EFFECT OF CROPPING SYSTEM ON THE INCIDENCE OF INSECT PESTS OF POTATO AND ASSOCIATED OTHER NATURAL ENEMIES

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*This is to certify that thesis entitled, "**EFFECT OF CROPPING SYSTEM ON THE INCIDENCE OF INSECT PESTS OF POTATO AND ASSOCIATED OTHER NATURAL ENEMIES**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (MS) in ENTOMOLOGY**, embodies the result of a piece of bona-fide research work carried out by **Sharifun Nahar Trisha**, **Registration no. 14-05987** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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DEDICATED TO

MY

BELOVED PARENTS

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ABSTRACT

A field experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka to investigate the effect of cropping system on the incidence of insect pests of potato and associated other natural enemies during the period from October-2019 to April 2020 in Rabi season. The experiment consisted of eight treatments and laid out in Randomized complete block design (RCBD) with three replications. Treatments *viz.* T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control) where ground nut and coriander were used as Intercrop (Ic) on other hand sweet potato, Fenugreek, spinach, coriander as well as radish were used as Border crop (Bc). Data on different parameters were collected for assessing results for this experiment. The overall result indicate that both border and inter crop in potato field reduced the incidence of major insect pest of potato comparing to sole cropping. The incidence of beneficial arthropods was higher in border crops and intercropping systems. The minimum leaf infestation by aphid, (4.74 %), white fly (2.12 %) and jassid (3.90 %) were recorded in T_7 treatment. The highest number of beneficial arthropods per plant such as pollinators like honey bee (124.33), carpenter bee (3.00), hover fly (5.80) and natural enemies like lady bird beetle (2.84), dragon fly (1.68) and bird (1.56) sat on the stick of bamboo were recorded in T_7 treatment. In term of edible yield and gross return, the highest edible yield of potato (12.30 ton/ha) and gross return (373680 taka/ha) were also recorded in T_7 treatment. The overall study of this experiment reveals that border crops and intercropping systems reduced incidence of major insect pest of potato field and border crops perform better than inter crop and significantly reduced pest infestation without use of any chemicals insecticides.

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ABBREVIATIONS

Full word	Abbreviations	Full word	Abbreviations
Agriculture	Agric.	Milliequivalents	Meqs
Agro-Ecological Zone	AEZ	Triple super phosphate	TSP
And others	et al.	Milligram(s)	mg
Applied	App.	Millimeter	mm
Asian Journal of Biotechnology and Genetic Engineering	AJBGE	Mean sea level	MSL
Bangladesh Agricultural Research Institute	BARI	Metric ton	MT
Bangladesh Bureau of Statistics	BBS	North	N
Biology	Biol.	Nutrition	Nutr.
Biotechnology	Biotechnol.	Randomized Complete Block Design	RCBD
Botany	Bot.	Regulation	Regul.
Centimeter	cm	Research and Resource	Res.
Cultivar	cv.	Review	Rev.
Degree Celsius	°C	Science	Sci.
Department	Dept.	Society	Soc.
Development	Dev.	Soil plant analysis development	SPAD
Dry Flowables	DF	Soil Resource Development Institute	SRDI
East	E	Technology	Technol.
Editors	Eds.	Tropical	Trop.
Emulsifiable concentrate	EC	Thailand	Thai.
Entomology	Entomol.	United Kingdom	U.K.
Environments	Environ.	University	Univ.
Food and Agriculture Organization	FAO	United States of America	USA
Gram	g	Wettable powder	WP
Horticulture	Hort.	Serial	Sl.
International	Intl.	Percentage	%
Journal	J.	Number	No.
Kilogram	kg	Microgram	µ
Least Significant Difference	LSD		
Liter	L		
Milliliter	mL		

CHAPTER I

INTRODUCTION

Potato is an important and leading food crop in Bangladesh. It is the seventh potato producing country in the world and ranks second after rice in terms of production and is the third most important food crop after rice and wheat in terms of human consumption in Bangladesh (FAOSTAT 2020).

Bangladesh experienced much progress in area, production and yield of potato in the last decade, as its area, production and yield raised to 461 thousand ha, 9605 thousand MT and 20.8 MT/ha in 2019-20 from 435 thousand hectares, 7930 thousand MT and 18.25 MT/ha in 2009-10, with growth rates 6%, 21% and 14%, during the period, respectively. It has happened due to the suitable environment and using high yielding varieties in potato production. As current production exceeds demand, Bangladesh started exporting fresh potato in the world market and exported 45000 MT of fresh potato in 2019-20 (Hortex, 2020). Annual potato consumption per capita also increased and reached 25.66 kg in 2016 from 23.65 kg in 2010, bringing the growth rate 8.5% during the only six-year period (HIES, 2016).

It is used as a popular vegetable by both the poor and rich people in Bangladesh. It has high nutritive value as per 100 gm of edible potato contains 97 kal calories, 1.6 gm protein, little amount of fat, 10.07 gm minerals and little amount of iron. It contains 74.7% moisture and 22.6% carbohydrate in combination with many other items of food (Hossain and Bose, 2000). It also contains significant levels of phenolic compounds and vitamin C as potent antioxidants (Brown, 2005) which inactivate reactive oxygen, reducing oxidative damage, lead to improved immune functions and reduce risk of cardiovascular disease, cancer, cataract, diabetes and aging (Kaur *et al*., 2004). People consume potatoes in various forms such as curry cooked food, fries, potato crackers and flour to make breads, biscuits, chips, etc. in both home and abroad. From the viewpoint of nutritional requirement Bangladesh has deficit in producing nutritional crops specially the tubers and vegetables. Around 80 per cent of potato production is achieved as a Rabi crop. The Rabi crop is sown in October and harvested in March. But it is grown as a kharif crop in some areas where it is sown in April-July and becomes available in the market by August-October. Although potato is a seasonal crop it is grown around the country based on climatic conditions and harvested at different times, thus making it available throughout the year.

Potato is a temperate or cool season crop which needs a low temperature, low humidity, less windy and bright sunny days. It does perform well under well distributed rains or moist weather situations to high temperatures. Moreover, humidity and rains are not conducive to potato crop as often suffered with insects, nematodes and disease attacks. In fact, insects, nematodes, rats and other pests are detrimental in reducing the agricultural production of potato in tropical countries (Waliullah 2007; Ghosh and Khan, 2010). Apart from the direct attack on plant some of the insects and nematodes are the vectors of virus particularly those of sap feeders *viz*., aphids, *Xiphinema, Longidorus* species etc. They suck sap of leaves, shoots, stem and roots and causing diseases to plants and indirectly affect photosynthesis also. Inspite of all efforts the control of insects and nematodes is challenging since vectors are usually mobile and small in size and more so it is very difficult to prevent colonization of some pests in fields (Chenula, 1984; Banjo, 2010). It is well documented that this important vegetable crop in fields is always subjected to qualitative and quantitative losses due to biotic and abiotic stresses. Potato yield losses due to pest and disease attacks could be as high as 100% depending on crop tolerance level, climatic conditions, soil, type of pest and disease (Olanya *et al.*, 2002).

Screening of literature revealed that potato crop is attacked by more than 100 arthropods and 156 species of plant-parasitic nematodes that belonged to 52 genera all over the world. Out of these, 80 arthropods and 93 species of nematodes fall under 40 genera have been reported from India alone (Pandey, 2007). Important insect pests which feed on both above and underground parts of potato include, cutworm, flea beetles, tobacco caterpillar, aphids, potato leafhopper, Lygus bugs, potato tuberworm, whitefly, wireworm, earwigs, moth, and white grub, etc. Potato tuber moth is one of the most devastating pests causing up to 100% yield loss due to its capacity to attack at the field and continue affecting tubers at the store (Ojero and Mueke ,1985; Okonya and Kroschel, 2016). Nematode species, *Globodera* and *Meloidogyne* are among those nematodes that have been reported as endoparasitic on potato crop (Waliullah, 1992).

The population of these insects multiplies rapidly and cause severe infestation that had led to use of perilous chemical pesticides. The chemical pesticides are hazardous to both human health and environment. Therefore, to reduce these hazards sustainable insect pest management must be adopted. The diversification of cultivation through different cropping system could repel and suppress the insect pest population. Among different cropping system border and intercropping is more economical method of pest management and has become popular, particularly among the small and marginal farmers and it is very well fitted in Integrated Pest Management.

A pest-suppressive agro-ecosystem can be designed by identifying a suitable intercrop having insect pest deterrence, and a border crop enhancing natural enemy activity by acting as a refugium (Landis *et al.,* 2000). An agronomic practice like border cropping of crops of diver's growth habits may be found as a very useful technique in controlling a large number of crop pests. Border cropping is the cultivation of two crops on the same field. It is situated in the border of the main crops. Border cropping reduces the insect pest's population because of the diversity of the crops grown. When other crops are present in the field, the insect pests are confused and they need more time in host selection pressure. Under the above perspective, border cropping has been thought to be an environment friendly option for the management of insect pests in potato.

Intercropping brings about increases diversity in an agro-ecosystem. It minimizes environmental impacts of agriculture through reduced pesticide requirements (Reddy, 2017). Several cultural practices are known to promote diversity and stability on the farm, including the Intercropping (Ouma and Jeruto, 2010). This practice increased the distance between plants of the same species which leads to complicate migration of pests or transmission of diseases from one plant to another in the same field. In crop protection generally there is a base crop and one or more associated plants grown within, acting as repellent or attractant for certain pests. Attractant species are mainly used as trap plants to reduce pest infestation on the base crop. Once pests are lured from the main crop on to the trap plants, they can be controlled in limited area with minimum cost (Gautam and Chhaya, 2017). Some plant combinations, for instance, with non hosts reduce the spread of pest within crops (Degri *et al.* 2014). Non host plant in such mixture may emit chemical or odors that adversely affect the pests, thereby conferring some level of protection to the host plant (Reddy 2012). Wszelaki (2014) reported that the use of intercropping can provide benefits to a management system, including decrease insect pest pressure, reduced need for external inputs, increase in biodiversity, enhanced production and lower economic risk. Separation susceptible plants with non host species provides a physical barrier to insect pest movement, limiting spread and decreasing livelihood of damage to susceptible varieties (Gautam and Chhaya, 2017). The use of intercropping system is one of alteration to insecticide. It is a non-chemical cultural practice that has the potential to reduce pest infestation because it increases crop diversity (Sullivan, 2003; Woomer *et al*. 2004; Degri *et al.* 2012; Degri *et al.* 2014). Crop intercropping or mixing as a traditional agricultural technique for preventing crop yield decrease from plant disease and pest infestation in different world geographical area can also increase biodiversity in field to encourage environmentally. sustainable agriculture production with low inputs of pesticide (Ghaley *et al.* 2005). However, very little attention has been given in this area in Bangladesh.

Considering the above facts, the present study was carried out with the following objectives:

- To find out the incidence of major insect pests and beneficial arthropods in potato field by using border crops and intercropping system
- To assess the level of infestation caused by major insect pests of potato using border crops and intercropping system.
- To observe the effects of border crops and intercropping system on the yield and gross return.

CHAPTER II

REVIEW OF LITERATURE

An attempt was made in this section to collect and study relevant information available regarding the effect of cropping system on the incidence of insect pests of potato and associated other natural enemies in potato field. The compiled literature was helpful in conducting the present piece of work.

2.1 Insect pest complex of potato

Medina-Hernández *et al.* (2019) a number of review paper assessed to know the effect of different environmental factor on the population of whitefly *Bemisia tabaci*. With this aim, they studied the different works done in India and abroad during 1982 to 2017 and found that different environmental factors affect the population in different extent even variation was found in same factors in different location or different time.

Castillo *et al.* (2016) demonstrated that bittersweet nightshade (*Solanum dulcamara* L.) is key non-crop host of the potato psyllid (*Bactericera cockerelli* Šulc) and could be a source of the psyllids that colonize potato (*Solanum tuberosum* L.) fields in the north-western United States. Furthermore, viz; aphid, beetle, thrips and other pests of potato also were collected on bittersweet nightshade by them.

D'Auria *et al*. (2016) reported the incidence of potato tuberworm (*Phthorimaea operculella* Zeller), beet leafhopper (*Circulifer tenellus* Baker) and green peach aphid (*Myzus persicae*) on the potato crops at Washington State, USA. Each of these pests was responsible for the direct mutilated potato foliage and/or tubers. *C. tenellus* and *M. persicae* also transmitted the viruses that can significantly reduce potato yields.

Nag (2016**)** observed that the sucking pest like whitefly, aphid, thrips, leaf hopper are the major insect pest of potato crop in Chhattisgarh plain region in India. The activity of all these insect pests commenced from second week of December on potato variety, Kufri Lauvkar causing damage at various stages of the crop. The activity of leafhopper peaked during the third week of January recording 4.52 nymphs and adults per plant with seasonal mean of 2.57 per plant. The density of whitefly reached its peak population of 4.16 and 3.60 per plant during 3rd weeks of December and January with seasonal mean of 2.76 per plant. The aphids recorded its peak activity of

13.00 per plant during last week of January with a seasonal mean of 5.53 aphids per plant.

Mandloi (2015) studied the activity period of Aphis gossypii Glover from October 2012 to March 2013 with two distinct peaks (11.22 and 11.66 aphid/ 6 leaves) during 7th and 11th SW (standard week) and Liriomyzatri folii Burges was observed from October 2012 to March 2013 with three distinct peaks (44.56%, 45.95%, and 44.02%) during 10th, 11th and 12th SW respectively. While *Bemisia tabaci* Genn appeared November 2012 to March 2013 with two distinct peaks (9.84 and 11.85 flies/10cm twigs) during 7th and 9th SW. *Amrasca devastans* Ishida and *Scirtothrips dorsolis* Hood were observed during November 2012 to March 2013 with two distinct peaks (9.26 and 9.15 jassid/6 leaves) 9th and 11th SW and 7th and 9th SW (2.08 and 1.85 thrips/ 6 leaves) respectively. Analysis of correlation coefficient between abiotic factors (weather parameters) and the major insect pests, showed that population of thrips had a significant positive correlation with evening relative humidity (R.H.), while fruit borer had a significant positive correlation with rainy days.

In the array of understanding the distribution and seasonal abundance potato tuber moth (PTM) in Nepal, Giri *et al.* (2014) conducted an annual monitoring of fifteen districts of Nepal during 2008-09. For this purpose they installed locally made pheromone traps and the observations were taken in every 24 hour intervals. The activity of PTM was observed in plains, mid hills and high hill districts. The population of PTM was found more in mid-hills than in plain whereas PTM was totally absent in high hill districts of Nepal. The highest average number of PTM was observed in May (480±238 moth/month) with no adult moths in October to December in plain whereas 522±174 moth/month was observed in July and 18±4 moth/month in December in mid-hills of Nepal. The seasonal abundance of PTM observed from March to July (74±63 to 126±100 moth/month) in Plain and March to October (191±157 to 104±60 moth/month) in mid-hills. The understanding of PTM population dynamics could be useful to make suitable management decision.

Pathipati *et al*. (2014) revealed that the infestation and severity of insect pests were highly influenced by weather parameters. Thrips population reached its peak (1.80/leaf) in the 52nd Standard Meteorological Week (SMW). Thrips population had a positive correlation with maximum temperature and negative correlation with minimum temperature, morning and evening relative humidity, and rainfall.

Shukla (2014) recorded the periodic incidence of different sucking pests on potato during the crop season. The aphid population reached its peak level (27.17 aphids / 3 leaves) during 14th week after sowing. Results revealed that maximum activity was recorded during January and the correlation studies showed positive correlation with rainfall and relative humidity and negative correlation with both maximum and minimum temperatures.

Attack of more than hundred species of insect pests such as white grubs, cutworms, potato tuber moth, termites, red ants and mole crickets on potato tubers was identified by Chandel *et al*. (2013). Their study revealed that damage due to sap-feeding insects such as aphids, leafhoppers, thrips and white files was by directly feeding on different parts of a plant and acting as vectors of plant viruses. Being a vector of viruses such as PLRV (Potato Leafroll Virus), PVY (Potato virus Y) and Gemini virus aphids and whiteflies constitute a major threat to the potato seed production. Order Lepidoptera and Coleoptera were the major foliar feeders those were damaging the potato plants. Among coleopterans, the most destructive pests are hadda beetle, flea beetle, blister beetle and chaffer beetles. Beside these *Spodoptera spp*., *H. armigera, Plusia orichalcea* and *Spilosoma obliqua* were the important leaf-feeding caterpillars of potato fields.

Giordanengo *et al.* ((2013) reported that in potatoes, aphids rarely reach populations which lower potato yields by their feeding alone, due to natural enemy complex including Coccinellidae, predatory bugs in genera *Orius, Nabis,* and Geocoris, lacewings, spiders, syrphid fly larvae, and/or predatory gall midge larvae (Cecidomyiidae), as well as aphid specific parasitoids, typically solitary koinobionts in family Aphidiidae.

