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First report on development of sustainable management strategy against *Pentalonia nigronervosa* coq. vector of banana bunchy top virus disease, its seasonal variation and effect on yield of banana in Jorhat district of Assam– A north eastern state of India

Nilakshi Kakati and PD Nath

Abstract
Field experiments were conducted during 2013-15 in experimental plots of Assam Agricultural University, Jorhat, Assam to evolve a suitable management strategy against *Pentalonia nigronervosa* vector of Banana bunchy top virus disease. Virus free planting material cv. Grand Naine (tissue cultured) along with different pesticide combinations were used to reduced vector population and disease incidence in the field. Banana plants treated with foliar spraying of Imidacloprid @ 0.1% at 60, 90, 120 and 150 days after planting showed no disease incidence (0.00%), zero insect vector population count in all the two cropping seasons. Insect vector population was recorded in the range of 0.00 to 10.67, average 3.28 (2013-14), 0.00 to 9.33, average 2.67(2014-15) and 0.00 to 10.75, average 3.39 (pooled data).Whereas in untreated control plots recorded the highest disease incidence 95.84 per cent corresponding with a highest vector population in the range of 0.00 to 110.55, average 24.86 (pooled data).

Keywords: *Pentalonia nigronervosa*, Banana Bunchy Top Virus, Banana Bunchy Top disease, Imidacloprid, Azadirachtin, *Verticillium lecanii*

Introduction
Assam along with other seven states of North East region of India is one of the micro-centre of evolution of wild bananas. Though India is the largest producer of bananas and plantains with an annual production of 29.78 million tones and productivity of 37.90 Mt/ha (NHB, 2014) [34] from an area of 0.748 million ha and accounts for 29 per cent of the world's production still Assam ranks 9th position in terms of production amongst the twelve major banana growing states of India with an annual production of 0.835 million tonnes and productivity of 15.20 t/ha from an area of 0.054 million ha (NRCB, 2012) [35]. This lower in production is due to various natural calamities, but diseases in particular, viral diseases constitute a major setback to this crop. Among viral infections, Banana bunchy top disease (BBTD) caused by a multi component single stranded DNA virus *Banana bunchy top virus* (BBTV) belongs to the genus Babuvirus and family *Nanoviridae* (Harding *et al.*, 1991) [21] is the most serious and devastating disease of Banana (*Musa* spp.) which alone can cause yield losses up to 100% (FAOSTAT, 2009) [15]. BBTV is primarily transmitted by planting materials and secondly by an insect vector, banana aphid which is widely distributed throughout tropical and subtropical areas of the world (Magee, 1940 and Foottit *et al.*, 2010) [27, 16]. The banana aphid, *Pentalonia nigronervosa* Coquerel (Hemiptera: *Aphididae*) is the only known vector of BBTV, transmitting the virus in a persistently circulative, nonpropagative manner (Magee, 1927 and Thomas and Dietzen, 1991) [26, 46]. Infective aphids may transmit the virus in 15-20 hours or more of feeding on healthy plant but not by feeding for shorter period. Aphids feeding for a period of 2-96 hours on diseased plants increase their transmitting ability from 20-100 per cent (Sun, 1961) [45]. The transmission of the virus by aphids is confined to short distance and the mean distance of new infections from their source of inoculums in an established plantation was estimated at 17.2m (Allen, 1987) [3]. Viral diseases had been considered practically incurable and the first aim in managing these kinds of diseases was to reduce or eliminate virus spread within the field. This approach would reduce disease incidence and yield loss. In

practice this aim could be achieved only when resistant varieties were grown. Unfortunately, there are no known commercial cultivars of banana that are immune to BBTV (Ranasingh, 2007) [40]. In case of BBTD also, control of the spread of viral pathogens transmitted by insect vectors is usually of greater concern to growers than control of the vector itself, insecticides are often not considered to be the primary method of control for this insect-vectored viral disease. This is especially true for non-persistently transmitted viruses, as brief probes are sufficient for vector inoculation of pathogen (Perring *et al.,* 1999) [37]. However, because acquisition and inoculation times are longer for persistently transmitted viruses, insecticidal control of vectors has been a useful component of control measures for this group of viruses. To control the secondary infection of BBTV transmitted by its insect vector *Pentalonia nigronervosa* in banana field there is a need to find out alternative agents that are pest specific, non-toxic, biodegradable, safe to natural enemies, less prone to resistance and less expensive. In the integrated pest management (IPM) schedule against the insect-vector, inclusion of neem based formulations as well as biocontrol agents (BCAs) like entomopathogenic fungi has been adopted globally (Alves and Lecuona, 1998; Ramarethinam *et al.,* 2004) [5, 39]. A lot of examples exist where application of different selective chemical insecticides and fungi when used in combination provide satisfactory control against many agricultural insect pests (Serebrove *et al.,* 2005; Purwar and Sachen, 2006) [43, 38]. But field application of such fungi cannot give satisfactory results as pesticides due to many abiotic and biotic factors. The use of fungal biocontrol agents in IPM cannot be ignored. On the other hand, the use of non selective or incompatible chemical pesticides may possibly have the potential to hinder the vegetative growth and development of fungi adversely affecting the IPM (Duarte *et al.,* 1992 and Malo, 1993) [13, 29]. For this reason, an understanding about the adverse effects of different insecticides on entomopathogenic fungi is necessary. A number of experiments have been done to evaluate the deleterious effects of chemical insecticides on different developmental stages of fungi (Alizadeh *et al.,* 2007) [4]. The effect of these products may vary in different species and strains of fungi (Anderson *et al.,* 1989) [6]. The results from such experimental work would direct the farmers to choose a more compatible pesticides and the adverse effects of the injudicious use of insecticides can be minimized (Butt *et al.,* 2001 and Inglis *et al.,* 2001) [9, 24]. Therefore, there is a need to manipulate the inhibitory effects of different insecticides on the mycelial growth and sporulation of isolates of different BCAs, as well as, to check the compatibility of these chemicals with these BCAs. Hence, an *in vitro* compatibility analysis of three entomopathogenic fungi *viz., Beauveria bassiana*, *Metarhizium anisopliae*, *Verticillium lecani* with the chemical pesticides generally used in banana production system in Assam in three different concentrations, *i.e*., recommended dose (RD) (lethal), half of the recommended dose (½ RD) (sub lethal) and one fourth of the recommended dose (¼ RD) (sub-sub lethal) was also conducted before application in main banana field and finally best two treatment combinations obtained were used further for conducting field experiments (Kakati *et al.,* 2018) [25]. Taking these background into account a field experiment was conducted to develop a suitable management strategy against Banana bunchy top disease and its aphid vector in the banana crop field.

