested pods was 9.76 times higher in shady conditions. Table 5 summarizing the relative proportion of the attack of the pest tells us that there was observed big inequality between the number of the infested pods under canopy cover and in shady conditions (up to 10 times). But the structure of the infestation is similar in both conditions. The most infested pods had between 11 to 15 cm both in shade and full-sun. Similarly, the longest and shortest pods were the least attacked in both conditions.

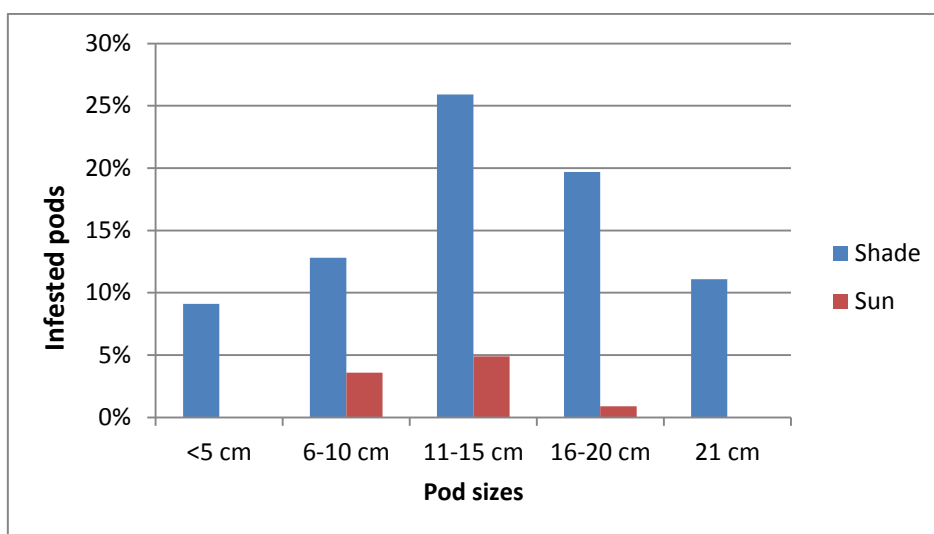


Figure 7: Graph of relative pod infestation of *M. dissimulatum* according to pod size.

Data analysis evaluating the influence of light conditions on level of infestation proved highly significant stimulative effect of light conditions. No preferred pod length was recognized. There was not observed any interaction (table 6). No important interaction was recognized during construction of the model.

Table 6: Data analysis of *M. dissimulatum* (values significant on 5 % level are in bold).

Insect	Trait	Factor	Intercept	Deviance	P-value
<i>Monalonion dissimulatum</i>	Punctures	Intercept	-5.800		
		Shade		2.391	<0.001
		Length		0.053	0.568
		Plantation		0.773	0.228
		Length:Plantation		-0.022	0.590

5.2. *PARAJALYSUS ANDINUS*

The number of leaves with *P. andinus* individuals was 1.22 times greater in closed canopy plantation compared to open (table 7). The insect is not attracted by any length of the leaf, similarly to *M. dissimulatum* (table8). Contrastingly to overall higher occurrence of insect in open cultivation, there was observed slightly higher proportion of infested small leaves in open cultivation. Structure of population was quite different in both conditions.

Table 7: Relative occurrence of *P. andinus* on leaves of different sizes under different light conditions.

Relative occurrence (%)	Shade						Sun					
	<5cm	6-10 cm	11-15 cm	16-20 cm	20 cm<	Σ	<5cm	6-10 cm	11-15 cm	16-20 cm	20 cm<	Σ
<i>Parajalysus andinus</i>	33.3	43.1	49.5	49.2	52.9	47.7	35	40	38	35.6	51.5	39