Meena *et al.* (2013) noticed that whitefly population during July to November and attained their peak in first and second week of September during 2006-07 (6.9 whiteflies/ 3 leaves/plant) and during 2007-08 (6.7 whiteflies/ 3 leaves/ plant), at Rajsamad in Rajasthan.

Khanal *et al.* (2012) studied the abundance and distribution of white grubs in three districts of Nepal namely Makawanpur, Tanahu and Chitwan, during June-July 2010. For assessing the activity of scarab beetles flight they installed two light traps for two nights in two locations of each of the districts and a season long light trap at Chitwan district from April to September 2010. They noted that the species composition of scarab beetles in these three districts were different. However, the most rampant species of scarab beetles in Chitwan were *Anomala dimidiata* (24%) *Maladera affinis* (23.75%), *A. varicolor* (23%), *Heteronychus lioderus* (14%) and *Holotrichia spp*.

Kumar *et al.* (2012) invested the influence of weather parameters on the efficiency of pheromone trap catches of *S. litura* in the Bengaluru district, Karnataka. The study shown that the efficiency of the pheromone traps, lures and the activity of the pest directly depends on several weather factors especially maximum and minimum temperatures, evaporation as well as wind speed. This exhibits a positive effect on the trap catches and percent defoliation caused by the pest. Furthermore it was observed that difference in trap catches was insignificant; however there was reported significant difference in moth catches during weeks and their interactions. It was also reported that trap catches lowered the damage caused by the insect.

Meena *et al.* (2012) found that the infestation of shoot and fruit borer was also observed during November and December and the maximum population was observed during 6th and 7th standard week of month February and maximum incidence of jassids during 52nd Standard Week (SMW) of December and minimum was during 12th SMW of March during *Rabi* season 2009 on brinjal.

Khan *et al.* (2009) reported that spring tails (*Sinella curvista*), cutworm (*A. ipsilon*), white grub (*Brahmina coriacea* and *H. longipennis*), green peach aphid (*M. persicae*), root knot (*M. hapla*) and root lesion nematode (*Pratylenchus spp*.) lead to heavy yield losses in potato in Kashmir valley.

Rai *et al.* (2009) reported that the incidence of thrips commenced from 2nd week of September to first week of November and was maximum (2 thrips/ three terminal leaves) in the first week of October.

Bharadiya and Patil (2005) recorded the maximum activity of *B. tabacii* during the fourth week of October. A positive significant correlation was observed between the whitefly and maximum and minimum temperature, whereas significant negative correlation was observed between the pest and maximum and minimum relative humidity, and rainfall. The meteorological factors contributed 72.30-92.30% for the build-up of whitefly population from the direct count and from yellow sticky traps.

Ali *et al*. (2004) observed the appearance of whitefly, *B. tabacii* mid-May and reached at peak in July. The lowest population was observed at the of the September. The population density of mites was the highest in early July and lowest in the second week of September.

Das *et al.* (2003) reported that the incidence of jassid commenced from the 26th standard week, reached peak intensity (69.6/25 leaves) during 30th standard week i.e., last week of July.

Chaudhuri *et al.* (2001) found that the maximum population density of whitefly on tomato (1.68 whiteflies/plant) in West Bengal during mid-February and high infestation levels were maintained from mid- February to mid-March.

Ratanpara *et al.* (1994) reported that population build trend of hopper negatively associated with temperature while positive relation was observed with sunshine.

In Haryana Sharma and Sharma (1997) recorded the highest population of jassid during the first week of August.

2.2 Cropping system

Cropping system is pattern of crops grown on a given piece of land or sequence in which the crops are cultivated on piece of land over a fixed period and their interaction with farm resources and other farm enterprises. Among various types of cropping system cultivation of border crop and intercropping are important for managements of insect pest in the crop field.

2.2.1 Influence of different border crops against incidence of different insect pests of potato

Border or barrier crops are crops, which interfere with the phototactic responses of vector aphids by disrupting host plant selection and restricting virus spread. They are secondary plants used within or bordering a primary crop that manipulates aphid flight behavior and virus transmission. Border crops use is a simple cultural technique applied to reduce virus incidence in seed potato. It is easy to plant, requires no specialized equipment, it is compatible with current production practices and can be applied in any cultivar and around a field of any size and shape.

Boiteau *et al.* (2009) found out that controlling aphid with oils reduced year to year variation and it was effective than crop border crop or oil sprays used separately. The mineral oil spray was applied on the border crop reducing the number of aphids that would transmit the virus to the main crop.

Muindi (2008) reported that border crops such as sorghum, millet, pigeonpeas, broad and maize have been used in management of aphid-transmitted potato virus diseases.

Nderitu *et al*. (2008) reported that Border crops of pigeonpeas, used in okra were found to be effective method in management of aphids.

Fereres (2000) reported that border crops are known to significantly reduce non-persistently transmitted aphid-borne viruses by intercepting viruliferous alate pest migration regardless of direction of attack They can also act as natural sinks for non-persistent viruses hence don not reduce aphid numbers landing in the protected crop.

Matteson *et al*. (1984) studied the cropping patterns traditionally used by the farmers and reported lower pest numbers in more diverse, intercropped or mixed cropping system than in mono cropping.

2.2.2 Influence of different intercrops against incidence of different insect pests of potato

Konar *et al.* (2010) concluded that potato intercropped with onion and garlic was most effective in decreasing the incidence of important pests attacking potato viz cutworm, various defoliators, Epilachna beetle, aphid, whitefly and viral disease incidence. They also made a research review on intercropping improvement and concluded that intercropping systems clearly have the potential to increase the long-term sustainability of food production under low inputs in many parts of the world.

Amarawardana *et al.* (2007) conducted investigation on odour-mediated effects of leek, *Allium porum* and chives, *A. schoenoprasum* on the host searching behaviour of the aphid *M. persicae*. In an olfactometer, odour of the host plant sweet pepper *Capsicum annuum* was significantly attractive, whereas odour of chives was significantly repellent. Combined odour of sweet pepper and chives was neither attractive nor repellent. When sweet pepper plants were exposed to volatiles from chives for five days, their odour subsequently became repellent to *M. persicae.* An extract of leek plants was significantly repellent to aphids in the olfactometer, as were sweet pepper plants sprayed with this extract. Because both leek and chives can disrupt host finding by the aphid, both plants have potential for intercropping with sweet pepper.

Mogahed (2003) found the efficacy of intercropping against insect population during the winter season at Oam Shyhan, Egypt. He recorded that potato cultivation had lesser infestation of cotton whitefly, cotton thrips, potato leaf aphids and potato leaf hoppers when intercropped with garlic and onion compared to the same cultivars of potato grown as sole crop. The average yield of potato tubers in plots of potato grown alone was lower compared to those of intercropped potatoes.

The influence of intercropping of bean, pea, carrot, onion and castor with potato on the population density of their economically important pests was investigated by Mateeva *et al*. 2002. The density of the major economically important pests related to the relevant crop was observed during the vegetative periods of onion (onion fly, *Hylemya antiqua*), carrot (carrot fly, *Psyla rosoe*), potato (Colorado potato beetle, *Leptinotarsa decemlineata*), bean (pea weevil, *Acanthoscelides obtectus)* and peas (green pea aphid, *Acyrthosiphon pisi*).The samples were collected by entomological sweep net and by bush counting. Based on the study, some of the plant species act as repellents on some of economically important pests. Onion, carrot, pea and castor oil plant repelled *P. rosae, H. antiqua, L. decemlineata* and *A. pisi,* respectively. The study of repellent behaviour of some plant species to different pest insects depicted new opportunities for decrease of chemical use, especially in vegetable-growing.

Ebwongu *et al.* (2001) investigated the effect of intercropping of maize and potato on the incidence of potato aphids (*M. persicae*) and leafhoppers *(Empoasco* spp.).Aphids and leafhoppers infestation in the different spatial arrangements were similar at early stages but significantly differed at later stages. Least aphid and leafhopper infestation was noticed in the additive mixture. There was no significant influence of spatial arrangement on tuber damage, although that tendency was for more damage in plots with high potato concentration. High relative humidity negatively affected the aphid population but not leafhoppers incidence.

Bhagabati *et al.* (1996) evaluated the total aphid vector population *(M. persicae* and *A. gossypii).* The vector population was assessed at 7 day intervals from the germination date (potato with at least 3 trifoliate leaves) up to 105 days after sowing (DAS). The mean population of aphid vector/plant was lowest (0.71) and the final PLRV disease incidence was lowest (9.14%) in the sole potato crop, whereas, the highest aphid population/plant (1.13) with the highest disease incidence (28.5%) occurred in the potato-wheat intercrop. The aphid population was absent from the potato crop in all treatments until 63 DAS.

Two field experiments were conducted in West Java, Indonesia by Potts and Gunadi (1991) to investigate the effect of intercropping (potato + *Allium cepa* or *A. sativum)* on the insect population. Intercropping reduced populations of *M. persicae, A. gossypii* and *Empoasca* spp. Leaf damage to potato by *H. sparsa (Epilachna sparsa)* was also decreased, but populations of *Thrips palmi or T. parvispinus* were increased.

2.3 Natural enemies

Sardana *et al*. (2006) reported that the release of *Trichogramma* sp. @ 5 lakh/ha was found to be effective against *L. orbonalis*. Higher population of coccinellids (4.69/plant), predatory spiders (3.24/plant) and *Chrysoperla* (4.15 eggs/plant) was observed in IPM fields compared to field adopting farmers practices. Coccinellids and predatory spiders were present throughout the crop season starting from September till mid-March.

Raja *et al*. (1998) noticed that release of an egg parasitoid, *T. chilonis* at fortnightly interval significantly reduced the *L. orbonalis* damage and recorded fruit yield of 20.3 t/ha in brinjal crop. Release of the egg parasitoid, *T. japonicum* resulted in very good control of shoot and fruit borer.

Gupta *et al.* (1997) stated that the *C. septempunctata* is one of the most dominant enemies to reduce aphid population in the field.

Mishra *et al.* (1995) recorded seven species of coccinellids, two of syrphids and a chryopid on potato around Farrukhabad, Agra and Meerut districts of Uttar Pradesh. However, the predominant one were Lady Bird beetle (*Cooccinella septempuncata* Linn.) and *M. sexmaculatus* Fabr.

Singh (1988) identified over 24 predators and 22 parasitoids attacking on aphids (M. *persicae*). He further reported that among predoters: *Allograpta favana* (Wiedemnn), *Sphaerophoria indiana* (Bigot), *Leucopis fumidilarva* (Tanas) and *Episyerphus balteatus* (De Geer) and *Menochilus sexmaculatus* (Fabr) and among parasitoids: *Aphelinus* spp. and *Aphidius colemani* (Viereck) were most effective against the aphids. He also reported five entomopathogenic fungi against aphids in Shimla.

Saxena and Raj (1980) observed 2.5 to 5.0 percent parasitisation of PTM larvae with *Melanips spp*. and *Diadgma molliplum* (Holmgren) in Shimla hills.

Diwakar and Pawar (1979), conducted a study on the efficacy of a larval parasitoid namely *Bracon hebator* Say against PTM and by releasing in field under natural conditions in Banglore. As a result they registered twelve percent parasitisation of the larvae under field conditions. Further, they recorded eleven important species of parasitoids from Bangalore on *Helicoverpa armigera.* Among ichnemonids, *Campoletis chlorideae* Uchida, *Eriborus* sp. and *Xanthopimia punctata* Fabr. ; In braconids, *Bracon hebetor* Say, *B. greeni* Ashm. and *Apanteles spp.* ; in bathylid *Goniozu* (Parasierola) spp., in trichogrammatid, *Trichogramma chilonis* Westwood; in tachinids, *Carcelia illota* Curq., *Palexorista laxa* Curr. and Goniophthalmus halli Mesnil and among mermithid *Hexmerimis spp*. were found to be most effective.

Verma *et al.* (1976) identified the maximum (100%) capability of Aphelinus of parasitizing *Myzus persicae*, alone.

Dalaya and Patil (1973) reported that *Copidosoma koehleri* Blanchard which is an exotic egg/larval parasitoid can parasitize 28.4-60.8 percent potato tuber moth. Thus may prove useful in controlling the population of PTM under field conditions.

Nair and Rao (1972) in Karnataka reported indigenous parasitoids like *Chelonus curvimaculatus* Cameron, *Bracon gelechiae* Asheamd, *Apanteles spp.*, *Pristomerus vulnerator Panzer* and several other braconids. These were reported to cause four to seventeen percent parasitisation of potato tuber moth (PTM) under field conditions.

2.4 Border crops and inter crops with crop yield

Rodge and Yadlod (2009) reported that the intercropping of coriander, onion, palak and radish in rabi season with solanaceous vegetable crops is profitable. Intercropping of coriander with brinjal revealed highest net profit followed by radish with tomato and palak with chilli.

The suitability of fenugreek, spinach, coriander (*Coriandrum sativum*), radish and carrot as intercrops for potato (cv. *Kufri Badshah*) was evaluated by Kumar *et al.* (2007) and reported that the potato-fenugreek intercropping system recorded the highest productivity (27.9 t/ha), net return/ha (51,428 Rs. /ha) and benefit cost ratio (2.10). This system also provided additional income to the farmers during the initial months of the crop, when they did not have income from farming activities.

Khurana and Bhatia (1995) reported that intercropping with onions or fennel increase net returns. Net return increased further when recommended N + P fertilizer rates for the intercrops were also applied. Returns from potatoes + onions were higher than from potatoes + fennel.

Nandekar *et al.* (1995) found that the potato/onion intercrop produced the highest potato yield and gave the highest net return. All yield of intercropping attributes of potatoes were better for sole-cropped potatoes. Hossain *et al.* (2003) reported that intercropping of sugarcane with potato and sesame produced highest yield of sugarcane followed by intercrop with onion and sesame.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka to investigate the effect of cropping system for controlling insect pest of potato and its impacts on other arthropods. Materials used and methodologies followed in the present investigation have been described in this chapter.

3.1 Experimental period

The experiment was conducted during the period from October-2019 to April 2020 in Rabi season.

3.2 Description of the experimental site

3.2.1 Geographical location

The experiment was conducted in the Experimental field of Sher-e-Bangla Agricultural University (SAU). The experimental site is geographically situated at 23°77′ N latitude and 90°33′ E longitude at an altitude of 8.6 meter above sea level (Anon., 2004).

3.2.2 Agro-Ecological Zone

The experimental site belongs to the Agro-ecological zone (AEZ) "The Modhupur Tract", AEZ-28 (Anon., 1988 a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon., 1988 b). For better understanding about the experimental site has been shown in the Map of AEZ of Bangladesh in Appendix-I.

3.2.3 Soil

The soil of the experimental field belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon soil series. Soil pH ranges from 5.4–5.6 (Anon., 1989). The land was above flood level and sufficient sunshine was available during the experimental period. Soil samples from 0–15 cm depths were collected from the agronomy field. The soil analyses were done at Soil Resource and Development

Institute (SRDI), Dhaka. The physicochemical properties of the soil are presented in Appendix II.