Materials and Methods

The field investigations were carried out in the experimental fields of Horticultural Experimental Farm, Assam Agricultural University (AAU), Jorhat during 2013-14 and 2014-15 for management of BBTD and its vector banana aphid. The experimental site was situated at 26º and 27ºN latitude, 94° and 95ºE longitude at an altitude of 86.8 m above mean sea level. The experimental site falls under the Upper Brahmaputra Valley Zone of Assam. Banana cultivar "Grand Naine" (Tissue cultured seedlings) was selected as virus free planting material for the experiments. BBTD susceptible cultivar "Dwarf Cavendish" was planted as border crop surrounding the whole experimental plot for natural infection. Field experiment was laid out in a randomized block design with 12 treatments *viz.*, (1) Azadirachtin @ 0.075% + B. bassiana @ 1x 10^8 cfu/ml, (2) Azadirachtin @ 0.075% + V. lecanii @ 1x 10^8 cfu/ml, (3) Imidacloprid @ 0.025% + B. bassiana @ 1x 10^8 cfu/ml, (4) Imidacloprid @ 0.025% + V. lecanii @ 1x 10^8 cfu/ml, (5) Dimethoate @ 0.5% + B. bassiana @ 1x 10^8 cfu/ml, (6) Dimethoate @ 0.5% + V. lecanii @ 1x 10^8 cfu/ml, (7) Azadirachtin @ 0.3%, (8) Imidacloprid @ 0.1%, (9) Dimethoate @ 0.2%, (10) B. bassiana @ 1x 10^8 cfu/ml, (11) *V. lecanii* @ 1x 10^8 cfu/ml and (12) Control in three replications. The treatments were imposed on 60, 90, 120 and 150 days after planting (DAP). The recommended dose of pesticides were used for the experiments (Azadirachtin (0.15%) @ 3ml/l, Imidacloprid 17.8% SL @ 1ml/l, Dimethoate 30EC (0.06%) @ 2ml/l and BCAs (1x10^8 cfu/ml) @600-700 l/ha). Insect vectors were estimated by direct count method. The population of the vector, banana aphid was counted at 15 days interval after planting up to harvesting of the crop from the all four plants of each plot and the average vector population was estimated. Natural incidence of BBTD was recorded by both Visual and PCR detection at 3rd month (90 DAP), 7th month (210 DAP) and 11th month (330 DAP) after planting. Each plant was regularly inspected for the first appearance BBTD incidence. It was calculated by counting number of plants infected and total number of plants in a plot.

$$\text{Percent disease incidence} = \frac{\text{Numberof plantsinfectedin a plot}}{\text{Total numberof plantsin a plot}} \times 100$$

The yield of banana was recorded per plant and expressed in the bunch weight (Kg/Plant). The data from field observations were analysed by using randomized block design described by Panse and Sukhatme (1978) [36]. Effect of different weather parameters on vector population and disease incidence as well as effect BBTD and banana aphid population on yield of banana was also calculated by using simple correlation coefficient formula and multiple linear regression equation.

Results and discussion

The effect of different treatments in the field during the two cropping seasons on population growth of Banana aphid, BBTD incidence were presented in Fig. 1. From the pooled data analysis of both the cropping season (2013-15), it was evident that there was no BBTD incidence (0.00%) in the treatment T_8 where Imidacloprid was applied @ 0.1% which was followed by lowest incidence of 12.50 per cent (T_7 =Azadirachtin @ 0.3% and T_9 =Dimethoate @ 0.2%) and 20.83 per cent in the treatment T_4 where Imidacloprid was applied @ 0.025% + V. lecanii @ 1x 10^8 cfu/ml. The treatments T_7 and T_9 were found statistically at par. While, the

highest BBTD incidence of 95.84 per cent was recorded in the control plots (T_{12}). The highest per cent reduction in BBTD incidence over control (T_{12}) was recorded 100.00 in the treatment T_8 followed by 86.96 (T_7 and T_9) and 78.27(T_4). The results of correlation analysis(Table not presented) of BBTD incidence and weather parameters during the two cropping seasons showed that out of seven weather parameters only relative humidity (morning) (2014-15) and bright sun shine hour (BSSH) (2014-15) showed significant negative correlation with BBTD incidence which means increase in relative humidity (morning) (2014-15) and BSSH (2014-15) there was decrease in BBTD incidence during the second cropping season (2014-15) whereas BBTD incidence with other weather parameters during the two cropping seasons showed non-significant correlation. The correlation coefficients of BBTD incidence with relative humidity (morning) and BSSH during the second cropping season were (-) 0.693 and (-) 0.639, respectively. It was also revealed that there was no banana aphids up to 165 DAP. Initial population of banana aphid was obtained from 180 DAP. There was no insect vector population in the treatment T_8 during the entire cropping seasons (2013-15) followed by lowest population recorded in T_9 and T_7 ranging from 0.00 to 10.92, average 3.04 and 0.00 to 10.75, average 3.39, respectively. Highest banana aphid population was recorded in the control (T_{12}) in the range of 0.00 to 110.55, average 24.86. It was found that in all the treatments the banana aphid population starts increasing gradually after 180 DAP (6th month after planting), attaining a peak at 195 DAP and starts decreasing gradually from 210 DAP (7th month after planting) with complete disappearance after 285 DAP. There was no banana aphid population was found at 300, 315 and 330 DAP (11th month after planting).