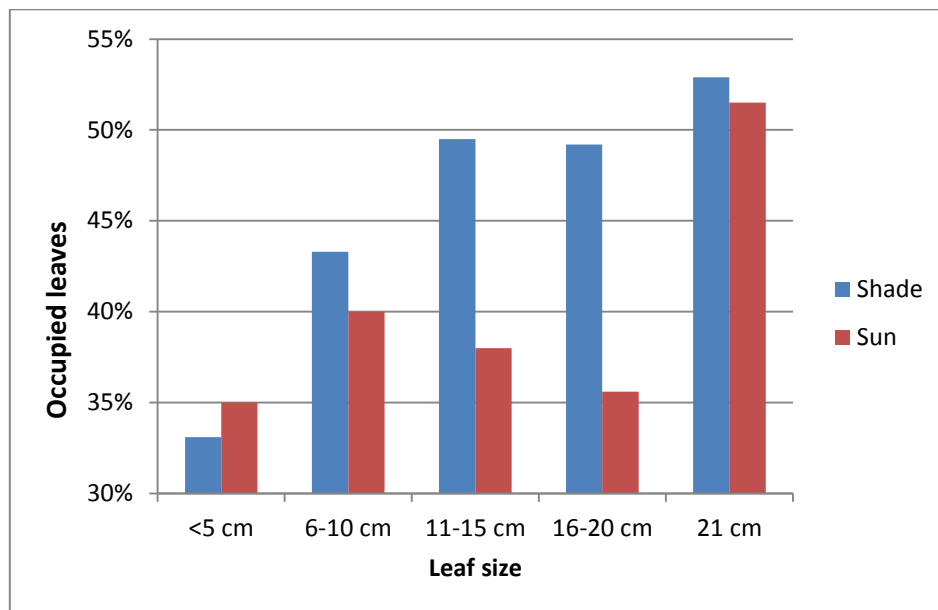


Figure 8: Graph of relative individuals occurrence of *P. andinus* according to leaf size.

Stimulative influence of shade on occurrence of *P. andinus* was recognized (table 6). However, during construction of the model was discovered interaction between influence of shade and plantation. This interaction was therefore studied. Insect population on plantation of Mr. Carlos del Aguila Encinas did not proved stimulative influence of shade on 5%

significance level. However, resulting probability was very close to critical value ($\alpha = 5.69\%$) and it did not changed results in the assessment of impact of shade employing data from all 3 plantations. As statistics and biology are two quite different sciences it should not be considered as highly significant variation.

Leaf length did not influence the occurrence of *P. andinus*.

Table 8: Data analysis of *P. andinus* (values significant on 5 % level are in bold).

Insect	Trait	Factor	Intercept	Deviance	P-value
<i>Parajalysus andinus</i>	Individuals	Intercept	-2.276		
		Shade		0.472	< 0.001
		Length		0.015	0.236
		Plantation		0.790	< 0.001
		Shade:Plantation		-0.677	0.002

6. DISCUSSION

Our analysis proved that there is highly significant difference between level of attack of both insects *M. dissimulatum* and *P. andinus* in shade and full-sun conditions, mainly on significance level smaller than 1%. No preferred length of pods or leaves was recognized. Donis (1988) stated the pod larger than 10 cm as the most attacked, similarly to results of Vargas et al. (2005). Only small amount of young cherelles was attacked in our testing and also in investigation carried out by above mentioned.

There were not observed any interactions between factors and neither significant influence of plantation.

Our results do not correspond with some similar works carried out on same (Donis, 1988) or other *Monalonia* species (Villacorta, 1973). The work of Donis (1988) using indices carried out in coastal part of Costa Rica proved highly significant stimulative influence of sun on insect attack. Our investigation proved highly significant stimulative effect of shade on insect attack. However, the reliability of indices is questioned, because greater number of pods is stimulating the amount of infested pods. On the contrary our testing proved that larger pods were more frequent under open cultivation and smaller pods more frequent under shady conditions. Also if we look on the total number of pods, it is higher under sunny conditions. This inequality was discussed also by others (Donis, 1988; Vargas et al., 2005). It is interesting to compare our result with results of these two authors, because they proved preference of the insect on larger pods. We did not recognize any preferred length, however if we consider that previous investigations were right, it would mean that open cultivation sites in our testing offered larger pods in greater number. It means that fruits of trees exposed to sun attracted the insect more. Contrastingly to this, we have recognized that greater level of infestation was present in shady conditions.