3.2.4 Climate and weather

The climate of the experimental site was subtropical, characterized by the winter season from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October (Edris *et al.*, 1979). Meteorological data related to the temperature, relative humidity and rainfall during the experiment period of was collected from Bangladesh Meteorological Department (Climate division), Sher-e-Bangla Nagar, Dhaka and has been presented in Appendix- III

3.3 Planting materials used

3.3.1 Major crop

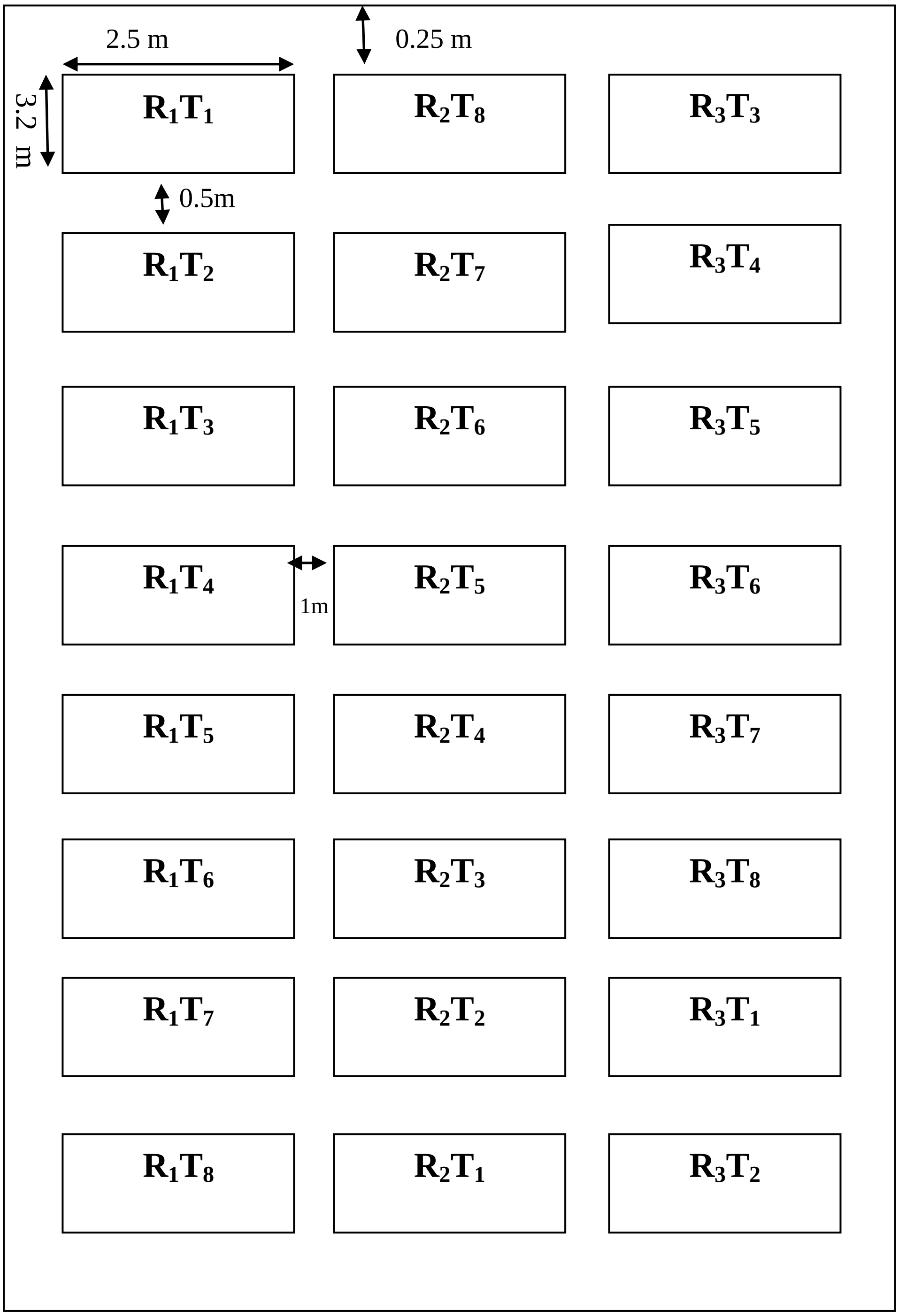
Tuber of BARI potato 7 (Diamond) was used as a planting materials for this experiment. It was collected from BADC (Bangladesh Agriculture Development Corporation) of Dhaka.

3.3.2 Border crops and intercropped crops

Sweet potato, fenugreek, spinach, coriander and radish were used as border crops and groundnut and coriander were used as intercropped crops. Tuber and seed of these crops were collected from local market.

3.4 Experimental design and layout

The experiment was laid out in Randomized complete block design (RCBD) with three replications. The experimental field was divided into 3 blocks maintaining 1m block to block distance and each block was subdivided into 8 plots for 8 treatments each maintaining 2 m x 1.5 m plot size. Thus the total number of plots was 24. The plot to plot distance was 0.5 m was kept to facilitate different intercultural operations. The layout of the experiment is shown in Figure 1.



LEGENDS

Border crop (Bc)

Inter crop (Ic)

Treatments

T_1= Potato+ Groundnut (Ic),

T_2= Potato+ sweet potato (Bc),

T_3= Potato+ Coriander (Ic),

T_4= Potato+ Fenugreek (Bc),

T_5= Potato+ Spinach(Bc),

T_6= Potato+ Coriander (Bc),

T_7= Potato+ Radish (Bc),

T_8= Sole potato (Control).

Figure 1. Layout of the experimental field

3.5 Land preparation

The experimental land was opened with a power tiller on Date 25th October, 2019. Ploughing and cross ploughing were done with power tiller followed by laddering. Land preparation was completed on 28 October, 2019. The field layout and design of the experiments were followed immediately after land preparation.

3.6 Manure and fertilizer

The fertilizers N, P, K in the form of Urea, Triple Super Phosphate (TSP), Muriate of Potash (MP), Gypsum (Ca), Zinc sulphate (Zn) respectively and as an organic manure, Cowdung were applied. The entire amount of organic manure and, MP, gypsum, zinc sulphate TSP were applied as basal during the final preparation of land. Urea was applied in two equal installments at the final preparation of land and at 35 days after planting (DAP) as topdressing under moist soil condition. The dose and method of application of fertilizers are shown in Table 1 (BARC, 2012).

Table 1. Dose and method of application of fertilizer in potato field.

Fertilizer and manure	Dose kg/ha	Application (%)	
		Basal	Topdressing (35 DAP)
Urea	320	50	50
TSP	200	-	-
Mop	220	-	-
Gypsum	100	-	-
Zinc sulphate	8	-	-
Cowdung	10000	-	-

3.7 Planting and sowing of border crops and intercrops

Tuber of sweet potato was planting as border crop and it was before plant 2 week of potato tuber planting. The seeds of both Border crops and intercrops were sown in the randomly assigned experimental plots before two weeks of planting of tuber potato. The seeds of border crops were sown in border area of the tuber potato planting area, whereas the seeds of intercrops were sown between two rows of the tuber potato.

3.8 Treatments

The tuber potato was cultivated in the field for combating major insect pests using border crops and intercropping practices. The experiment was conducted using five border crops, two intercrops and one untreated control considering cultivation of potato sole crop. Each of border crops, were treated as an individual treatment, which is presented in Table 2.

Table 2. List of treatments used in the study

Treatment	Treatment description	Remarks
T_1	Potato+ Groundnut	Cultivated as intercrop
T_2	Potato+ sweet potato	Cultivated as border crop
T_3	Potato+ Coriander	Cultivated as intercrop
T_4	Potato+ Fenugreek	Cultivated as border crop
T_5	Potato+ Spinach	Cultivated as border crop
T_6	Potato+ Coriander	Cultivated as border crop
T_7	Potato+ Radish	Cultivated as border crop
T_8	Sole potato (Control)	Cultivation of tuber potato as control

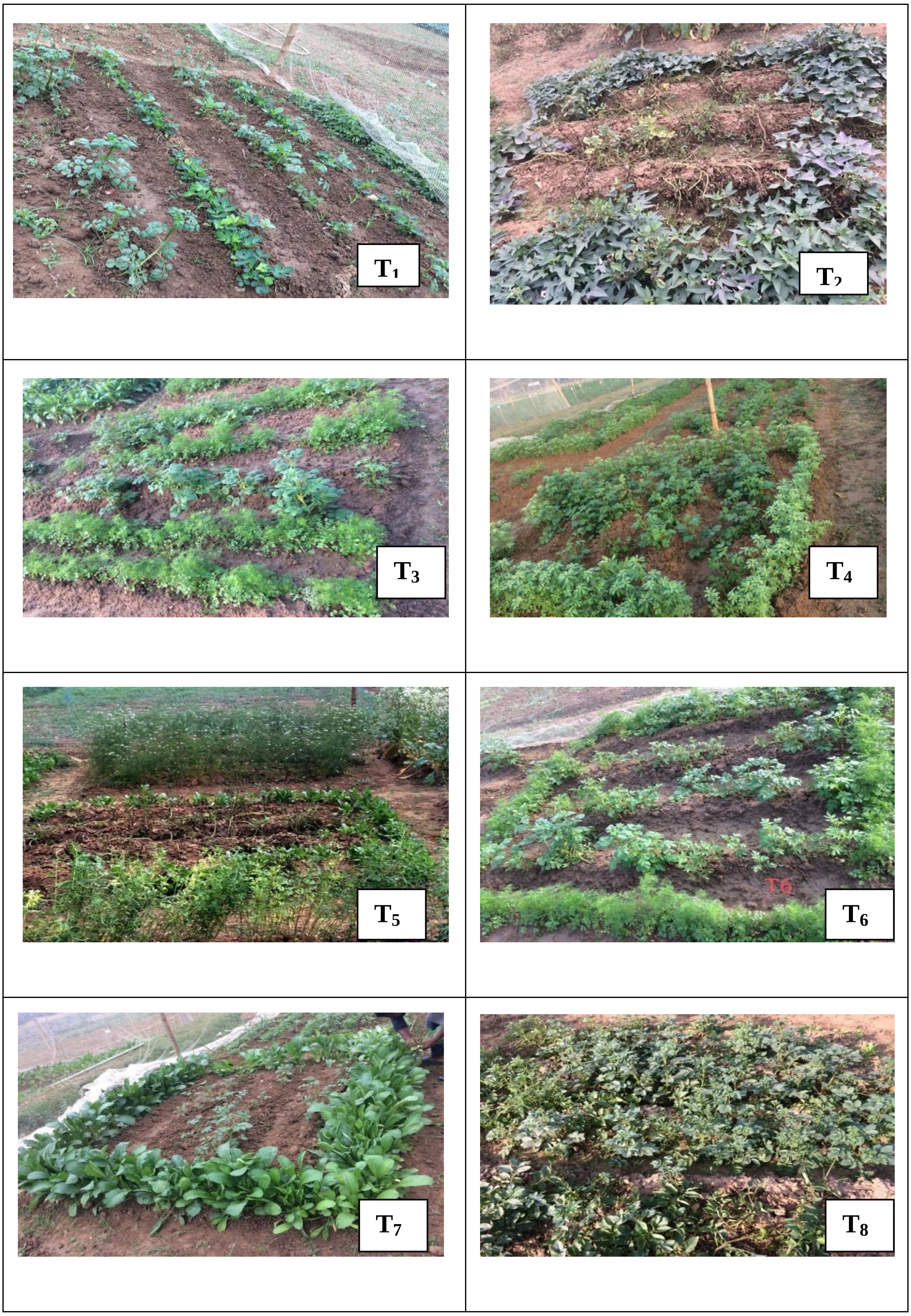


Plate 1. Showing experiment field crops used during the study period

T_1= Potato+ Groundnut, T_2= Potato+ sweet potato, T_3= Potato+ Coriander, T_4= Potato+ Fenugreek, T_5= Potato+ Spinach, T_6 = Potato+ Coriander, T_7= Potato+ Radish and T_8= Sole potato (Control).

Plate 2. Showing experiment field at the reproductive stage of crops during the study period

Plate 3. Showing potato research field border cropping with Coriander during the study period

Plate 4. Showing potato research field border cropping with methi during the study period

Plate 5. Showing potato research field inter-cropping with Coriander during the study period

Plate 6. Showing potato research field border-cropping with Radish during the study period

Plate 7. Showing potato research field inter-cropping with groundnut during the study period

Plate 8. Showing potato research field border-cropping with sweet potato during the study period

3.9 Planting of potato tuber

The potato tubers were planted in the experimental field on 1st November, 2019.

3.10 Intercultural operation

3.10.1 Irrigation

Three times irrigation was done. At first 10 days of planting, secondly 15 and 35 days after planting.

3.10.2 Weeding

At 15 and 35 days after emergence of seedling, weeding was done before irrigation.

3.10.3 Earthing up

Earthing up was done at 15 and 35 days after planting on both sides of rows by taking the soil from the space between the rows by a small spade.

3.11 Monitoring of insect pest and data collection

For data collection five plants per plot were randomly selected and tagged. Data collection was started at seedling stage to harvest. The results are presented as an average value of the five tagged plants. The data were recorded on different parameters. The following parameters were considered during data collection.

- Pest complex of potato field
- Incidence of insect pests per plant
- Leaf infestation (%)
- Reduction leaf infestation over control
- Incidence of beneficial arthropods per plant
- Diversity of other arthropods community per plot
- Total edible yield (ton/ha)
- Gross return (tk/ha)

3.12 Pest complex of potato field

Insect found in control treatment were recorded according to their incidence and severity and recorded with their common name, scientific name main characteristic of them. Observations were recorded at 10 days intervals starting from 30 days of germination up to 160 Days After Planting (DAP).

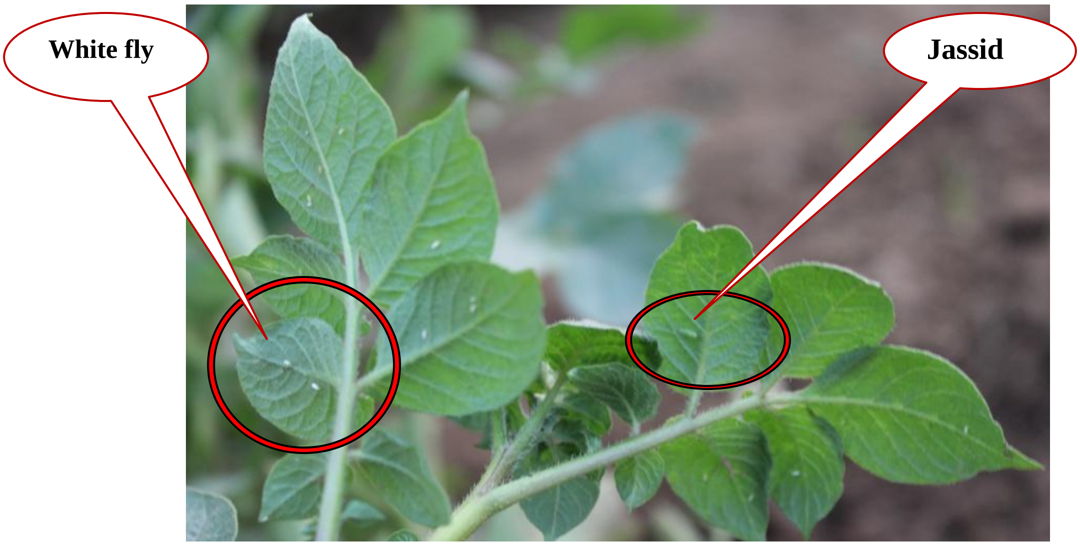


Plate 9. White fly and jassid infested potato leaves in the research field

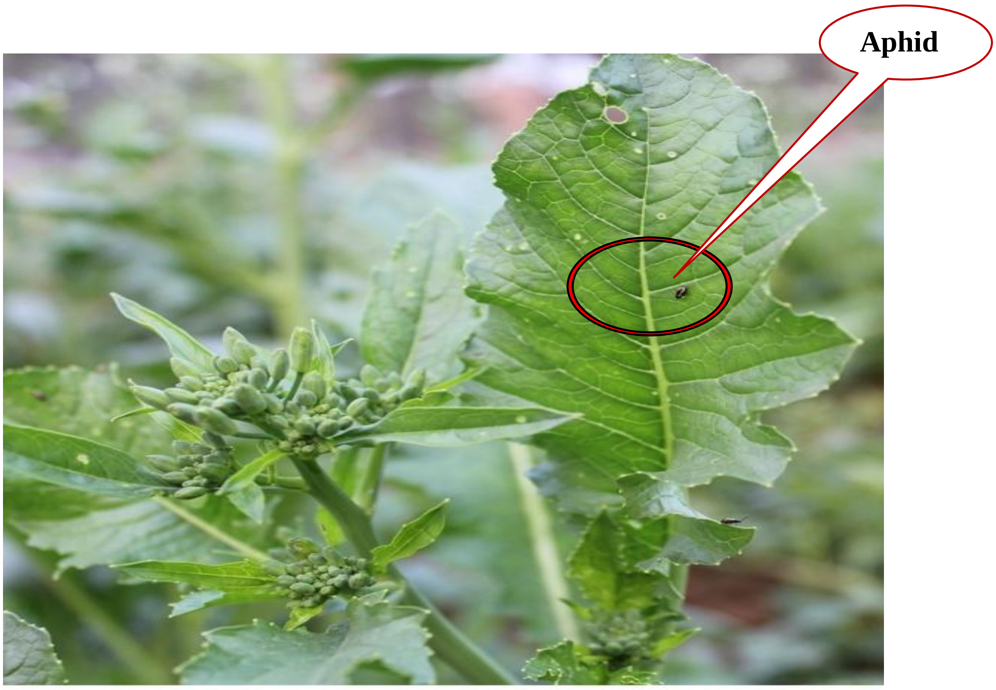


Plate 10. Winged black aphid infested radish leaves in the research field

3.13 Incidence of insect pests per plant

In each treatment, 5 plants were selected from each side of one treatments, thus the total number of plants selected per treatment was 15 for recording various data at different intervals. Data were collected on the number of cutworm, Aphids, epilacna beetle, jassid, white fly, leaf eating caterpillar etc. per plant at early, mid and late vegetative stage of potato. Lay visual contact/observation.