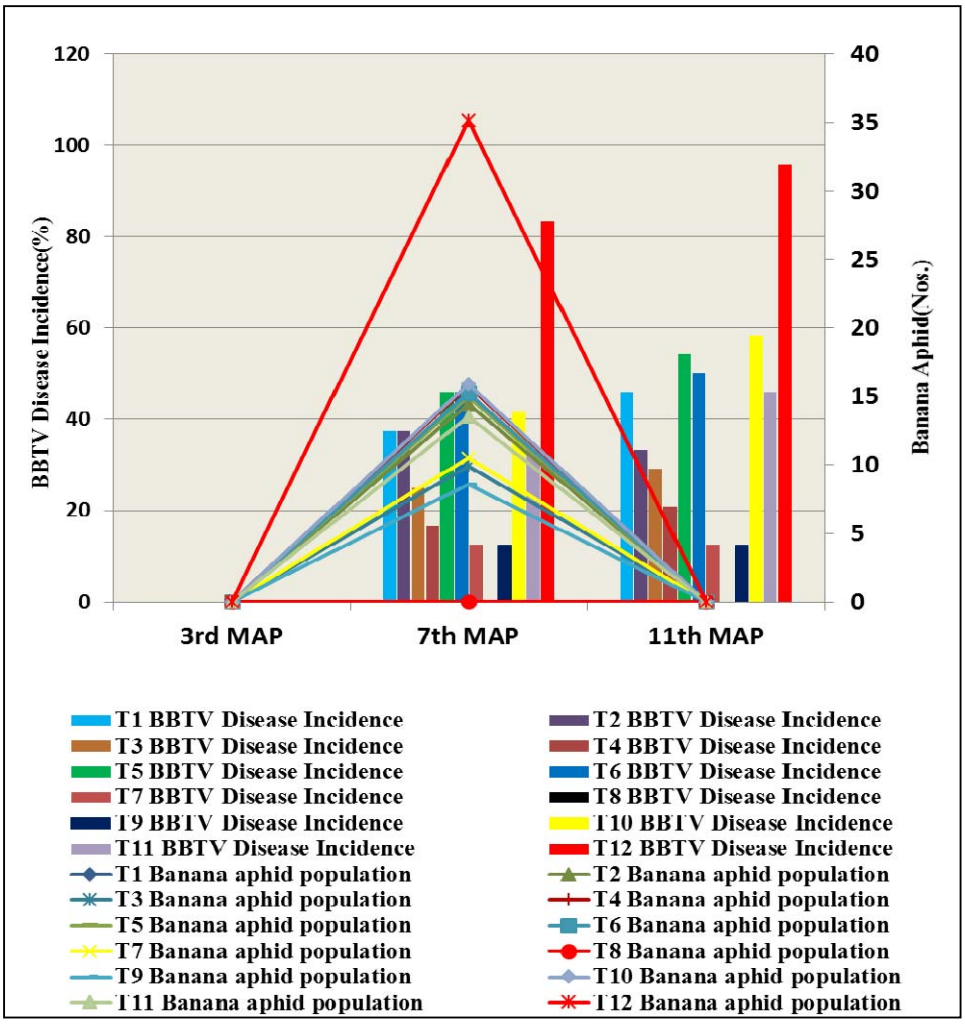

Fig 1: Bbtv Disease Incidence And Banana Aphid Population At 3rd, 7th And 11th Map (Months After Planting) (2013-15)

The results of correlation analysis of banana aphid population and weather parameters of the two cropping seasons revealed that out of seven weather parameters only temperature (2013-15) and relative humidity (evening) (2014-15) showed significant (negative) correlation which means increase in temperature and relative humidity (evening) for the respective cropping seasons there was a decrease in vector population in the field. The correlation coefficients of banana aphid population with maximum temperature (2013-14), maximum temperature (2014-15), minimum temperature (2013-14), minimum temperature (2014-15) and relative humidity (evening) (2014-15) were (-)0.626), (-)0.621, (-) 0.603), (-) 0.647) and (-)0.582, respectively. The above results support the earlier findings of Young and Wright (2005) [51] that there was no distinct or consistent pattern in seasonal distribution of banana aphid population in Hawaii field condition. Similarly, the results of correlation coefficient of banana aphid population and BBTD incidence when analysed with different

weather parameters during the two cropping seasons (2013-14 and 2014-15) showed that no direct and significant correlation can be made between recorded aphid numbers and disease incidence.

It was evident from the pooled data analysis of the two cropping season (2013-15) that banana aphid population showed extreme seasonal fluctuation throughout the cropping seasons with increase in population during the winter in field. These fluctuations in aphid numbers in field condition throughout the year were significantly influenced by the prevailing high temperature and relative humidity (evening). The banana aphid population was also negatively influenced by rainfall and number of rainy days during the two cropping seasons but it was not significant. In all the treatments there were no banana aphid populations recorded up to 165 DAP. Population starts increasing gradually after 180 DAP, attaining a peak at 195 DAP and starts decreasing gradually from 210 DAP with complete disappearance after 285 DAP in all the cropping seasons. The highest banana aphid numbers were recorded in the period 180-210 DAP (January and February) which corresponds to the dry and winter season in Jorhat, Assam. These findings were confirmatory to the earlier reports that in India, banana aphid population increased in winter in plain areas, whereas in hill areas population increased in summer (Anon, 2012) [7]. This period is characterized by maximum temperatures (23.8 to 26 °C), minimum temperatures (10.1-12.4 °C), relative humidity morning (88-95%), relative humidity evening (55-73%), BBSH (136.4 to 199.6 hrs.), rainfall (4.3 to 36.1mm) in addition to the lowest number of rainy days only 1 to 3. The present findings were in concurrence with earlier reports of seasonal distribution and correlation of banana aphid population with weather parameters and BBTD incidence (Agarwala and Bhattacharya, 1994; Young and Wright, 2005; Robson *et al.*, 2006 and Niyongere, 2012) [1, 51, 41, 33].