As the independence of the data modification was rejected we employ not modified data. Data analysis confirmed higher occurrence of *M. dissimulatum* at trees cultivated in closed canopy cover. This result is corresponding to one observation from Peru (Wille, 1944).

Vargas et al., (2005) evaluated the influence of light conditions and height above sea level on population of *M. dissimulatum*. They proved that higher populations were at higher altitudes (500-700 m.a.s.l.) compared to lower (300-500 m.a.s.l.) ones. They observed no

significant difference between shade and sun; however, at lower altitudes it seemed that more insects are in shade conditions and at higher altitudes higher number of insect in sunny conditions was observed. In high and low altitudes they observed 22.16 and 9.2 individuals of *M. dissimulatum* per tree, respectively (regardless to light).

Scientific works bring different view about behavior of *M. dissimulatum* (Villacorta, 1973; Donis, 1988). Works, which mention about open cultivation and low precipitation as stimulative for its occurrence could describe this insect as thermophilic. However, our testing proved higher occurrence under shady plantations and Vargas et al., (2005) observed higher occurrence of the pest in higher altitudes. This would describe *M. dissimulatum* as insect loving shade and high relative humidity. If we would like to compare various works carried out on this insect before, one of possibility is to assess average proportion of infested pods. In our testing it was about 9%. It is not so different from values observed by others. Donis (1988) observed about 11.5% of infested pods, similarly to 11.1% observed by Vargas et al., (2005). The maximum occurrence of insect was similar in investigation carried out in the zone with stable temperature (in our testing and in the tests in Costa Rica) like in Alto Beni, where exists greater oscillations in monthly average temperature (about 10 °C) (Somarriba and Trujillo, 2005). From the facts mentioned above follows that *M. dissimulatum* has site-specific behavior, which has to be assessed in each particular zone where this pest can cause crop loss (Phillips-Mora, 1993). It is important to mention, that investigation of Donis (1988) was located at more or less same altitude, however study of Vargas et al., (2005) was about two times more southerly from the equator, compared to our investigation. This is more interesting with regards that they insect was more abundant on plantations located higher.

As Donis (1988) studied the insect population throughout the year, he stated that population peaks coincided with month with lowest precipitation and highest temperature. Stimulative effect of low precipitation was observed also by Vargas et al., (2005) in Bolivia, but he stated that highest insect populations were in the coldest months. This does not correspond with behavior of related *M. annulipes* studied in Costa Rica by Villacorta (1973), who observed highest ratio of infested pods in rainy period with high daily temperature oscillations, but he does not discuss average monthly temperature and precipitation in detail. Monthly temperature in San Alejandro varies about 2°C (Domus, 2008). In Alto Beni, Bolivia where study of Vargas et al., (2005) was carried out, the difference between average monthly temperatures can vary up to 10°C. Here the population peak of *M. dissimulatum* corresponds to July and August; to coldest months from the year (average is 16°C). The annual

temperature patterns in La Lola, Costa Rica, where worked other specialist on *Monalonia* sp. is more similar to patterns from San Alejandro (Villacorta, 1973; Donis, 1988; Jimenez Guerra, 1996).

Therefore lower precipitation was recognized to have stimulative effect on attack of *M. dissimulatum*, independently at two places. If we consider low precipitation as effective at our study site, it is possible to suppose that the testing was carried out on the population peak of *M. dissimulatum* in San Alejandro, because June 2014 had the lowest precipitation from dry period (see table 2). This could be correspondent also to study on total insect occurrence on cocoa evaluated by, as he stated that the peak of insect population lays in the driest months, from May to July (Del Aguila, 1996).

The employment of alternative host trees could have possible positive effect on occurrence of *M. dissimulatum*, although alternative host of this insects are not widely studied. From suggested alternative trees only members of genus *Cecropia* sp. are cultivated in the zone of San Alejandro (Vebrova, 2012).

In the spite of advanced harvest period it could be supposed that increased competition for food resources could be reason for low incidence of *M. dissimulatum* in our investigation. Mirids are considered as highly competitive, as they are demanding for nutritive alimentation (Wheeler, 2001).