3.14 Leaf infestation (%)

Number of infested leaves was counted from total leaves per plant and percent leaves infested by potato insect pests were calculated as follows:

$$\text{Infested leaves (\%)} = \frac{\text{Number of infested potato leaves}}{\text{Total number of potato leaves}} \times 100$$

3.15 Reduction of leaf infestation over control

The number of infested potato leaves, total potato leaves and untreated control plot were recorded for each treated plot and the reduction of infestation on number basis was calculated using the following formula:

Leaf infestation (%) reduction over control=

$$\frac{\text{\% infested leaves in control} - \text{\% infested leaves in the treatment}}{\text{\% infested leaves in control}} \times 100$$

3.16 Incidence of pollinators

Data were collected on the incidence of pollinators such as honey bee, carpenter bee, hover fly etc. per plant and counted separately for each treatment through visual observation in the field.

3.17 Incidence of natural enemies

Number of natural enemies present per five plants of potato, inter and border crops, were recorded at 10 days interval starting from 30 days of germination up to 120 DAP in potato, up to 50 DAP in border crop and up to 65 DAP in intercrop. The insects were collected from the plots by sweep-net and hand picking method. Total number of natural enemies like lady bird beetle, hover fly larvae, dragon fly, ground beetle, ant, spider, millipede, bird etc. per plant and counted separately for each treatment through visual observation in the field.

3.18 Diversity of other arthropods community

For diversity of other arthropods community the simplest measure of species diversity is counting of the number of species. The concept was extended up to order and family level. In this experiment it was performed by sweeping net methods.

3.19 Sweeping net method

This method was used for counting flying and stationary insects on host plants to know the abundance pattern of insects in the present study. Five times double staked sweeping was done in different days in each plot to make a composite sample by a sweeping net at early, mid and late vegetative stages of cabbage. Each sample was examined separately without killing the insects and released them immediately after counting in the same plot. The individuals of each sample were counted by order.

3.20 Measurement of diversity index and equitability

To assess both the abundance pattern and the species richness, Simpson's diversity index was used (Simpson, 1949).

Simpson's Index, $D = \frac{1}{\sum_{i=1}^{s} Pi^2}$

Where, Pi is the proportion of individual for the i-th insect family and S is the total number of insect family in the community (i.e., the richness). The value of index depends on both the richness and the evenness (equitability) with which individuals were distributed among the families. Equitability was quantified by expressing Simpson's index, D as a proportion of the maximum possible value of D.

Equitability, $E = \frac{D}{D\ max} = \frac{1}{\sum_{i=1}^{s} Pi^2} \times \frac{1}{S}$

3.21 Harvesting of main crop and other crops

Potato

Storage potatoes, also called main-crop potatoes, are ready at the end of the growing season when the foliage has turned yellow and begun to dry. Harvesting of potato was done on 12th March, 2020. Finally per hectare yield was calculated by converting yield of harvested potato /per plant.

Harvesting of sweet potato

Harvest sweet potato was done when the leaves and ends of the vines have started turning yellow.

Ground nut When its turn into brown color then its harvested by hand pulling.

Fenugreek

3-5 months after planting Fenugreek seeds were ready for harvest. Once the plant has finished flowering, died back, and begun to turn yellow. The seeds develop within small pods, and each pod contains about 10 to 20 seeds.

Spinach

Spinach leaves are ready to harvest as soon as they are big enough to eat. Harvest by removing only the outer leaves and allowing the center leaves to grow larger; this will allow the plant to keep producing. Picking the outer leaves also gives the advantage of briefly delaying bolting

Radish

Radish was cultivated as oilseed radish and harvest seeds when pods turn from green to yellow/brown. Care was taken for harvesting, threshing and also cleaning of radish seed. The seeds were cleaned and finally the weight was recorded and converted into per hectare yield. The cumulative radish yield per plot was calculated.

Coriander

Coriander was harvested after 120 days of sowing. The harvested coriander was threshed manually and seeds were separated, clean and dried in bright sunshine. The dried seed yield thus obtained was converted into per hectare yield.

Plate 11. Healthy potato plant in the research

Plate 12. Different photograph showing sole crop and other crops after harvesting

3.22 Yield

3.22.1 Total edible yield

Harvested yield of an individual crop, Border crops and intercrops that we consume considered as total edible yield.

3.22.3 Marketable yield per hectare and gross return

The marketable yield per hectare was measured by converting marketable yield per plot into yield per hectare and was expressed in tons and the measuring the gross return of it.

3. 23 Data analysis technique

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program name Statistix 10 Data analysis software and the mean differences were adjusted by Least Significant Difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

Results obtained from the present study have been presented and discussed in this chapter with a view to study the effect of cropping system for controlling insect pest of potato and its impacts on other arthropods. The data are given in different tables and figures. The results have been discussed, and possible interpretations have been given under the following headings.

4.1 Pest complex of potato field

Pests insects can have adverse and damaging impacts on agricultural production and market access, the natural environment, and our lifestyle. Pest insects may cause problems by damaging crops and food production, parasitising livestock, or being a nuisance and health hazard to humans. In this experiment the potato field was infested with different types of pest. Various pest were observed in the experimental field of which sometimes they occurred with higher incidence at particular growth stages of potato and sometimes their occurrence with lesser extent at particular growth stages of potato (Table 3). The incidence of cutworm occurred at lower extent in early and mid vegetative stage of potato and quite increasing at late vegetative stage of potato. In case of aphid it was occurred at higher extent at various growth stage of potato. Jassid occurred in less extent in early vegetative stage of potato but increasing with mid and late vegetative stage of potato. In case of leaf eating caterpillar it was occurred at lower extent at various growth stage of potato. White fly infestation was occurred at higher extent and its quite higher in mid vegetative comparatively to early and late vegetative stage of potato. In case of epilachna beetle the infestation was higher extent in late vegetative stage of potato comparable to early and mid vegetative stage of potato. The infestation of various insect pest of potato might varied due to the location and seasonal variation. The result obtained from the present study was similar with the findings of Medina-Hernández *et al.* (2019) who reported that different environmental factors affect the population in different extent even variation was found in same factors in different location or different time. D'Auria *et al*. (2016) also reported that potato crop infested with different types of pest such as, potato tuberworm (*Phthorimaea operculella* Zeller), beet leafhopper (*Circulifer tenellus* Baker) and green peach aphid (*M. persicae*). Chandel *et al*. (2013) reported that potato field was attacked of more than hundred species of insect pests such as white grubs, cutworms, potato tuber moth, termites, red ants and mole crickets on potato tubers.

Table 3: List of insect pests found in potato field during Rabi season 2019-2020

Pests	Early vegetative stage	Mid vegetative stage	Late vegetative stage
Cutworm (*Agrotis ipsilon*)			
Aphid (*Myzus persicae*)			
Jassid (*Amrasca biguttula*)			
Leaf eating caterpillar *(Helicoverpa armigera)*			
White fly (*Bemisia tabaci*)			
Epilachna Beetle *(Epilachna varivestis)*			

Colored area represent the infestation of various insect pest at different growing stage of potato

Yellow colored area represent pest occurrence at less extent

Green colored area represent pest occurrence at higher extent

4.2 Incidence of major insect pests during the study period in experimental field

4.2.1 Incidence of cutworm (No. / plant)

Number of cutworm incidence per plant was recorded at early, mid and late vegetative stage of potato and significant variation was recorded for different types of treatment (Table 4).

At early vegetative stage of potato, incidence of cutworm was maximum (0.20) in T_8 (Control) treated plot whereas no incidence was recorded in other treated plots.

At mid vegetative stage, incidence of cutworm was maximum (0.40) in T_8 (Control) treated plot whereas no incidence was recorded in T_1, T_2, T_3, T_4, T_6 and T_7 treated plots.

At late vegetative stage , incidence of cutworm was maximum (0.45) in T_8 (Control) treated plot whereas no incidence was recorded in $T_{1,}$ T_2 and T_7 treated plot. As a result, the trend of order of effectiveness of the treatments applied against cutworm per plant at the late vegetative stage including untreated sole potato in terms of reducing number was ($T_{1,}$ T_2 and T_7) < T_4< T_6< T_5< T_3< T_8

Table 4. Effect of different cropping system on the incidence of cutworm per plant at different growth stage of potato

Treatments	Incidence of cutworm (No./plant)		
	Early vegetative stage	Mid vegetative stage	Late vegetative stage
T_1	0.00 b	0.00 c	0.00 e
T_2	0.00 b	0.00 c	0.00 e
T_3	0.00 b	0.00 c	0.33 b
T_4	0.00 b	0.00 c	0.20 d
T_5	0.00 b	0.20 b	0.32 bc
T_6	0.00 b	0.00 c	0.30 c
T_7	0.00 b	0.00 c	0.00 e
T_8	0.20 a	0.40 a	0.45 a
$LSD_{(0.01)}$	0.004	0.008	0.02
CV(%)	7.07	4.71	5.71

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.2.2 Incidence of aphid (No./ plant)

The data on table 5 showed significant variation in respect of incidence of aphid (No./plant) at early, mid and late vegetative stage of potato.

Experiment result revealed that at early vegetative stage of potato showed significant variation in respect of incidence of aphid (No. /plot). The incidence of aphid per plant was minimum in T_4 (1.20) treatment. Whereas the higher number of aphid per plant was recorded in T_8 (6.75) treatment and it was statistically different among all other treatment. As a result, the trend of order of effectiveness of the treatments applied against aphid per plant at the early vegetative stage including untreated sole potato in terms of reducing number was $T_4 < T_6 < T_2 < T_7 < T_1 < T_5 < T_3 < T_8$.

At mid vegetative stage of potato experiment result showed significant variation in respect of incidence of aphid (No./plant). Experiment result showed that T_7 treatment recorded the minimum incidence of aphid per plant (5.83). Whereas the maximum incidence of aphid per plant (10.40) was recorded in T_8 treatment which was statistically similar with T_6 and T_3 treatment recorded incidence of aphid per plant (10.15 and 10.03). As a result, the trend of order of effectiveness of the treatments applied against aphid per plant at the mid vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_4 < T_5 < T_2 < T_1 < T_3 < T_6 < T_8$.

At late vegetative stage of potato different treatment significantly effect on number of aphid incidence per plant. Experiment result showed that T_7 treatment recorded the minimum incidence of aphid per plant (9.17) whereas the maximum incidence of aphid per plant (16.70) was recorded in T_8 treatment. As a result, the trend of order of effectiveness of the treatments applied against aphid per plant at the late vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_5 < T_2 < T_4 < T_1 < T_3 < T_6 < T_8$.

Table 5. Effect of different cropping system on the incidence of aphid per plant at different growth stage of potato

Treatments	Incidence of aphid (No./plant)		
	Early vegetative stage	Mid vegetative stage	Late vegetative stage
T_1	4.00 cd	9.50 b	13.47 cd
T_2	3.40 d	8.37 c	12.57 e
T_3	5.40 b	10.03 ab	14.07 c
T_4	1.20 f	7.00 d	13.10 de
T_5	4.60 bc	7.40 d	10.07 f
T_6	2.10 e	10.15 ab	15.77 b
T_7	3.70 d	5.83 e	9.17 g
T_8	6.75 a	10.40 a	16.70 a
$LSD_{(0.01)}$	0.89	0.82	0.63
CV(%)	9.39	5.48	2.76

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.2.3 Incidence of epilachna beetle (No. / plant)

In potato field number of epilachna beetle incidence was showed significant variation at early, mid and late stage of potato at various types of treatment and presented in table 6.

At early vegetative stage of potato, incidence of epilachna beetle per plant was maximum (1) in T_8 (Control) treated plot whereas no incidence was recorded in other treated plots except T_5 (0.20) treatment.

At mid vegetative stage, incidence of epilachna beetle per plant was maximum (5.67) in T_8 (Control) treated plot whereas the minimum incidence (0.50) was recorded in T_7 treatment. The trend of order of effectiveness of the treatments applied against epilachna beetle per plant at the mid vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_4 < T_5 < T_2 < T_1 < T_6 < T_3 < T_8$.

At late vegetative stage, incidence of epilachna beetle per plant was maximum (8.25) in T_8 (Control) treated plot whereas minimum incidence (2.05) was recorded in T_7 treated plot. As a result, the trend of order of effectiveness of the treatments applied against white grabs per plant at the late vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_4 < T_5 < T_2 < T_1 < T_6 < T_3 < T_8$

Table 6. Effect of different cropping system on the incidence of epilachna beetle per plant at different growth stage of potato

Treatments	Incidence of epilachna beetle (No./plant)		
	Early vegetative stage	Mid vegetative stage	Late vegetative stage
T_1	0.00 c	1.50 c	3.87 c
T_2	0.00 c	1.25 d	3.40 d
T_3	0.00 c	2.01 b	4.50 b
T_4	0.00 c	0.95 e	2.85 e
T_5	0.20 b	1.00 e	3.10 de
T_6	0.00 c	1.56 c	4.07 c
T_7	0.00 c	0.50 f	2.05 f
T_8	1.00 a	5.67 a	8.25 a
$LSD_{(0.01)}$	0.03	0.12	0.36
CV(%)	11.79	3.88	5.24

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.2.4 Incidence of jassid (No. / plant)

The data on table 7 showed significant variation in respect of incidence of jassid (No./plant) at early, mid and late vegetative stage of potato.

Experiment result revealed that at early vegetative stage of potato showed significant variation in respect of incidence of jassid (No./plant). The incidence of jassid per plant was minimum in T_3, T_4 and T_7 treatment recorded (0.0) no incidence of jassid per plant. Whereas the higher number of jassid per plant was recorded in T_8 (0.40) treatment and it was statistically different among all other treatment. As a result, the trend of order of effectiveness of the treatments applied against jassid per plant at the early vegetative stage including untreated sole potato in terms of reducing number was (T_3, T_4 and T_7) $< T_5 < T_6 < T_2 < T_1 < T_8$.

At mid vegetative stage of potato experiment result showed significant variation in respect of incidence of jassid (No./plant). Experiment result showed that T_7 treatment recorded the minimum incidence of jassid per plant (0.47) which was statistically similar with T_6 and T_2 treatment recorded incidence of jassid per plant (0.60 and 0.64). Whereas the maximum incidence of jassid per plant (3.27) was recorded in T_8 treatment. As a result, the trend of order of effectiveness of the treatments applied against mite per plant at the mid vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_6 < T_2 < T_4 < T_3 < T_5 < T_1 < T_8$.

At late vegetative stage of potato different treatment significantly effect on number of jassid incidence per plant. Experiment result showed that T_7 treatment recorded the minimum incidence of jassid per plant (0.90) which was statistically similar with T_3 treatment recorded incidence of jassid per plant (1.13) whereas the maximum incidence of jassid per plant (4.30) was recorded in T_8 treatment. As a result, the trend of order of effectiveness of the treatments applied against jassid per plant at the late vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_3 < T_2 < T_4 < T_6 < T_1 < T_5 < T_8$.

Table 7. Effect of different cropping system on the incidence of jassid per plant at different growth stage of potato

Treatments	Incidence of jassid (No./plant)		
	Early vegetative stage	Mid vegetative stage	Late vegetative stage
T_1	0.32 b	1.88 b	1.57 c
T_2	0.17 c	0.64 ef	1.34 cd
T_3	0.00 f	1.02 d	1.13 de
T_4	0.00 f	0.76 e	1.38 cd
T_5	0.06 e	1.42 c	2.12 b
T_6	0.14 d	0.60 ef	1.43 cd
T_7	0.00 f	0.47 f	0.90 e
T_8	0.40 a	3.27 a	4.30 a
$LSD_{(0.01)}$	0.02	0.20	0.37
CV(%)	5.97	6.56	8.77

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.2.5 Incidence of white fly (No./ plant)

Effect of different cropping system on the incidence of white fly per plant was recorded at early, mid and the late vegetative stage of potato and significant variation was found for different types of treatments and it has been represent in Table 8.

At the early vegetative stage of potato, significant variations were recorded in different treatments in case of number of white fly per plant. Results showed that, the lowest incidence of white fly per plant (0.79) was recorded in T_7 treatment which was statistically similar with T_6 treatment recorded incidence of white fly per plant (1.03). Whereas the maximum incidence of white fly per plant (3.61) was recorded in T_8

treatment. As a result, the trend of order of effectiveness of the treatments applied against white fly per plant at the early vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_6 < T_1 < T_4 < T_2 < T_3 < T_5 < T_8$.

At mid vegetative stage of potato significant variation were recorded in different treatments in case of number of white fly per plant. Results showed that, the lowest incidence of white fly per plant (0.73) was recorded in T_1 treatment. Whereas the maximum incidence of white fly per plant (3.31) was recorded in T_8 treatment. As a result, the trend of order of effectiveness of the treatments applied against white fly per plant at the early vegetative stage including untreated sole potato in terms of reducing number was $T_1 < T_7 < T_6 < T_4 < T_2 < T_3 < T_5 < T_8$.