From the regression analysis following regression equations of weather parameters and disease incidence could be deduced:

For First cropping season (2013-14):

$Y = 192.614 – 1.530X_1 + 2.659X_2 - 0.040X_3 + 1.067X_4 + 0.570X5 - 2.577X_6 - 0.409X_7$

$R^2 = 0.531$

For Second cropping season (2014-15):

$Y = 292.679 + 2.687X_1 - 3.625X_2 + 0.102X_3 - 1.060X_4 – 3.205\ X_5 + 0.330X_6 - 0.153X_7$

$R^2 = 0.875$,

Where, Y=BBTD incidence (percentage), X_1= Maximum Temperature (°C), X_2= Minimum Temperature (°C), X_3= Rainfall (mm), X_4 =Rainy days(nos.), X_5 =Relative Humidity(Morning) (percentage), X_6 =Relative Humidity(Evening) (percentage), X_7 =BSSH(hrs.), R^2=Coefficient of determination.

The result of the regression analysis of different weather parameters against BBTD incidence showed that the there were no significant effects of weather parameters on BBTD incidence during the two cropping seasons (2013-14 and 2014-15). During the first cropping season (2013-14), BBTD incidence was negatively influenced by maximum temperature, rainfall, relative humidity (evening) and BSSH which means for 1% decrease in the BBTD incidence, the contribution of maximum temperature, rainfall, relative humidity (evening) and BSSH were 0.236, 0.312, 1.058 and 0.584 per cent, respectively. Whereas, BBTD incidence was positively influenced by minimum temperature, rainy days and relative humidity (morning) which means for 1% increase in the BBTD incidence the contribution of minimum temperature, rainy days and relative humidity (morning) were 0.725, 0.327 and 0.069 per cent, respectively during the first cropping season.

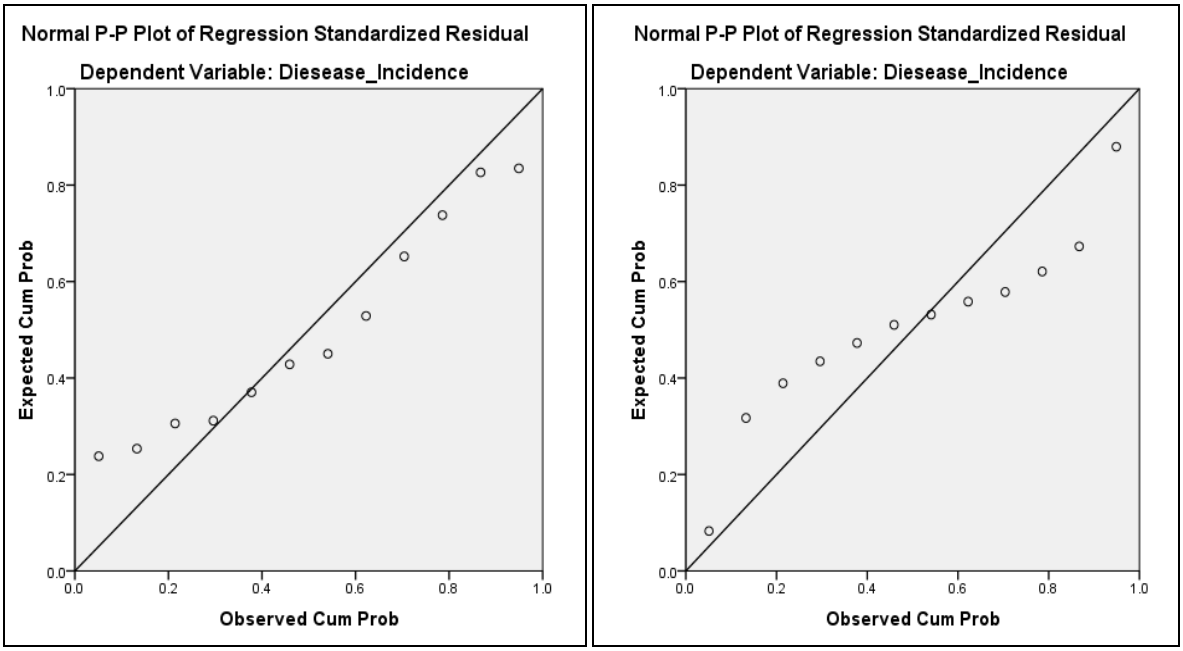

Fig 2: Normal Probability Curve Showing Effect of Weather Parameters on Bbtd Incidence During Different Cropping Seasons (2013-14 And 2014-15)

During the second cropping season (2014-15), it was found that BBTD incidence was negatively influenced by minimum temperature, rainy days, relative humidity (morning) and BSSH which means for 1% decrease in the BBTD incidence the contribution of minimum temperature, rainy days, relative humidity (morning) and BSSH were 1.649, 0.614, 0.444 and 0.569 per cent, respectively. Whereas, BBTD incidence was positively influenced by maximum temperature, rainfall, relative humidity (evening) which means for 1% increase in the BBTD incidence the contribution of maximum temperature, rainfall and relative humidity(evening) were 0.664, 1.162 and 0.209 per cent, respectively. Maximum contribution to the BBTD incidence was contributed by minimum temperature followed by rainfall in the second year cropping season (2014-15) (Figure 2).These findings were in concurrence with those reported earlier by Niyongere (2012) [33].