During our investigation was not observed any visible sign of shoot die-back caused by feeding of *M. dissimulatum*. This supports hypothesis stated by Wheeler (2001), who said that mirid populations feeding on shoots and fruits do not have to be related. This makes the mirid damage specified to pods. It is interesting to compare this phenomenon with laboratory studies on *M. annulipes* by Villacorta (1967), who stated that cocoa shoots are preferred by females to lay the eggs.

During creation of this thesis were observed many plantations with neglected basic phytosanitary treatments, like removing of infested pods. Debilitated trees affected by increased sporulation of diseases offer easier alimentation for pests.

In the case of *Parajalysus andinus* no investigation of insect behavior was carried out before. Almost all works on this insect investigate its taxonomy, mainly by great effort of Thomas J. Henry (Henry, 1997; Henry 2000; Henry and Froeschner, 1998). He refers about insect economic importance (Henry, 1997). However, Pruett (1996) cited by Henry (1997)

stated also possible importance of insect in process of pollination of cocoa, as he observed cocoa pollen on majority of adults of *P. andinus* flying around cocoa flowers during flowering period. During our investigation was observed warping of leaf surface possibly caused by *P. andinus*. Top part of attacked leaves turned brown. This insect is very common in Ucayali region; however it seems that the infestation of *P. andinus* does not create important economic loss. It was observed that the feeding of *P. andinus* causes more damage on the leaves of cocoa if it is taking place on young leaves. The leaf which was attacked when it was young is largely warped and with wilted top, but the leaf was never destroyed totally. In our testing was observed higher amount of insect on smaller leaves in open condition, which would describe more important impact of insect feeding in open cultivation.

Figure 8 and table 5 demonstrate relative proportion of occupied leaves and they show that in the investigation *P. andinus* was always observed higher insect occurrence under closed canopy cultivation. This difference was much higher in the case of *M. dissimulatum*, when there were observed almost 10 times higher proportion of total infested pods in the shady cultivation compared to open plantations. This was not so marked in the case of *P. andinus*, where total proportion of leaves occupied by insects was 47.7% in canopy and 39% in open cultivation.

7. CONCLUSION

Higher occurrence of pest insects in shade cultivation, which we have confirmed, would support farmers in the practice of elimination of canopy cover after juvenile phases of plantation (this practice is already used-personal observation and Juhbandt et al., 2010). However, as these pests does not play important role in the region for now and cover trees play many important ecological services, this recommendation remains disputable (Lojka et al., 2010). The elimination of the shade should not be considered as solution of the pest-related problems. The eventuality of pest outbreak should be taken in account even on plantations with lower level of shade.

The occurrence of important pest *M. dissimulatum* in Ucayali department is under surveillance for long time, when it was studied by scientist (Vergara Yulca et al., 1983) and also it is monitored by SENASA, Peruvian national service for crop protection. In year 2014 one farm with important crop loss induced by this pest was observed. It lays about 30 km easterly from San Alejandro (ACATPA; Henry Abelardo Mamani Chanini, personal communication). This describes a possibility of growing importance of cocoa pests simultaneously with the increasing production of cocoa in the department (Chauvin, 2010).

We still do not know key driving factor of pest occurrence under different light and climatic conditions. The biology of *P. andinus* was not studied; and it was discussed as having beneficial behavior. More research will be necessary.

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9. APPENDIX A



Advanced instar of nymphs of *M. dissimulatum* feeding on cherrille showing strong mirid infestation (author).



Young nymphs of *M. dissimulatum* (author).



The lesion made by mirid on young shoot-not observed during elaboration of this thesis (Coto, 2003).



Imago of *M. dissimulatum* feeding on a pod (author).



Three female and one male imago (with removed reproductive organs) of *M. dissimulatum* (author).

10. APPENDIX B



Imago, moulting imago and nymph of *P. andinus* on cocoa leaf (author).