At late vegetative stage of potato significant variation were recorded in different treatments in case of number of white fly per plant. Results showed that, the lowest incidence of white fly per plant (0.66) was recorded in T_7 treatment which was statistically similar with T_4 and T_6 treatment recorded incidence of white fly per plant (0.77 and 0.97). Whereas the maximum incidence of white fly per plant (2.50) was recorded in T_8 treatment. As a result, the trend of order of effectiveness of the treatments applied against white fly per plant at the early vegetative stage including untreated sole potato in terms of reducing number was $T_7 < T_4 < T_6 < T_3 < T_2 < T_5 < T_1 < T_8$.

Table 8. Effect of different cropping system on the incidence of white fly per plant at different growth stage of potato

Treatments	Incidence of white fly (No./potato plant)		
	Early vegetative stage	Mid vegetative stage	Late vegetative stage
T_1	1.20 ef	0.93 g	2.04 b
T_2	1.67 cd	1.98 cd	1.43 c
T_3	1.80 c	2.12 c	1.03 d
T_4	1.43 de	1.85 d	0.77 de
T_5	2.52 b	2.78 b	1.65 c
T_6	1.03 fg	1.13 e	0.97 de
T_7	0.79 g	0.73 f	0.66 e
T_8	3.61 a	3.31 a	2.50 a
$LSD_{(0.01)}$	0.32	0.14	0.35
CV(%)	7.49	3.21	10.52

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.2.6 Incidence of leaf eating cater pillar (No./plant)

Different cropping system of potato significantly effect on number of leaf eating cater pillar per plant at mid and later vegetative stage of potato and showed in table 9.

At early vegetative stage of potato, no incidence of leaf eating cater pillar was recorded in all treated plots.

At mid vegetative stage, incidence of leaf eating cater pillar was maximum (0.30) in T_8 (Control) treated plot and comparatively lower incidence of leaf eating cater pillar (0.25) was recorded in T_5 treatment whereas no incidence was recorded in $T_{1,}$ $T_{2,}$ $T_{3,}$ $T_{4,}$ T_6 and T_7 treated plots.

At late vegetative stage, incidence of leaf eating cater pillar per plant was maximum (0.50) in T_8 (Control) treated plot and comparatively lower incidence of leaf eating cater pillar per plant (0.25 and 0.45) was recorded in T_3 and T_5 treatment whereas no incidence was recorded in $T_{1,}$ $T_{2,}$ $T_{4,}$ T_6 and T_7 treated plot. As a result, the trend of order of effectiveness of the treatments applied against leaf eating cater pillar per plant at the late vegetative stage including untreated sole potato in terms of reducing number was ($T_{1,}$ $T_{2,}$ $T_{4,}$ T_6 and T_7) < T_3< T_5< $T_{8.}$

Table 9. Effect of different cropping system on the incidence of Leaf eating cater pillar per plant at different growth stage of potato

Treatments	Incidence of leaf eating cater pillar (No./plant)		
	Early vegetative stage	Mid vegetative stage	Late vegetative stage
T_1	0.00	0.00 c	0.00 d
T_2	0.00	0.00 c	0.00 d
T_3	0.00	0.00 c	0.25 c
T_4	0.00	0.00 c	0.00 d
T_5	0.00	0.25 b	0.45 b
T_6	0.00	0.00 c	0.00 d
T_7	0.00	0.00 c	0.00 d
T_8	0.0	0.30 a	0.50 a
$LSD_{(0.01)}$	-	0.02	0.02
CV(%)	-	10.29	5.12

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.3 Overall effect of border and intercrops on the incidence of different insect pests in potato field during the study period

During the whole cropping season, potato field was infested with various types of insect pest which has been showed in figure 3. At a glance the figure showed that, a number of insect pests were recorded in the field of potato, of which sometimes they occurred with higher incidence and sometimes their occurrence with lesser extent during the study period. Among different treatment, T_7 treatment comprising with Potato+ Radish (Bc) showed the best performance in term of lowest population of insect pests during the study period, comparable to other treatments. Whereas the maximum number of insect pests was recorded in T_8 treated plot comprising with sole potato.

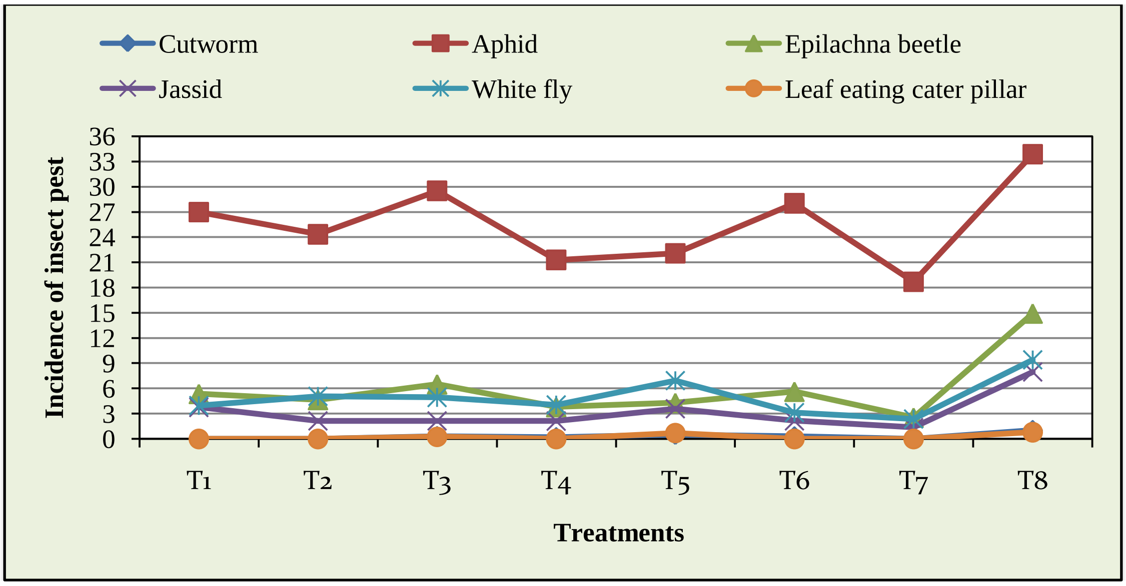


Figure 3. Incidence pattern of different insect pests population in potato during experiment period

[Here, T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.4 Leaf infestation (%)

4.4.1 Leaf infestation of potato caused by aphid at harvesting stage

Different cropping system showed significant variation in respect of leaf infestation of potato caused by aphid at harvesting stage which has been shown in table 10.

Experiment result showed that, the highest number of total leaves per plant (141.80) was recorded in T_5 treatment, which was statistically similar with T_7 (141.40) and T_4 (138.20) treatment. Whereas the lowest total number of leaf per plant (116.20) was recorded in T_6 treatment which was statistically similar with T_1 (116.30) and T_3 (117.50) treatment.

In term of number of infested leaves per plant, experiment result showed that T_8 treatment recorded the maximum leaves infestation per plant (20.75) whereas T_7 treatment recorded the minimum leaves infestation per plant (6.70) which was statistically similar with T_1 (7.00) treatment.

Again considering the leaf infestation percentage, minimum leaf infestation (4.74 %) caused by aphid was recorded in T_7 treatment whereas maximum leaf infestation (15.32 %) was recorded in T_8 treatment which was significantly different from all other treatments.

Considering the reduction of leaf infestation over control caused by aphid, the highest reduction of leaf infestation over sole (67.471%) was recorded in T7 treatment. Whereas, the lowest reduction of leaf infestation over sole potato was recorded in T_6 (7.23 %) treatment.

From the above findings it was revealed that, the lowest leaf infestation (5.55 %) and the highest reduction of leaf infestation over sole (67.47 %) were recorded in T_7 treatment using the potato + radish (as a border crop) crop combination in the field. As a result, the order of effectiveness of the treatments in terms of leaf infestation reduction caused by aphid was $T_7 < T_1 < T_4 < T_2 < T_5 < T_3 < T_6 < T_8$. The result obtained from the present study was similar with the findings of reported that Muindi (2008) and reported that border crops such as sorghum, millet, pigeonpeas, broad and maize have been used in management of aphid-transmitted potato virus diseases.

Table 10. Effect of different cropping system on leaf infestation of potato caused by aphid at harvesting stage

Treatments	Leaf infestation of potato by aphid			
	Total number of leaves/plant	Number of infested leaves/plant	Leaf infestation percentage (%)	Reduction of leaf infestation over control
T_1	116.30 d	7.00 f	6.00 f	66.27
T_2	133.40 c	14.20 d	10.65 d	31.57
T_3	117.50 d	15.70 c	13.36 c	24.34
T_4	138.20 ab	8.70 e	6.30 f	58.07
T_5	141.80 a	14.25 d	10.05 e	31.33
T_6	116.20 d	19.25 b	16.57 a	7.23
T_7	141.40 a	6.70 f	4.74 g	67.71
T_8	135.40 bc	20.75 a	15.32 b	0
$LSD_{(0.01)}$	4.45	0.71	0.45	
CV(%)	1.95	3.05	2.47	

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.4.2 Leaf infestation of potato caused by white fly

The significant variation was showed in different cropping system in respect of leaf infestation of potato caused by white fly at harvesting stage which has been shown in table 11.

Experiment result showed that, the highest number of total leaves per plant (141.80) was recorded in T_5 treatment, which was statistically similar with T_7 (141.40), T_8 (138.40) and T_4 (138.20) treatment. Whereas the lowest total number of leaf per plant (116.20) was recorded in T_6 treatment which was statistically similar with T_1 (116.30) and T_3 (117.50) treatment.

In term of number of infested leaves per plant, experiment result showed that T_8 treatment recorded the maximum leaves infestation per plant (12.20) whereas T_7 treatment recorded the minimum leaves infestation per plant (3.00) which was statistically similar with T_6 (3.20) treatment.

Again considering the leaf infestation percentage, minimum leaf infestation (2.12 %) caused by white fly was recorded in T_7 treatment whereas maximum leaf infestation (8.82 %) was recorded in T_8 treatment which was significantly different from all other treatments.

Considering the reduction of leaf infestation over control caused by white fly, the highest reduction of leaf infestation over sole (75.41 %) was recorded in T_7 treatment. Whereas, the lowest reduction of leaf infestation over sole potato was recorded in T_5 (68.85 %) treatment which was similar with T_1 (68.85 %) T_2 (68.85 %) treatment.

From the above findings it was revealed that, the lowest leaf infestation (2.12 %) and the highest reduction of leaf infestation over sole (75.41 %) were recorded in T_7 treatment using the potato + radish (as a border crop) crop combination in the field. As a result, the order of effectiveness of the treatments in terms of leaf infestation reduction caused by aphid was $T_7 < T_6 < T_4 < T_3 < T_1 < T_2 < T_5 < T_8$.

Table 11. Effect of different cropping system on leaf infestation of potato caused by white fly at harvesting stage

Treatments	Leaf infestation of potato by white fly			
	Total number of leaves/plant	Number of infested leaves/plant	Leaf infestation percentage (%)	Reduction of leaf infestation over control
T_1	116.30 c	3.80 b	3.28 b	68.85
T_2	133.40 b	3.80 b	2.85 cd	68.85
T_3	117.50 c	3.60 bc	3.06 bc	70.49
T_4	138.20 a	3.40 cd	2.46 e	72.13
T_5	141.80 a	3.80 b	2.68 de	68.85
T_6	116.20 c	3.20 de	2.75 d	73.77
T_7	141.40 a	3.00 e	2.12 f	75.41
T_8	138.40 a	12.20 a	8.82 a	0
$LSD_{(0.01)}$	4.27	0.24	0.25	
CV(%)	1.87	3.07	4.03	

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.4.3 Leaf infestation of potato by jassid

The significant variations were observed among the different treatments used for the management practices in terms of percent leaf infestation by jassid at harvesting stage, which has been shown in Table 12.

Experiment result showed that, the highest number of total leaves per plant (153.40) was recorded in T_2 treatment. Whereas the lowest total number of leaf per plant (116.20) was recorded in T_6 treatment which was statistically similar with T_1 (116.20) and T_3 (117.50) treatment.

In term of number of infested leaves per plant, experiment result showed that T_8 treatment recorded the maximum leaves infestation per plant (7.85) whereas T_7 treatment recorded the minimum leaves infestation per plant (5.52).

Again considering the leaf infestation percentage, minimum leaf infestation (3.90 %) caused by jassid was recorded in T_7 treatment which was statistically similar with T_2 (4.02 %) treatment whereas the maximum leaf infestation (5.80 %) was recorded in T_8 treatment which was significantly similar with T_1 (5.77 %) treatment.

Considering the reduction of leaf infestation over control caused by jassid, the highest reduction of leaf infestation over sole (29.68 %) was recorded in T_7 treatment. Whereas, the lowest reduction of leaf infestation over sole potato was recorded in T_1 (14.65 %) treatment.

From the above findings it was revealed that, the lowest leaf infestation (3.90 %) and the highest reduction of leaf infestation over sole (29.68 %) were recorded in T_7 treatment using the potato + radish (as a border crop) crop combination in the field. As a result, the order of effectiveness of the treatments in terms of leaf infestation reduction caused by jassid was $T_7 < T_3 < T_4 < T_6 < T_5 < T_2 < T_1 < T_8$. Matteson *et al*. (1984) also found similar result which supported the present finding and reported that the cropping patterns traditionally used by the farmers and reported lower pest numbers in more diverse, intercropped or mixed cropping system than in mono cropping.

Table 12. Effect of different cropping system on leaf infestation of potato caused by jassid at harvesting stage

Treatments	Leaf infestation of potato by jassid			
	Total number of leaves/plant	Number of infested leaves/plant	Leaf infestation percentage (%)	Reduction of leaf infestation over control
T_1	116.30 d	6.70 b	5.77 a	14.65
T_2	153.40 a	6.20 c	4.04 cd	21.01
T_3	117.50 d	5.85 e	4.98 b	25.48
T_4	138.20 bc	5.90 e	4.27 c	24.84
T_5	141.80 b	6.10 cd	4.30 c	22.29
T_6	116.20 d	5.93 de	5.10 b	24.46
T_7	141.40 b	5.52 f	3.90 d	29.68
T_8	135.40 c	7.85 a	5.80 a	0
$LSD_{(0.01)}$	5.00	0.18	0.27	
CV(%)	2.16	1.65	3.26	

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.5 Incidence of beneficial arthropods

4.5.1 Incidence of pollinators

Different cropping system viz. border crops and intercropping system applied in potato field were greatly influenced by the presence different types of pollinators like honey bee, carpenter bee, hover fly etc. that increase crop yield.

In this experiment different treatments used in potato field significantly effect on incidence of beneficial arthropods which has been shown in table 13.

In case of honey bee the highest number of honey bee per plant (124.33) was recorded in T_7 treatment which was statistically different among all other treatments. Whereas the minimum number of honey bee per plant (0.00) was recorded in T_8 treatment.

In term of carpenter bee, the highest number of carpenter bee per plant (3.00) was recorded in T_7 treatment which was statistically different among all other treatments. Whereas the minimum number of carpenter bee per plant (0.00) was recorded in T_8 treatment which was similar to T_2 (0.0), T_4 (0.0) and T_5 (0.0) treatment.

In case of hover fly, the highest number of hover fly per plant (5.80) was recorded in T_7 treatment which was statistically different among all other treatments. Whereas the minimum number of hover fly per plant (0.00) was recorded in T_8 treatment.

Table 13. Effect of different cropping system on the incidence of pollinators in potato field

Treatments	Number of pollinators per plant		
	Honey bee	Carpenter bee	Hover fly
T_1	0.27 d	0.07 c	2.16 d
T_2	0.70 d	0.00 d	1.00 f
T_3	81.70 b	0.33 b	2.67 c
T_4	1.67 d	0.00 d	1.33 e
T_5	0.00 d	0.00 d	1.00 f
T_6	38.33 c	0.08 c	5.67 b
T_7	124.33a	3.00 a	5.80 a
T_8	0.00 d	0.00 d	0.00 g
$LSD_{(0.01)}$	2.52	0.03	0.13
CV(%)	3.35	2.62	2.11

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.5.2 Incidence of natural enemies

In case of incidence of natural enemies per plant in potato field, significant variation were recorded among different treatment used for the insect management practices which have been shown in table 14.

In case of lady bird beetle, hover fly, dragon fly and bird sat on the stick bamboo, the highest number of natural enemies per plant such as 2.84, 5.80, 1.68 and 1.56 were recorded in T_7 treatment whereas minimum number of lady bird beetle was recorded in T_4 (0.87) treatment which was statistically similar with T_2 (1.07) treatment. The minimum number of hover fly and dragon fly was recorded in T_8 (0.0 and 0.24) treatment. The minimum number of bird sat on the bamboo stick was recorded in T_1 (0.23) treatment which was statistically similar with T_8 (0.31) treatment.