The regression equations of weather parameters and banana aphid population could be deduced as:
For First cropping season (2013-14):
$Y = 300.816-0.921X_1-1.960X_2-0.001X_3+0.729X_4-3.129X_5+0.763X_6+0.009X_7$
$R^2 = 0.954$
For Second cropping season (2014-15):
$Y = 108.586+0.689X_1-0.887X_2-0.060X_3 +0.698X_4 – 0.180X_5 - 0.858X_6 -0.162X_7$
$R^2 =0.575$
Where, Y=BBTD incidence (percentage), X_1= Maximum Temperature (°C), X_2= Minimum Temperature (°C), X_3= Rainfall(mm), X_4 =Rainy days(nos.), X_5 =Relative Humidity(Morning) (percentage), X_6 =Relative Humidity(Evening)(percentage), X_7 =BSSH(hrs.), R^2=Coefficient of determination.

The result of the regression analysis of different weather parameters against banana aphid population showed that the there were no significant effects of weather parameters on banana aphid population during the two cropping seasons (2013-14 and 2014-15) except relative humidity (morning) during the first cropping season (2013-14). During the first cropping season (2013-14), banana aphid population was negatively influenced by maximum temperature, minimum temperature, rainfall and relative humidity (morning) (significant) which means for 1% decrease in the banana aphid population, the contribution of maximum temperature, minimum temperature, rainfall and relative humidity (morning) were 0.327, 1.232, 0.024 and 0.871 per cent, respectively. Whereas, banana aphid population was positively influenced by rainy days and relative humidity (evening) and BSSH which means for 1% increase in the BBTD incidence the contribution of rainy days and relative humidity(evening) and BSSH were 0.514, 0.722 and 0.029 per cent, respectively which very negligible and nonsignificant. During the second cropping season (2014-15), it was found that banana aphid population was negatively influenced by minimum temperature, rainfall, relative humidity(morning), relative humidity(evening) and BSSH which means for 1% decrease in the banana aphid population the contribution of minimum temperature, rainfall, relative humidity (morning), relative humidity (evening) and BSSH were 0.482, 0.818, 0.030, 0.649 and 0.721 per cent, respectively. Whereas, banana aphid population was positively influenced by maximum temperature and rainy days which means for 1% increase in the banana aphid population the contribution of maximum temperature and rainy days were 0.203 and 0.483 per cent, respectively. Maximum contribution to the banana aphid population was contributed by minimum temperature followed by relative humidity (morning) in the first year cropping season (2013-14) (Fig. 3). These findings were in concurrence with those reported earlier by Niyongere (2012) [33].

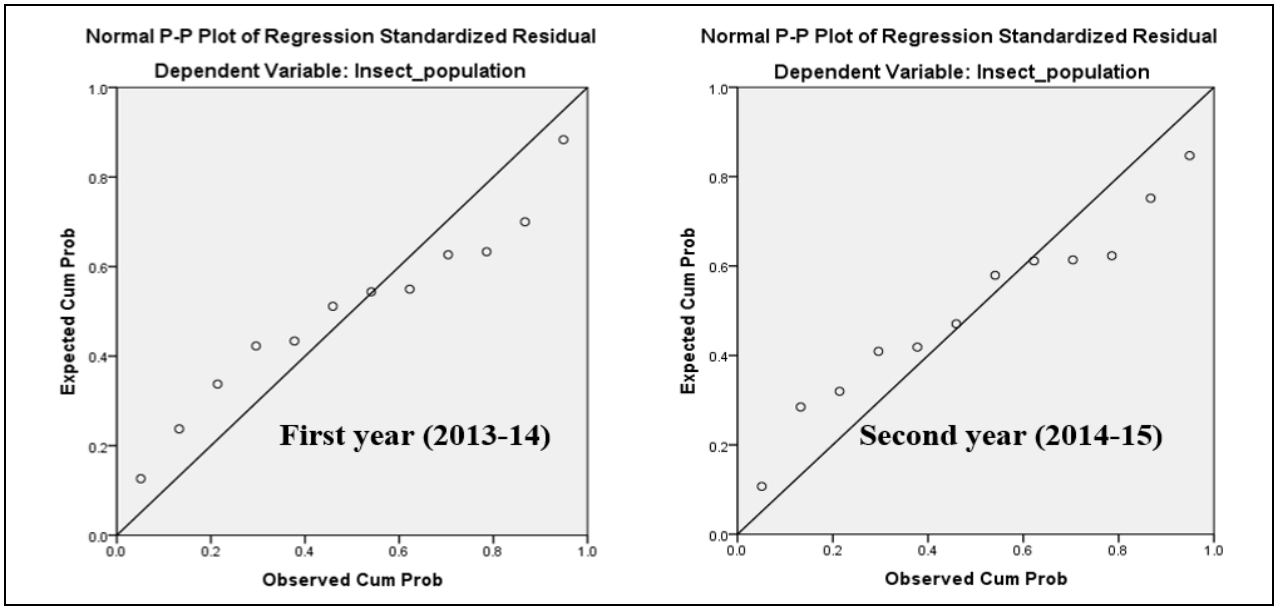

Fig 3: Normal Probability Curve Showing Effect of Weather Parameters on Banana Aphid Population During Different Cropping Seasons (2013-14 And 2014-15)