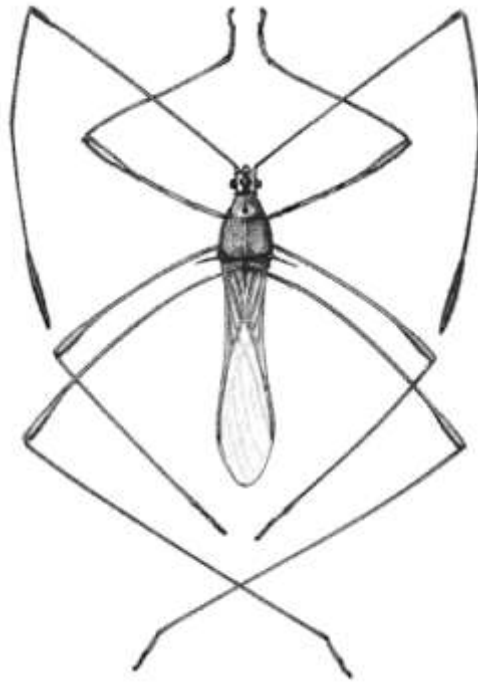
High population density of *P. andinus* on cocoa leaf (author).



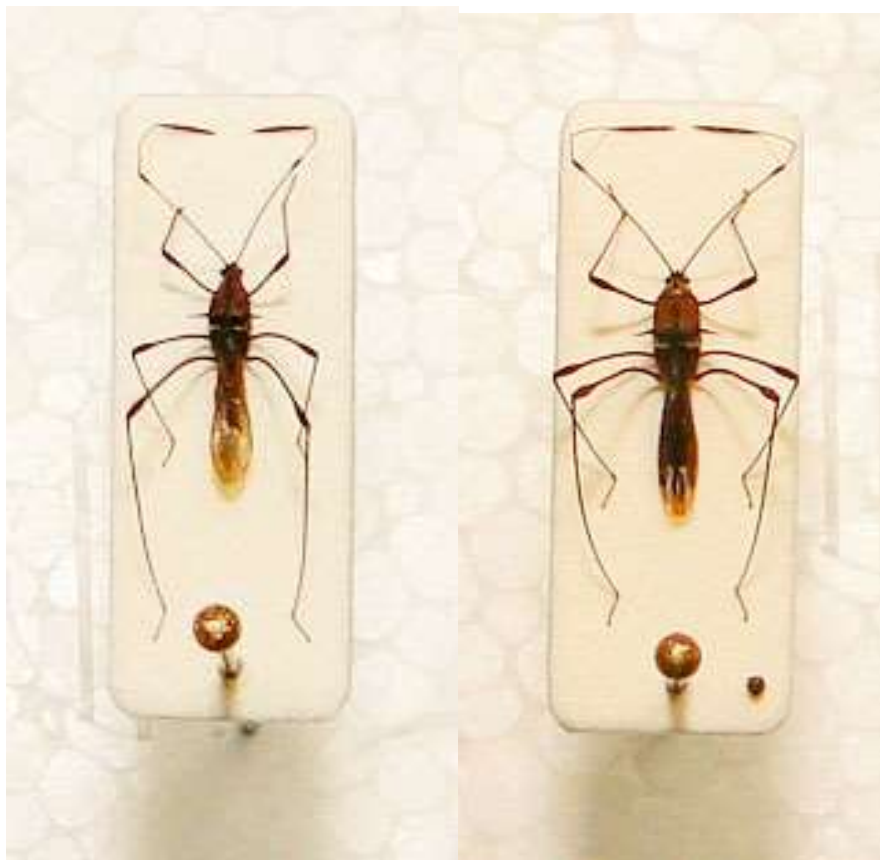
Cocoa shoot with damage possible caused by feeding of *P. andinus* (author).



Female *P. andinus* laying eggs into the leaf of *T. cacao* (author).



Dorsal habitus of imago of *P. andinus* (with kind permission of Henry, 1997).



Female and male (with extracted reproductive organs) imago of *P. andinus* (author).



Male *Zelus* sp., predatory assassin bug (*Heteroptera: Reduviidae*) which was caught feeding on *P. andinus*, (author).



Zelus sp., predatory assassin bug (*Heteroptera: Reduviidae*) caught feeding on *P. andinus* (author).