In case of ground beetle and ant, the maximum number was recorded in T_1 (1.35 and 3.10) treatment whereas the minimum number was recorded in T_8 treatment (0.27 and 0.42).

In case of presence of spider, the maximum number of spider was recorded in T_5 (1.85) treatment where as the minimum number of spider was recorded in T_8 (0.23) treatment.

The result obtained from the present study was similar with the findings of Sardana *et al*. (2006) and reported that the release of *Trichogramma* sp. @ 5 lakh/ha was found to be effective against *L. orbonalis*. Higher population of coccinellids (4.69/plant), predatory spiders (3.24/plant) and *Chrysoperla* (4.15 eggs/plant) was observed in IPM fields compared to field adopting farmer‟s practices. Coccinellids and predatory spiders were present throughout the crop season starting from September till mid-March and reduced insect infestation. Mishra *et al.* (1995) recorded seven species of coccinellids, two of syrphids and a chryopid on potato around Farrukhabad, Agra and Meerut districts of Uttar Pradesh. However, the predominant one were Lady Bird beetle (*Cooccinella septempuncata* Linn.) and *M. sexmaculatus* Fabr.

Table 14. Effect of different cropping system on the incidence of natural enemies per plant in potato field

Treatments	Number of natural enemies per plant						
	Lady bird beetle	Hover fly	Dragon fly	Ground beetle	Ant	Spider	Bird
T_1	2.62 ab	2.16 d	1.25 c	1.35 a	3.10 a	1.31 b	0.23 f
T_2	1.07 de	1.00 f	0.99 d	0.37 e	1.23 b	1.36 b	0.12 g
T_3	2.56 b	2.67 c	1.48 b	0.61 d	1.34 b	0.89 e	0.88 c
T_4	0.87 e	1.33 e	0.66 e	0.67 c	0.95 c	1.23 bc	0.58 e
T_5	1.32 d	1.00 f	1.48 b	0.77 b	0.84 c	1.85 a	0.77 d
T_6	2.53 b	5.67 b	1.57 b	0.62 d	1.32 b	1.11 cd	1.12 b
T_7	2.84 a	5.80 a	1.68 a	0.37 e	1.23 b	0.95 de	1.56 a
T_8	2.15 c	0.00 g	0.24 f	0.27 f	0.42 d	0.23 f	0.31 f
$LSD_{(0.01)}$	0.28	0.08	0.09	0.05	0.14	0.18	0.09
CV(%)	5.72	1.44	3.34	3.10	4.38	6.47	5.37

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Lest significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.6 Diversity of insect community

Trends in diversity pattern of insects under different treatments using relative methods viz. sweeping net method at the early, mid and late vegetative stages of crop growth of potato are shown after calculating the data from collected samples in Appendix IV and Table 15. Some unidentified insects which are not regarded as crop pests were also trapped incidentally in this methods. These were also included in data because the relative significance of their presence in a particular ecosystem is not clearly known to us.

4.6.1 Sweeping net method

Diversity index of insect pest community showed significant variation under different treatments using sweeping net method at the early, mid and late vegetative crop growth of potato are showed in table 15.

Using sweeping net method at early vegetative growth stage of potato, the maximum number of insect species per plant (11) was recorded in T_5 treatment and this treatment also recorded the maximum diversity index (3.67) and equitability (0.73). Whereas T_7 treatment the minimum number of insect species per plant (6). The minimum diversity index (1.81) was recorded in T_1 treatment and the minimum equitability (0.33) was recorded in T_8 treatment.

At mid vegetative stage T_7 treatment recorded the maximum number of insect species per plant (11), diversity index (4.63) and equitability (0.93). Whereas T_8 treatment recorded the minimum number of insect species per plant (11). The minimum diversity index (2.87) and equitability (0.41) was recorded in T_1 treatment.

At late vegetative stage of potato T_7 treatment recorded the maximum number of insect species per plant (18), diversity index (4.5) and equitability (0.90). Whereas T_8 treatment recorded the minimum number of insect species per plant (8). The minimum diversity index (1.98) and equitability (0.33) was recorded in T_6 treatment. Diversity index assessed through sweeping net method also revealed that high species diversity tends to mean that an area is healthier than when there is low species diversity.

Table 15. Diversity index and equitability of insect community of different families under different cropping system at early mid and late vegetative stage of potato

Treatments	Early vegetative stage			Mid vegetative stage			Late vegetative stage		
	No. of insect species per plant	Diversity index (D)	Equitability (E)	No. of insect species per plant	Diversity index (D)	Equitability (E)	No. of insect species per plant	Diversity index (D)	Equitability (E)
T_1	7	1.81	0.36	13	2.87	0.41	14	3.92	0.65
T_2	9	2.08	0.35	16	3.68	0.53	15	3.46	0.49
T_3	10	2.78	0.56	16	3.19	0.40	8	2.90	0.73
T_4	10	2.5	0.42	14	3.39	0.56	15	3.36	0.48
T_5	11	3.67	0.73	13	4.57	0.91	14	3.38	0.56
T_6	9	2.61	0.52	17	3.94	0.66	9	1.98	0.33
T_7	6	2.00	0.5	18	4.63	0.93	18	4.5	0.90
T_8	9	1.98	0.33	11	3.64	0.73	8	2.29	0.46

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Least significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications. [Here, T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4 = Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6= Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.7 Edible yield (ton/ha)

Significant variations were recorded in respect of edible yield (t/ha) of potato for different treatment which has been showed in Table 16.

In this experiment, result showed that the highest edible yield of potato (12.30 ton/ha) was recorded in T_7 treatment which was statistically similar with T_4 (12.28 ton/ha) and T_3 (12.26 ton/ha) treatment. Whereas the minimum edible yield of potato (6.61 ton/ha) was recorded in T_8 (Sole potato) treatment.

As a result, the trend of effectiveness of different treatment in terms of increasing the yield of potato was $T_7 > T_4 > T_3 > T_5 > T_6 > T_1 > T_2 > T_8$.

Table 16. Yield performance of potato, border and intercrops under the present study

Edible yield (ton/ha)												
Treatments	potato	Ground nut	Sweet potato	Coriander		Fenugreek		Spinach		Radish		
				Leaves thinning	Seeds	Leaves	Seeds	Leaves	Seeds	Leaves	Root	Seeds
T_1	10.40 b	1.0										
T_2	7.73 c		8.67									
T_3	12.26 a			0.05	0.44							
T_4	12.28 a					0.04	0.35					
T_5	10.93 b							0.25	0.20			
T_6	10.57 b			0.63	0.47							
T_7	12.30 a									0.44	2.16	0.40
T_8	6.61 d											
$LSD_{(0.01)}$	3.62											
CV(%)	0.91											

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Least significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[Here, T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4 = Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6= Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

4.8 Gross return

Gross return was significantly differ among different treatment for potato production which has been showed in table 17. From economic point of view, it was noticed that, Border crop and intercropping, gave higher economic return than monoculture (Table 17). The highest gross return (373680 taka/ha) was recorded in T_7 treatment whereas the lowest gross return (132200 taka/ha) was recorded in T_1 (control) treatment.

In sole cropping of potato higher extent of crop pests and diseases/weeds occurred which impact on the yield production of the potato crop. Whereas different cropping system such as Border crops and inter cropping system, can increase production and income and has additional benefits increased crop diversity, improved functioning of agricultural systems, spare land for biodiversity or other uses and reduced use of inorganic fertilizer and pesticides. Hasheela (2009) reported that cabbage from plots bordered with Indian mustard and Coriander had the highest mean number of marketable yield. Rodge and Yadlod (2009) reported that the intercropping of coriander, onion, palak and radish in rabi season with solanaceous vegetable crops is profitable. Intercropping of coriander with brinjal revealed highest net profit followed by radish with tomato and palak with chilli.

From the above findings, it was concluded that, the gross return over the sole potato was less where spinach was used as border crops; but when Radish was used as border crop, the gross return was higher than the sole potato.

Table 17. Gross return in border crops and intercrops of potato under different cropping system

Gross return (Tk/ha)													
Treatments	potato	Ground nut	Sweet potato	Coriander		Fenugreek		Spinach		Radish			Total taka
				Leaves (thinning)	Seeds	Leaves	Seeds	Leaves	Seeds	Leaves	Root	Seeds	
T_1	208000	100000											308000
T_2	154600		130050										284650
T_3	245200			2500	66000								313700
T_4	245600					1200	56000						302800
T_5	218600							5000	50000				273600
T_6	211400			3150	70500								285050
T_7	246000									1680	54000	72000	373680
T_8	132200												132200

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.01 level of probability by Least significant different Test (LSD). In a column, the mean values are the average of five potato plants per plant; numeric value represents the mean of 3 replications.

[Here, T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4 = Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6= Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control).]

Market price of commodities: potato 20 Tk/kg, Ground nut 100 Tk/kg, Sweet potato 20 Tk/kg, Coriander leaves 50 Tk/kg, Coriander seeds 150 Tk/kg, Fenugreek leaves 30 Tk/kg, Fenugreek seeds 160 Tk/kg, Spinach leaves 20 Tk/kg, Spinach seed 250 Tk/kg, Radish leaves 20 Tk/kg, Radish roots 25 Tk/kg and Radish seeds 180 Tk/kg

4.9 Relationship between numbers of insect species and diversity index

A positive linear relationship was observed between numbers of insect species and diversity index of all crop growth stage of potato (Fig.3 and table 15).

In case of sweeping net method for all the crop growth stages of potato, significant relationships between number of insect species and diversity index of insect community was observed (R^2 = 0.602, 0.100 and 0.782). The result of the experiment revealed highly significant positive relationship be between numbers of insect species and diversity index of all crop growth stage of potato which clearly notified that diversity index of insects community was influenced by the number of insects (i.e. richness) in diversity agro-ecosystems where the diversity index was increased with the increase of number of insect population in the community.

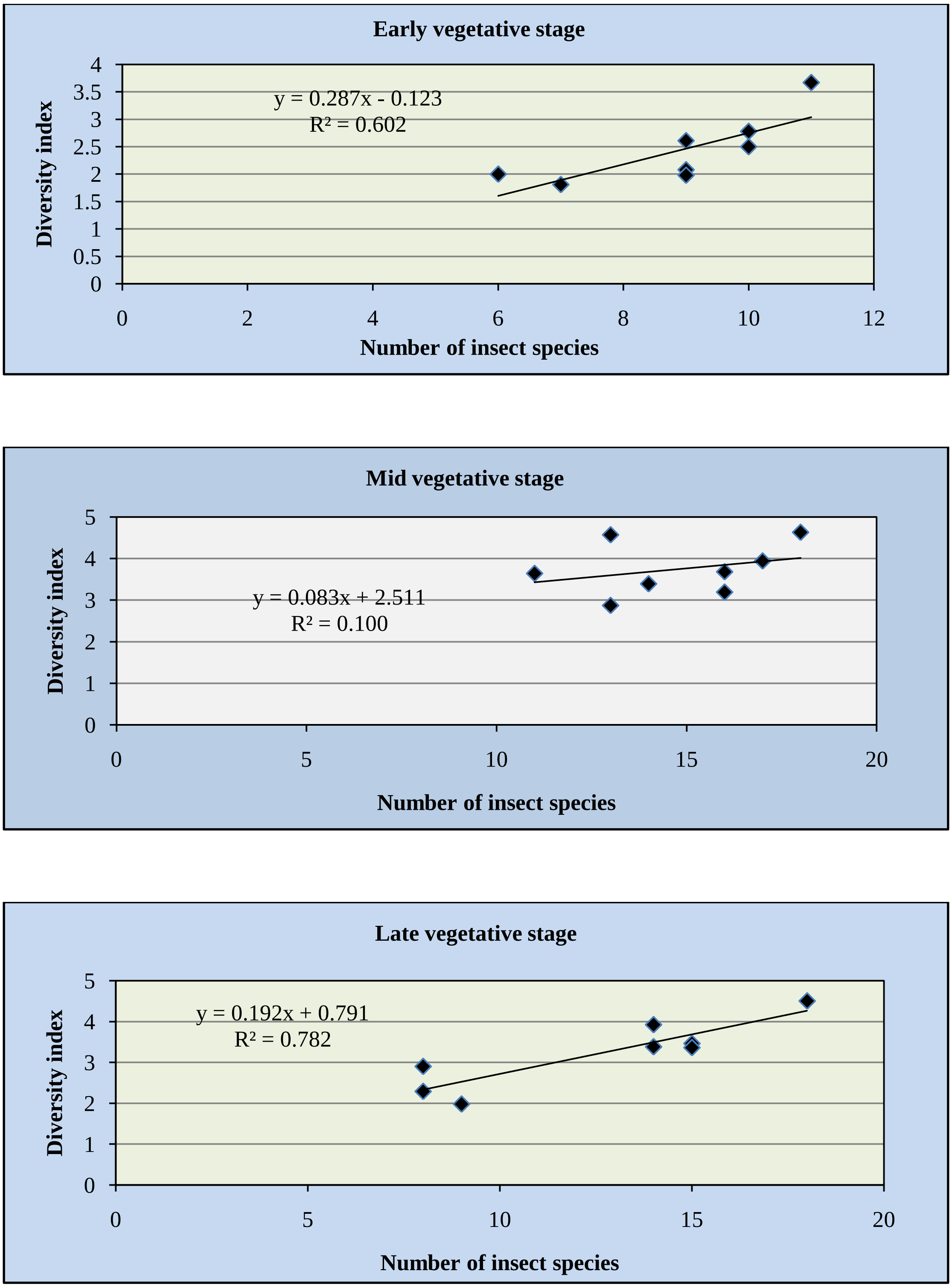


Figure 3. Relationship between the number of insect species under different orders and insect diversity index of insect community in potato sole, border crop and intercrops, cropping system for early, mid and late vegetative stages of potato using sweeping net method.

4.10 Relationship between numbers of insect species and equitability

A positive linear relationship was observed between numbers of insect species and equitability of all crop growth stage of potato (Fig.4 and table 15).

In case of sweeping net method for all the crop growth stages of potato, significant relationships between number of insect species and diversity index of insect community was observed (R^2 = 0.198, 0.003 and 0.197).

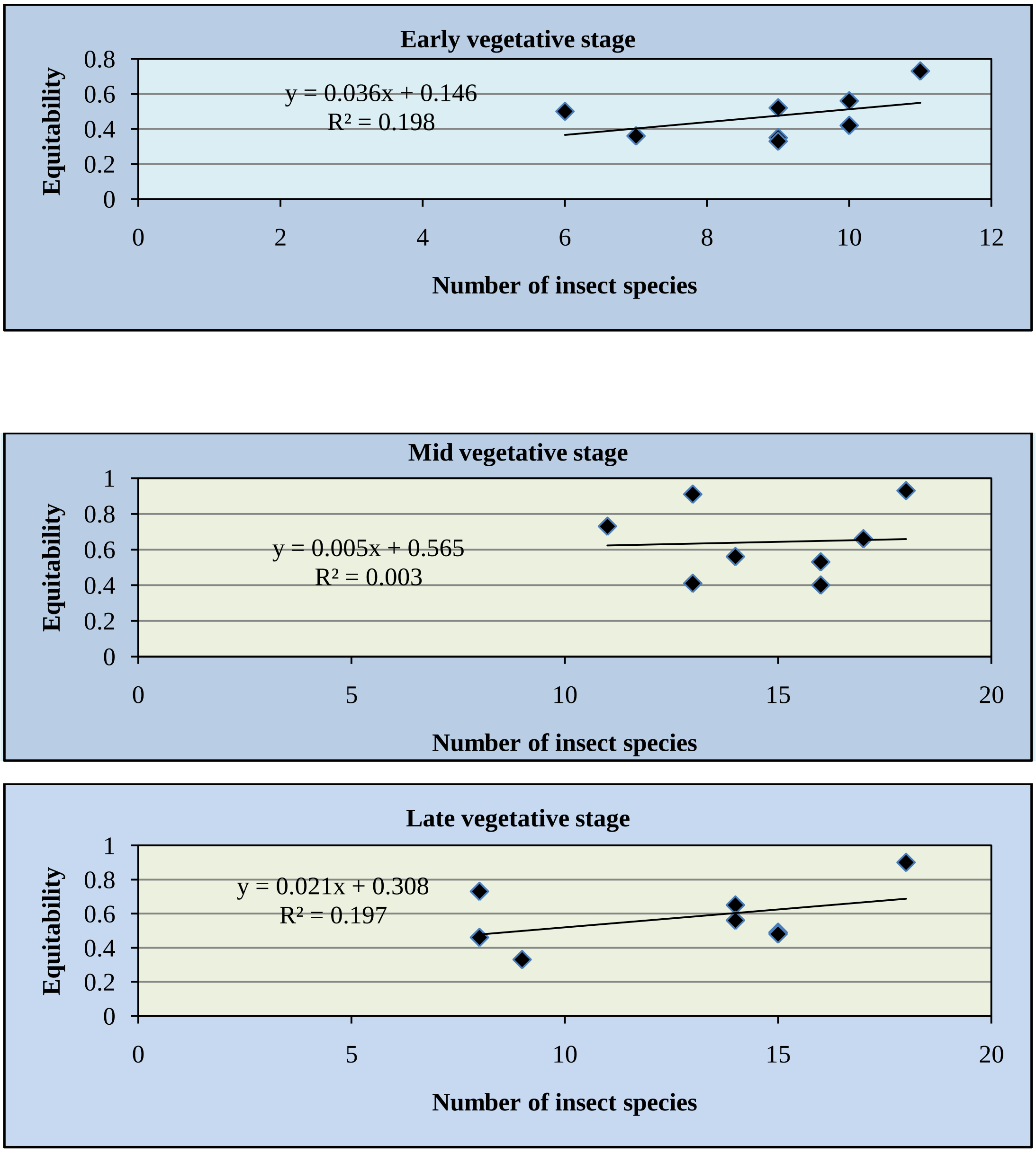


Figure 4. Relationship between the number of insect species under different orders and insect equitability of insect community in potato sole, border crop and intercrops cropping system for early, mid and late vegetative stages of potato using sweeping net method.