Yield of banana

The effects of different treatments in the field during the two cropping seasons (pooled data, 2013-15) on yield of banana were presented in Figure 4. It was evident from the data that the banana yield was significantly increases as the BBTV disease incidence and banana aphid population decreases in all the cropping seasons. The pooled data analysis of the first and second year cropping seasons (2013-15) revealed that, the highest banana yield was recorded 43.55 kg/plant in the treatment T_8 where Imidacloprid was applied @ 0.1% followed by 36.54, 36.07 and 35.50 kg/plant in the treatments T_9 (Dimethoate @ 0.2%), T_7(Azadirachtin @ 0.3%) and T_4(Imidacloprid was applied @ 0.025% + V. lecanii @ 1x 10^8 cfu/ml), respectively. However, the treatments T_9 and T_7 were found to be statistically at par. The lowest yield of 0.88 kg/plant was recorded in the control (T_{12}). The overall variation in yield in all the treated plots ranged from of 0.88 to 43.55 kg/plant. The increase in banana yield over control recorded a maximum of 97.98 per cent in the treatment T_8 followed by 97.59, 97.56 and 97.52 per cent in the treatments T_9, T_7 and T_4, respectively. The results of field experiments presented in the during the different cropping seasons showed that both chemical as well as botanical pesticide had significant effect on BBTD incidence, banana aphid population and yield of banana plants. The most promising treatment T_8 (Imidacloprid @ 0.1% at 60, 90, 120 and 150 DAP) recorded 0.00 per cent incidence of BBTD and zero insect vector population in all seasons with highest 42.67 kg/plant (2013-14) and 44.42 kg/plant (2014-15) yield of banana. Similar results found in pooled data (2013-15) with 0.00 per cent BBTD incidence, zero insect vector population and highest banana yield 43.55 kg/plant. These results were in accordance with that of managing BBTD by controlling banana aphid using Imidacloprid as foliar application under field conditions in Hawaii as reported by Wright *et al*. (2007) [50]. Imidacloprid is a neonicotinoid insecticide which interrupts the binding of nicotinergic acetylcholine in post-synaptic receptors of insects (Romoser and Stoffolano, 1998) [42]. Effective control of the spread of viral pathogens transmitted persistently by their insect vectors by using Imidacloprid was reported earlier by several researchers on different viral diseases. For example, Potato leaf roll virus (PLRV) by *Myzus persicae* (Boiteau and Singh, 1999; Mowry and Ophus, 2002; Mowry, 2005) [8, 31, 30], *Beet mild yellowing virus* (BMYV) in sugar beets (Dewar *et al.*, 1992) [11], *Barley yellow dwarf virus* (BYDV) in small grains (Gourmet *et al.*, 1994 and Gray *et al.*, 1996) [19, 20] and *Bean leaf roll virus* (BLBLRV), *Faba bean necrotic yellows virus* (FBNBNYV), and *Soybean dwarf virus* (SbDV) in faba bean and lentil (Makkouk and Kumari, 2001) [28]. This holds true in case of the present field experiment of BBTD management. From pooled data (2013-15), it was found that the botanical pesticide, Azadirachtin @ 0.3% at 60, 90, 120 and 150 DAP (T_7) also showed promising results of lower BBTD incidence (12.50%) and 0.00 to 10.75, average 3.39 banana aphid population with 36.07 kg/plant banana yield. These results were in confirmatory to the earlier works conducted by researchers on management of *Pentalonia nigronervosa* f. *caladii* Van der Goot transmitting Katte disease in cardamom through application of neem formulations which significantly affected the settling and colonization behaviour and multiplication of aphids in cardamom (Venugopal, 1999 and Gahukar, 2011) [48, 17]. However, the control treatment T_{12} recorded highest BBTD incidence of 100.00 per cent (2013-14), 91.67 per cent (2014-15), 95.84 per cent (pooled, 2013-15) and with the lowest yield of banana *viz.*, 0.83 kg/plant (2013-14), 0.92 kg/plant (2014-15), 0.88 kg/plant (pooled, 2013-15).These results were in conformity with those findings reported earlier that because of high transmission efficiency of banana aphid, the disease incidence can increase rapidly without control of aphid populations in field (Hu *et al.*, 1996 and Smith *et al.*,1998) [23, 44]. Dale, 1987 [10] and Hooks *et al.*, 2008 [22] reported that the BBTD incidence within the field trial increased around 12 per cent per year resulting onto a gradual decrease in banana yields. They explained that the lower average of bunch weight of BBTV infected banana plants might be due to the low photosynthesis rate of chlorotic leaves of infected plants which affecting the banana production.

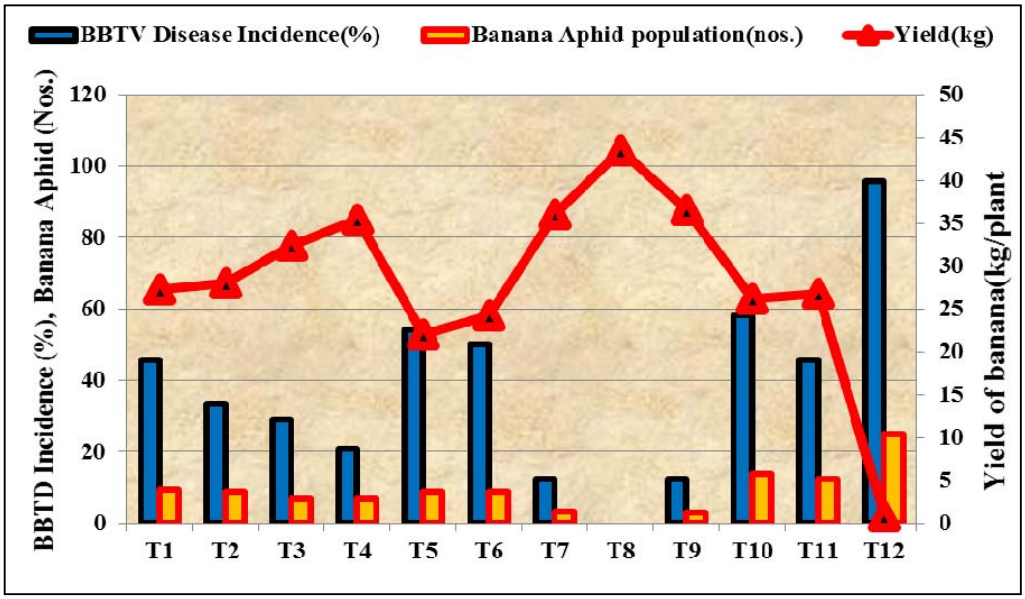

Fig 4: Effect of Different Treatments on Bbtd Incidence, Banana Aphid Population and Yield of Banana (Pooled Data, 2013-15)

The correlation analysis of BBTD incidence and banana aphid population with yield of banana plants revealed that banana aphid population and BBTD incidence were positively correlated and showed highly significant relation between them in all the cropping seasons (2013-14, 2014-15 and pooled data, 2013-15), which means increase in banana aphid population there was increase in BBTD incidence in all the seasons. The correlation coefficients of banana aphid population and BBTD incidence were 0.905, 0.980 and 0.967 during the first cropping season (2013-14), second cropping season (2014-15) and the pooled data, 2013-15, respectively.