4.11 Relationship between leaf infestation and yield of potato

4.11.1 Correlation between leaf infestation of potato caused by aphid and edible yield of potato

Correlation analysis was done to establish the relationship between, leaf infestation of potato caused by aphid at harvesting stage and potato yield (ton/ha). From the study it was revealed that, significant correlation was observed between the percent leaf infestation caused by aphid at harvesting stage and potato yield (ton/ha).

It was evident from the Figure 6 that the regression equation y = -0.227x + 13.03 gave a good fit to the data, and the co-efficient of determination (R^2 = 0.263) showed that, fitted regression line had a significant regression co-efficient. From this regression analysis, it was evident that there was a strongly negative relationship between percent leaf infestation caused by aphid at harvesting stage and potato yield (ton/ha), i.e., the increase of the infestation of leaf caused by aphid at harvesting stage decreased the yield of potato.

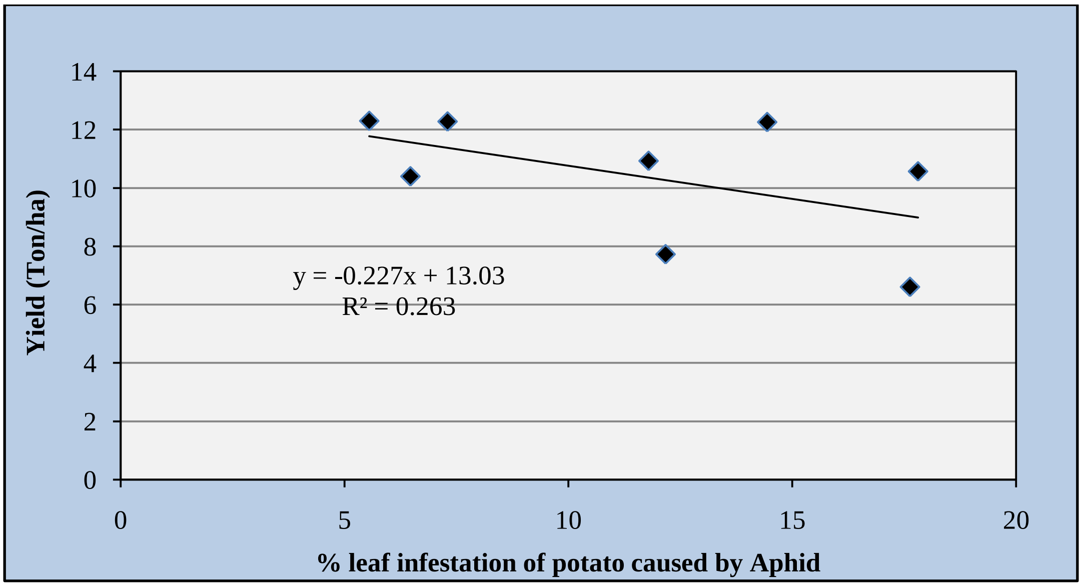


Figure 5. Relationship between percent leaf infestation by aphid and potato yield at harvest

4.11.2 Correlation between leaf infestation of potato caused by white fly and edible yield of potato

Correlation analysis was done to establish the relationship between, leaf infestation of potato caused by white fly at harvesting stage and potato yield (ton/ha). From the study it was revealed that, significant correlation was observed between the percent leaf infestation caused by white fly at harvesting stage and potato yield (ton/ha).

It was evident from the Figure 7 that the regression equation y = -1.951x + 13.95 gave a good fit to the data, and the co-efficient of determination (R^2 = 0.574) showed that, fitted regression line had a significant regression co-efficient. From this regression analysis, it was evident that there was a strongly negative relationship between percent leaf infestation caused by white fly at harvesting stage and potato yield (ton/ha), *i.e.*, the increase of the infestation of leaf caused by white fly at harvesting stage decreased the yield of potato.

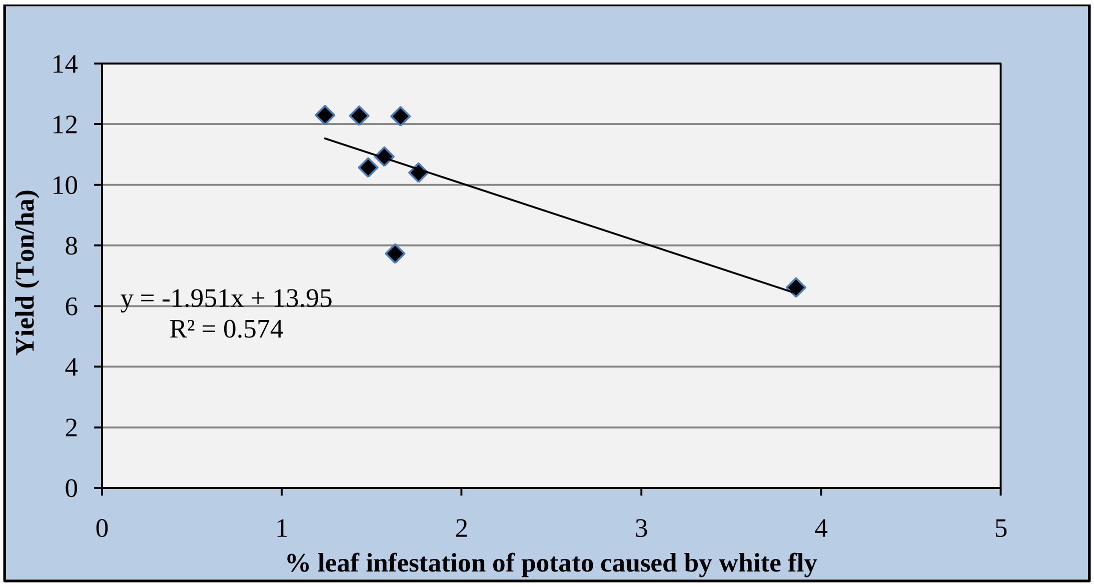


Figure 6. Relationship between percent leaf infestation by white fly and potato yield at harvest

4.11.3 Correlation between leaf infestation of potato caused by jassid and edible yield of potato

Correlation analysis was done to establish the relationship between, leaf infestation of potato caused by jassid at harvesting stage and potato yield (ton/ha). From the study it was revealed that, significant correlation was observed between the percent leaf infestation caused by jassid at harvesting stage and potato yield (ton/ha).

It was evident from the Figure 8 that the regression equation y = -3.616x + 15.38 gave a good fit to the data, and the co-efficient of determination (R^2 = 0.327) showed that, fitted regression line had a significant regression co-efficient. From this regression analysis, it was evident that there was a strongly negative relationship between percent leaf infestation caused by jassid at harvesting stage and potato yield (ton/ha), i.e., the increase of the infestation of leaf caused by jassid at harvesting stage decreased the yield of potato.

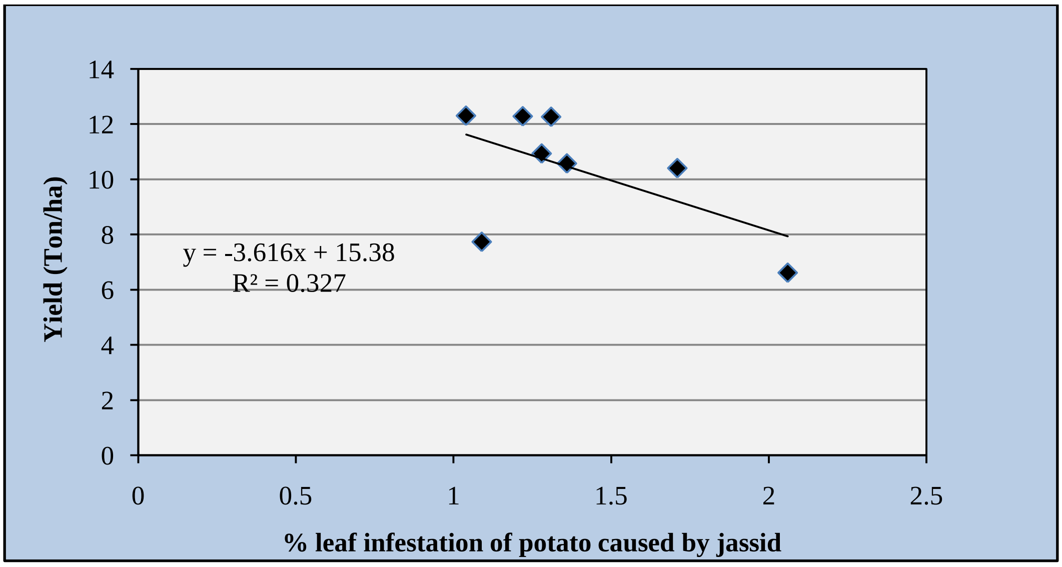


Figure 7. Relationship between percent leaf infestation by jassid and potato yield at harvest

CHAPTER V

SUMMARY AND CONCLUSION

A field experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka to investigate the effect of cropping system on the incidence of insect pests of potato and associated other natural enemies during the period from October-2019 to April 2020 in Rabi season. The experiment consisted of eight treatments and followed Randomized complete block design (RCBD) with three replications. Treatments *viz.* T_1= Potato+ Groundnut (Ic), T_2= Potato+ sweet potato (Bc), T_3= Potato+ Coriander (Ic), T_4= Potato+ Fenugreek (Bc), T_5= Potato+ Spinach (Bc), T_6 = Potato+ Coriander (Bc), T_7= Potato+ Radish (Bc) and T_8= Sole potato (Control) where ground nut and coriander were used as Intercrop (Ic) on other hand sweet potato, Fenugreek, spinach, coriander as well as radish were used as Border crop (Bc). Data was collected on pest complex of potato field, incidence of major insect pests per plant, leaf infestation (%), incidence of beneficial arthropods per plant, diversity of other arthropods community per plant, total edible yield (ton/ha) and gross return (tk/ha).

Significant variation was recorded at early, mid and late vegetative stage for the incidence of various insect pest and beneficial arthropods in potato experimental field. At early vegetative stage, the lowest number of cutworm was recorded in all other treatment except T_8 treatment, incidence of aphid per plant was minimum in T_4 (1.20) treatment, in case of epilachna beetle no incidence was recorded in other treated plots except Control T_8 (1) and T_5 (0.20) treatment, the incidence of jassid per plant was minimum in T_3(0.0), T_4 (0.0) and T_7 (0.0) treated plot, the lowest incidence of white fly per plant (0.79) was recorded in T_7 treatment and at early vegetative stage of potato, no incidence of leaf eating cater pillar was recorded in all treated plots whereas the highest number of cutworm, aphid, epilachna beetle, jassid and white fly (0.20, 6.75, 1.0, 0.40 and 3.61) were recorded in T_8 treatment. In case of mid vegetative stage, no incidence of cutworm was recorded in T_1 (0.0), T_2(0.0), T_3(0.0), T_4 (0.0), T_6(0.0), and T_7(0.0) treated plots. The lowest incidence of aphid per plant (5.83) was recorded in T_7 treatment, on the other hand at mid vegetative stage, minimum incidence of epilachna beetle per plant (5.83) was recorded in T_7 treatment The minimum incidence of jasid per plant (0.47), white fly per plant (0.73), was recorded in T_7 treatment whereas in case of leaf eating cater pillar no incidence was recorded in T_1,

T_2, T_3, T_4, T_6 and T_7 treated plots. On the other hand highest number of, cutworm (0.40), aphid (10.40), epilachna beetle (5.67), jassid (3.27), white fly (3.31), and leaf eating cater pillar (0.30) per plant were recorded in T_8 treatment. At late vegetative stage, no incidence occurred by cutworm was recorded in T_1, T_2 and T_7 treated plot. On the other hand at late vegetative stage, lowest incidence of aphid per plant (9.17) was recorded in T_7 treatment. Minimum incidence occurred by epilachna beetle was recorded in T_7 (2.05) treated plot. The lowest incidence of jassid (0.90) and white fly (0.66) were recorded in T_7 treatment, whereas no incidence by leaf eating cater pillar was recorded in T_1, T_2, T_4, T_6 and T_7 treated plot. On the other hand, the highest number of, cutworm (0.45), aphid (16.70), epilachna beetle (8.25), jassid (4.30), white fly (2.50) and leaf eating cater (0.50) per plant were recorded in T_8 treatment.

In case of percent leaf infestation at harvesting stage, minimum leaf infestation (4.74 %) caused by aphid, (2.12 %) caused by white fly and (3.90 %) caused by jassid were recorded in T_7 treatment, whereas maximum leaf infestation (15.32 %, 8.82 % and 5.80 %) caused by aphid, white fly and jassid were recorded in T_8 treatment.

Significant variation was also recorded in case of beneficial arthropods. In case of the incidence of highest number of pollinators per plant like honey bee (124.33), carpenter bee (3.00) and hover fly (5.80) were recorded in T_7 treatment whereas the minimum number of (0.0, 0.0, and 0.0) honey bee, carpenter bee and hover fly were recorded in T_8 treatment.

In case of natural enemies, the highest number of natural enemies like lady bird beetle (2.84), hover fly (5.80), dragon fly (1.68) and bird (1.56) sat on the stick bamboo were recorded in T_7 treatment whereas minimum number of lady bird beetle was recorded in T_4 (0.87) treatment. The minimum number of hover fly and dragon fly was recorded in T_8 (0.0 and 0.24) treatment. The minimum number of bird sat on the bamboo stick was recorded in T_1 (0.23) treatment. In case of ground beetle and ant, the maximum number was recorded in T_1 (1.35 and 3.10) treated plot whereas the minimum number was recorded in T_8 treatment (0.27 and 0.42). In case of presence of spider, the maximum number of spider was recorded in T_5 (1.85) treatment where as the minimum number of spider was recorded in T_8 (0.23) treatment.

For, diversity index of insect pest community showed significant variation under different treatments using sweeping net method at the early, mid and late vegetative crop growth of potato. At early vegetative stage, the maximum number of insect species per plant (11), diversity index (3.67) and equitability (0.73) were recorded in T_5 treatment whereas T_7 treatment recorded the minimum number of insect species per plant (6). The minimum diversity index (1.81) was recorded in T_1 treatment and the minimum equitability (0.33) was recorded in T_8 treatment.

At mid and late vegetative stage, T_7 treatment recorded the maximum number of insect species per plant (11 and 18), diversity index (4.63 and 4.5) and equitability (0.93 and 0.90) whereas at mid vegetative stage T_8 treatment recorded the minimum number of insect species per plant (11). The minimum diversity index (2.87) and equitability (0.41) was recorded in T_1 treatment. At late vegetative stage T_8 treatment recorded the minimum number of insect species per plant (8). The minimum diversity index (1.98) and equitability (0.33) was recorded in T_6 treatment.

In term of edible yield and gross return, the highest edible yield of potato (12.30 ton/ha) and gross return (373680 taka/ha) were recorded in T_7 treatment whereas the minimum edible yield of potato (6.61 ton/ha) and lowest gross return (132200 taka/ha) were recorded in T_1 (control) treatment.

Conclusion

From the present study, it may be concluded that both border and inter crop in potato field reduced the incidence of major insect pest of potato comparing to sole cropping. The incidence of beneficial arthropods was higher in border crops and intercropping systems. The edible yield and gross return was also higher both in border crops and intercropping systems than sole cropping and its was maximum in T_7 treatment recorded the highest edible yield of potato (12.30 ton/ha) and gross return (373680 taka/ha) comparatively to others treatment. The overall study of this experiment showed that both in border crops and intercropping systems reduces incidence of major insect pest of potato field and represent as a eco-friendly pest management practice for potato by which border crops perform well than inter crop and significantly reduced pest infestation without use of any chemicals insecticides.