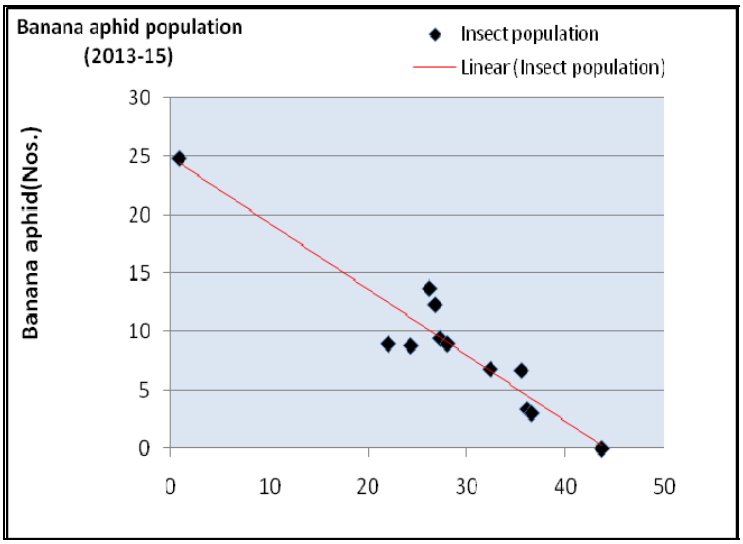

Fig 5: Correlation between yield of banana and banana aphid population during different cropping seasons (pooled data, 2013-15)

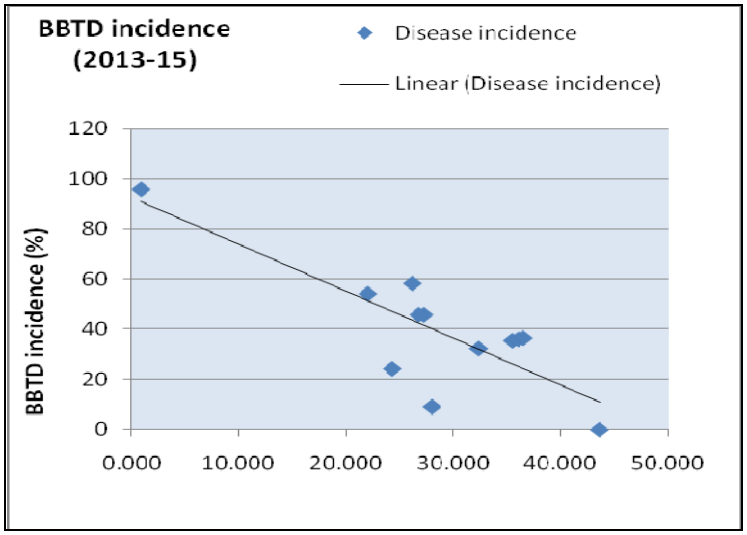

Fig 6: Correlation between yield of banana and bbtd incidence during different cropping seasons (pooled data, 2013-15)

The correlation coefficient results showed that banana aphid population and yield of banana were highly significant and negatively correlated in all the cropping seasons, which means that increase in banana aphid population there was decrease in yield of banana in all the seasons. The correlation coefficients of banana aphid population and yield were (-) 0.860, (-) 0.947) and (-) 0.949 during the first cropping season (2013-14), second cropping season (2014-15) and the pooled data, 2013-15, respectively (Figure 5).

Similarly, the results of correlation analysis showed highly significant and negative correlation between BBTD incidence and yield in all the cropping seasons, which means that with increase in BBTD incidence there was decrease in yield of banana in all the cropping seasons. The correlation coefficients of BBTD incidence and yield were (-)0.959, (-) 0.962 and (-)0.975 during the first cropping season (2013-14), the second cropping season (2014-15) and pooled data, 2013-15, respectively (Figure 6).

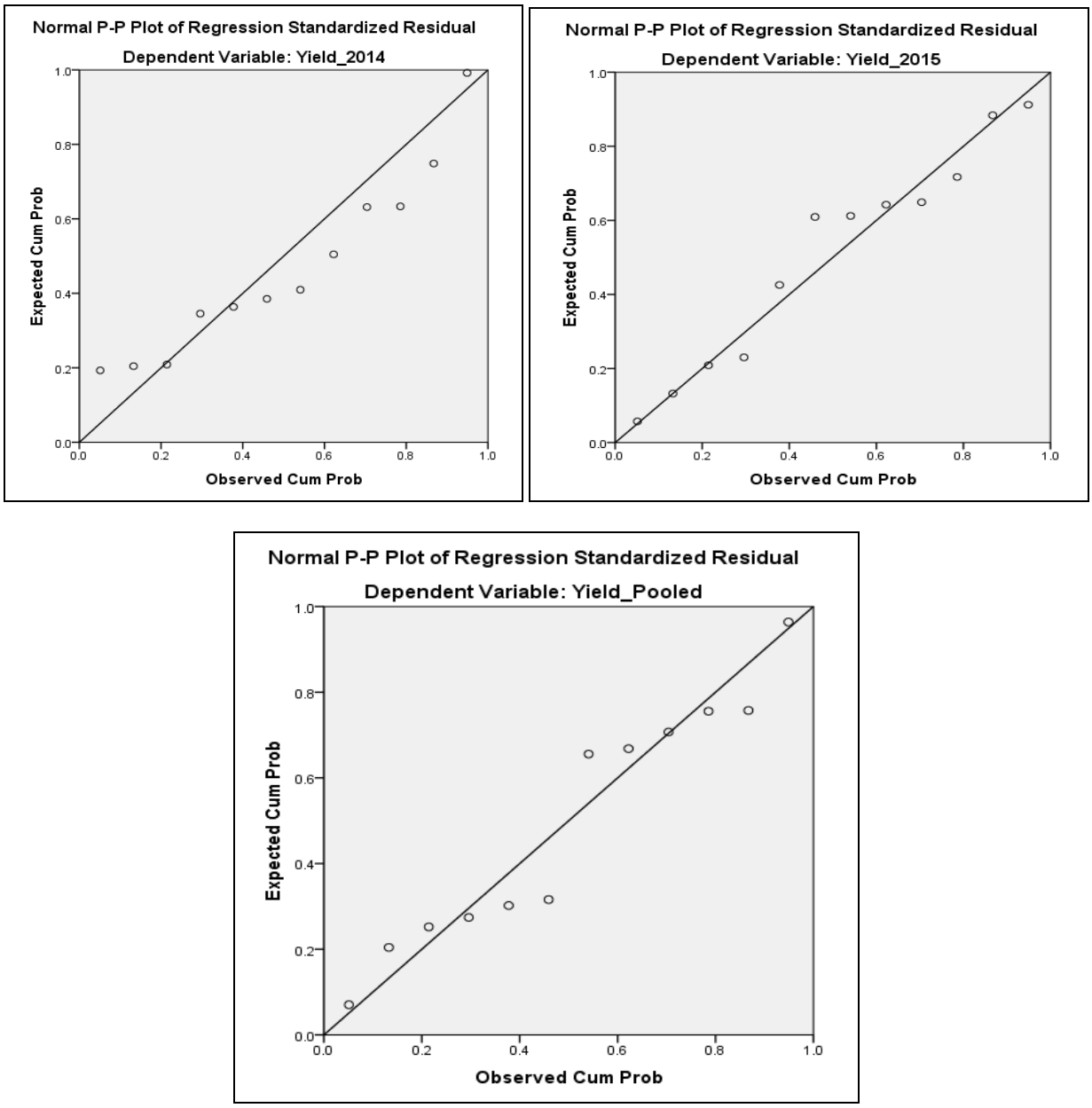

Fig 7: Normal probability curve showing effect of BBTD Incidence and Banana aphid population on Yield of banana during different cropping seasons (2013-14, 2014-15 and pooled data, 2013-15)

From the analysis of regression the following regression equations of banana aphid population, BBTD incidence and yield of banana could be deduced:

For first cropping season (2013-14): $Y=44.072-0.468X_1+0.069X_2$, $R^2=0.920$

For Second cropping season (2014-15): $Y=46.897 - 0.460X_1 - 0.166X_2$, $R^2=0.927$

For pooled data of first and second cropping season (2013-15):

$Y=45.211-0.429X_1 – 0.162X_2$, $R^2=0.951$

Where, Y=Yield (kg/plant), X_1=BBTD incidence (percentage), X_2=Banana aphid population (nos.) R^2=Coefficient of determination.

The results of the regression analysis of different cropping seasons of banana showed that the yield of Banana was negatively influenced by the BBTD incidence. For 1 per cent reduction in yield, the BBTD incidence contribution was (-) 0.996 per cent (highly significant) during the first cropping season (2013-14). Though, banana aphid population contribution (0.04%) was found positive, it was very negligible and non-significant also (2013-14). The regression analysis of second cropping season (2014-15) of banana showed that the yield of banana was negatively influenced by the BBTV disease incidence and vector population. It was recorded that for 1per cent reduction in yield, the BBTD incidence contribution was (-) 0.872 per cent whereas, banana aphid population contribution was (-) 0.092 per cent but they were non-significant (2014-15).The regression analysis of pooled data of the two cropping seasons (2013-15) also showed that the yield of Banana was negatively influenced by the BBTV disease incidence and vector population. It was

recorded that for 1 per cent reduction in yield, the BBTD incidence contribution was (-) 0.882 per cent (significant) whereas, banana aphid population contribution was 0.096 per cent but it was non-significant (pooled data, 2013-15). Maximum contribution to the yield reduction was contributed by BBTV disease incidence in the first cropping season (2013-14) (Figure 7). The above results were in concurrence with those reported by Robson *et al.*, 2006 [41] and Niyongere (2012) [33].

The findings of this research would be helpful for initiating future strategies in disease diagnostics and resistant breeding. The above research findings elucidate the importance of use of disease free planting material and chemical control in effective management of the spread of viral pathogens transmitted persistently by their insect vectors. To the best of our knowledge these findings are the first report from Assam. Field efficacy of biocontrol agents with chemical and botanical pesticides used in banana production system are important in developing strategies for the efficient utilization of entomopathogens against insect vector in the integrated pest management of banana. Therefore an integrated approach such as use of certified disease free banana planting material (tissue cultured, Grand Naine) as well as field application of chemical pesticides *viz.*, Imidacloprid @ 0.1 per cent at 60, 90, 120 and 150 DAP or botanical pesticides *viz.*, Azadirachtin @ 0.3% at 60, 90, 120 and 150 DAP would be applicable in the farmer's field for sustainable management of BBTD. In the present day context, due to the limited use of conventional chemical control, there is a need to develop eco-friendly strategies to combat the high incidence of BBTD and its vector population. Hence, the strategies mentioned above would play an important role in managing the BBTD in a sustainable manner.

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