Recommendations

Considering the situation of the present experiment, further recommendations in the following areas may be suggested:

- Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability.

- Other crops as border crop and intercrop may be included in the future study.

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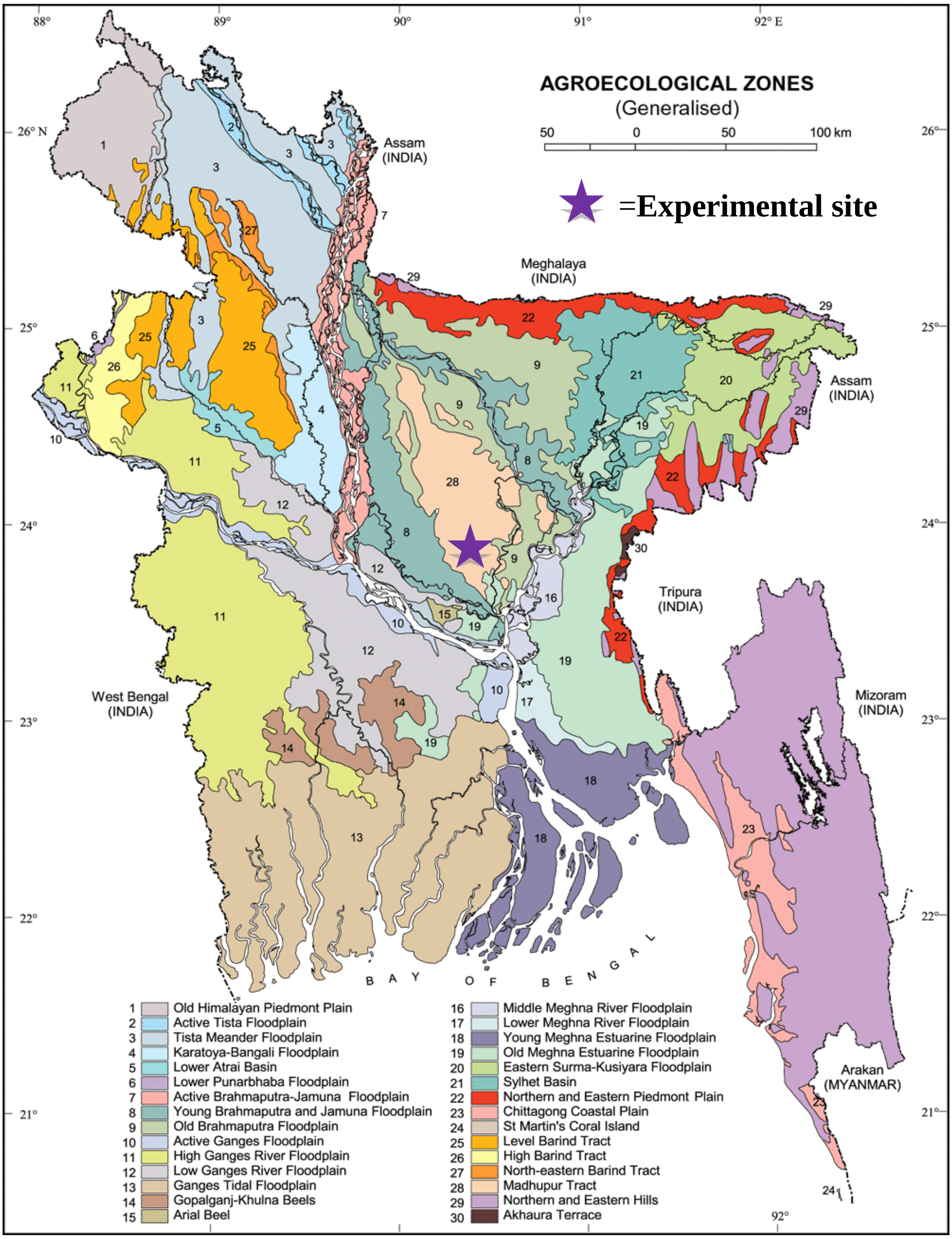
APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Characteristics of soil of experimental pot

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristics	
Constituents	Percent
Sand	26
Silt	45
Clay	29
Textural class	Silty clay

Chemical characteristics	
Soil characteristics	Value
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10
Organic carbon (%)	0.45
Organic matter (%)	0.78
pH	5.6
Total nitrogen (%)	0.03

Appendix III. Monthly meteorological information during the period from November, 2019 to April 2020.

Year	Month	Air temperature (^0C)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2019	October	31.2	23.9	76	52
	November	29.6	19.8	53	00
	December	28.8	19.1	47	00
2020	January	25.5	13.1	41	00
	February	25.9	14	34	7.7
	March	31.9	20.1	38	71
	April	33.7	23.9	74	168

(Source: Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix IV. Analysis of variance of the data of the incidence of cutworm at different growth stage of potato

Source	Df	Mean square of the incidence of cutworm		
		Early vegetative stage	Mid vegetative stage	Late vegetative stage
Replication	2	3.125E-06	0.00001	0.00009
Treatment	7	0.01500**	0.06643**	0.09591**
Error	14	3.125E-06	0.00001	0.00013
Total	23			

**: Significant at 0.01 level of probability

Appendix V. Analysis of variance of the data of the incidence of aphid at different growth stage of potato

Source	Df	Mean square of the incidence of aphid		
		Early vegetative stage	Mid vegetative stage	Late vegetative stage
Replication	2	0.10500	0.22111	0.2450
Treatment	7	9.29665**	8.66631**	19.7450**
Error	14	0.13357	0.22111	0.1307
Total	23			

**: Significant at 0.01 level of probability

Appendix VI. Analysis of variance of the data of the incidence of epilachna beetle at different growth stage of potato

Source	Df	Mean square of the incidence of epilachna beetle		
		Early vegetative stage	Mid vegetative stage	Late vegetative stage
Replication	2	0.00031	0.00720	0.1012
Treatment	7	0.36857**	7.93860**	10.5550**
Error	14	0.00031	0.00491	0.0441
Total	23			

**: Significant at 0.01 level of probability

Appendix VII. Analysis of variance of the data of the incidence of jassid at different growth stage of potato

Source	Df	Mean square of the incidence of jassid		
		Early vegetative stage	Mid vegetative stage	Late vegetative stage
Replication	2	0.00004	0.00395	0.01125
Treatment	7	0.07114**	2.65789**	3.50678**
Error	14	0.00007	0.00681	0.02411
Total	23			

**: Significant at 0.01 level of probability

Appendix VIII. Analysis of variance of the data of the incidence of white fly at different growth stage of potato

Source	Df	Mean square of the incidence of white fly		
		Early vegetative stage	Mid vegetative stage	Late vegetative stage
Replication	2	0.00875	0.00166	0.01711
Treatment	7	2.53114**	2.44517**	1.26278**
Error	14	0.01732	0.00355	0.02111
Total	23			

**: Significant at 0.01 level of probability

Appendix IX. Analysis of variance of the data of the incidence of leaf eating caterpillar at different growth stage of potato

Source	Df	Mean square of the incidence of leaf eating caterpillar		
		Early vegetative stage	Mid vegetative stage	Late vegetative stage
Replication	2	0.00000	0.00005	0.00009
Treatment	7	0.00000**	0.04915**	0.14357**
Error	14	0.00000	0.00005	0.00006
Total	23			

**: Significant at 0.01 level of probability

Appendix X. Analysis of variance of the data of number of leaf present per plant at harvesting stage incidence by aphid, white fly and jassid

Source	Df	Mean square of the number of leaves per plant		
		Aphid	White fly	Jassid
Replication	2	4.875	3.375	3.875
Treatment	7	390.658**	407.854**	598.515**
Error	14	6.446	5.946	8.161
Total	23			

**: Significant at 0.01 level of probability

Appendix XI. Analysis of variance of the data of number of infested leaf present per plant at harvesting stage incidence by aphid, white fly and jassid

Source	Df	Mean square of the number of infested leaves per plant caused by		
		Aphid	White fly	Jassid
Replication	2	0.0938	0.0200	0.00500
Treatment	7	86.9077**	28.5600**	1.58785**
Error	14	0.1652	0.0200	0.01071
Total	23			

**: Significant at 0.01 level of probability

Appendix XII. Analysis of variance of the data of leaf infestation percentage by aphid, white fly and jassid at harvesting stage

Source	Df	Mean square of the leaf infestation percentage caused by		
		Aphid	White fly	Mite
Replication	2	0.0277	0.0094	0.00263
Treatment	7	59.7523**	14.2240**	1.70341**
Error	14	0.0658	0.0200	0.02418
Total	23			

**: Significant at 0.01 level of probability

Appendix XIII. Analysis of variance of the data of the incidence of pollinators

Source	Df	Mean square of pollinators		
		Honey bee	Hover fly	Carpenter bee
Replication	2	0.50	0.0013	0.00009
Treatment	7	6848.25**	14.2222**	3.25989**
Error	14	1.07	0.0027	0.00013
Total	23			

**: Significant at 0.01 level of probability

Appendix XIV. Analysis of variance of the data of the incidence of natural enemies

Source	Df	Mean square of the number of infested leaves per plant caused by						
		Lady bird beetle	Hover fly	Dragon fly	Ground beetle	Ant	Spider	bird
Replication	2	0.009	0.001	0.0009	0.0002	0.002	0.004	0.001
Treatment	7	1.85**	14.22**	0.76**	0.34**	1.87**	0.66**	0.72**
Error	14	0.013	0.001	0.0015	0.0004	0.003	0.005	0.001
Total	23							

**: Significant at 0.01 level of probability

Appendix XV. Diversity and equitability of insect community of different families under different cropping system using sweeping net method at vegetative stage of potato

Treatment	**Insect families**	**No. of individual**	**Proportion of individual (Pi)**	**Pi^2**	**Diversity index (D)**	**Equitability (E)**
T_1	Aphididae	1	0.14	0.02	1.81	0.36
	Aleyrodidae	1	0.14	0.02		
	Formicidae	5	0.71	0.51		
T_2	Taronemidae	1	0.11	0.01	2.08	0.35
	Aphididae	1	0.11	0.01		
	Arachnidae	6	0.67	0.44		
	Noctuidae	1	0.11	0.01		
T_3	Aphididae	1	0.1	0.01	2.78	0.56
	Aleyrodidae	1	0.1	0.01		
	Anachnidae	5	0.5	0.25		
	Formicidae	3	0.3	0.09		
T_4	Aphididae	1	0.1	0.01	2.5	0.42
	Aleyrodidae	1	0.1	0.01		
	Anachnidae	6	0.6	0.36		
	Formicidae	1	0.1	0.01		
	Noctuidae	1	0.1	0.01		
T_5	Aphididae	1	0.09	0.008	3.67	0.73
	Aleyrodidae	1	0.09	0.008		
	Cicadellidae	1	0.09	0.008		
	Coceinellidae	2	0.18	0.03		
	Formicidae	5	0.45	0.21		
	Noctuidae	1	0.09	0.008		
T_6	Aphididae	1	0.11	0.012	2.61	0.52
	Aleyrodidae	1	0.11	0.012		
	Anachnidae	5	0.56	0.31		
	Coceinellidae	2	0.22	0.049		
T_7	Aphididae	1	0.17	0.028	2.00	0.5
	Coceinellidae	4	0.67	0.44		
	Noctuidae	1	0.17	0.028		
T8	Aphididae	1	0.11	0.012	1.98	0.33
	Coceinellidae	6	0.67	0.444		
	Tarsonemidae	2	0.22	0.049		

Appendix XVI. Diversity and equitability of insect community of different families under different cropping system using sweeping net method at mid vegetative stage of potato

Treatment	Insect families	No. of individual	Proportion of individual (Pi)	Pi^2	Diversity index (D)	Equitability (E)
T_1	Formicidae	7	0.54	0.29	2.87	0.41
	Arachinidae	2	0.15	0.024		
	Coccinellidae	2	0.15	0.024		
	Aeshnidae	1	0.08	0.005		
	Syrphidae	1	0.08	0.006		
T_2	Formicidae	7	0.44	0.19	3.68	0.53
	Arachinidae	3	0.19	0.035		
	Coccinellidae	3	0.19	0.035		
	Aeshnidae	1	0.06	0.004		
	Syrphidae	1	0.06	0.004		
	Cicadellidae	1	0.06	0.004		
T_3	Aphididae	1	0.06	0.004	3.19	0.40
	Aleyrodidae	1	0.06	0.004		
	Coccinellidae	3	0.19	0.035		
	Formicidae	8	0.50	0.25		
	Arachinidae	2	0.13	0.016		
	Cicadellidae	1	0.06	0.004		
T_4	Aphididae	2	0.14	0.020	3.39	0.56
	Aleyrodidae	1	0.07	0.005		
	Coceinellidae	3	0.21	0.046		
	Formicidae	6	0.43	0.184		
	Syrphidae	2	0.14	0.020		
	Apidae	2	0.14	0.020		
T_5	Cicadellidae	1	0.08	0.006	4.57	0.91
	Apidae	3	0.23	0.053		
	Formicidae	5	0.38	0.148		
	Coceinellidae	1	0.08	0.006		
	Gelechiidae	1	0.08	0.006		
T_6	Formicidae	5	0.29	0.087	3.94	0.66
	Arachinidae	6	0.35	0.125		
	Cicadellidae	2	0.12	0.014		
	Apidae	2	0.12	0.014		
	Syrphidae	2	0.12	0.014		
T_7	Apidae	5	0.28	0.078	4.63	0.93
	Syrphidae	2	0.11	0.012		
	Formicidae	4	0.22	0.049		
	Arachinidae	4	0.22	0.049		
	Coceinellidae	3	0.17	0.028		

Treatment	Insect families	No. of individual	Proportion of individual (Pi)	Pi^2	Diversity index (D)	Equitability (E)
T_8	Noctuidae	5	0.45	0.21	3.64	0.73
	Coceinellidae	2	0.18	0.033		
	Formicidae	1	0.09	0.008		
	Arachinidae	1	0.09	0.008		
	Tarsonemidae	1	0.090	0.008		
	Gelechiidae	1	0.09	0.008		

Appendix XVII. Diversity and equitability of insect community of different families under different cropping system using sweeping net method at late vegetative stage of potato

Treatment	Insect families	No. of individual	Proportion of individual (Pi)	Pi^2	Diversity index (D)	Equitability (E)
T_1	Formicidae	2	0.14	0.02	3.92	0.65
	Arachinidae	2	0.14	0.020		
	Tarsonemidae	1	0.07	0.005		
	Aphididae	1	0.07	0.005		
	Coceinellidae	2	0.14	0.020		
	Apidae	6	0.43	0.18		
T_2	Formicidae	7	0.47	0.22	3.46	0.49
	Arachinidae	2	0.13	0.018		
	Coceinellidae	2	0.13	0.018		
	Carabidae	2	0.13	0.018		
	Syrphidae	2	0.13	0.018		
T_3	Aphididae	1	0.13	0.016	2.90	0.73
	Aeshnidae	2	0.25	0.063		
	Gelechiidae	1	0.13	0.016		
	Apidae	4	0.5	0.25		
T_4	Aphididae	1	0.07	0.004	3.36	0.48
	Coceinellidae	3	0.2	0.04		
	Carabidae	2	0.13	0.018		
	Formicidae	7	0.47	0.218		
	Scarabaidae	2	0.13	0.018		
T_5	Aphididae	1	0.07	0.005	3.38	0.56
	Noctuidae	1	0.07	0.005		
	Scarabaidae	2	0.14	0.020		
	Formicidae	4	0.29	0.082		
	Arachinidae	6	0.43	0.184		

Treatment	Insect families	No. of individual	Proportion of individual (Pi)	Pi^2	Diversity index (D)	Equitability (E)
T_6	Aphididae	1	0.11	0.012	1.98	0.33
	Coceinellidae	2	0.22	0.049		
	Apidae	6	0.67	0.444		
T_7	Aphididae	3	0.17	0.027	4.5	0.90
	Scarabaidae	3	0.17	0.027		
	Coceinellidae	2	0.11	0.012		
	Formicidae	5	0.28	0.077		
T_8	Arachinidae	5	0.28	0.077	2.29	0.46
	Aphididae	1	0.13	0.016		
	Coceinellidae	1	0.13	0.016		
	Formicidae	5	0.63	0.39		
	Arachinidae	1	0.13	0.016		

Appendix XVIII. Analysis of variance of the data of edible yield of potato

Source	Df	Mean square of edible yield of potato
Replication	2	0.0988
Treatment	7	13.8879**
Error	14	0.1416
Total	23	

**: Significant at 0.01 level of probability