B. REVIEW OF LITERATURE.
Although a virus disease of rice was one of the first plant virus diseases that have been described, identified and studied thoroughly (Iida 1969; Ling, 1968a, 1972), it took a long time for the scientific establishment of tungro virus disease of this crop. The appearance of symptoms of this disease, however, was not unknown in the rice fields of Philippines (where it was popularly known as 'tungro', a Illacano word meaning degenerated growth) and other parts of South-East-Asia. Nonavailability of appropriate methodology and scientific understanding impeded the exposition of the disease nature of this malady for a long time. As the general symptom of this malady is the degenerated growth of plants; it was regarded as physiological disorder in the early days and was given different names in different countries. In Malaysia, Coleman-Doscas (1935) observed stunting of plants and discolouration of leaves. He recorded this disease a 'Penyakit merah'; according to him "the initial symptoms in the affected plants were chlorotic mottle, but with the development of the disease, the chlorotic leaves turned yellow to yellow orange and the leaves dried up from the tip. The root systems of the affected plants developed very poorly and produced a few tillers".

In Philippines, stunting and discolouration of rice plants were observed by Agati and Peralta (1939), Agati et al. (1941) and Serrano (1957). Agati et al. (1941) recorded this disease as "stunt" or "dwarf", while Serrano (1957) recorded it as"acep-nupula". Similar symptoms were also observed by
Reyes (1957) and Reyes et al. (1959) but they retained the name used by Agati et al. (1941).

In Indonesia, discolouration of leaves and stunting of rice plants were observed as early as 1859. This disease was regarded as physiological one and named as "mentek". Ou (1965a) and Rivera et al. (1968) while studying the "mentek" disease of Indonesia observed the similarity of it with tungro disease. Similar symptoms of rice were also observed in Thailand by Wathankul (1965) but he recorded it as "yellow-orange-leaf".

In India, tungro like symptoms were first observed by Raychaudhuri et al. (1967a, 1967b). They observed yellowing of leaves, stunting of plants and reduction in tillering due to this disease.

When systematic and comprehensive researches on rice were initiated in Philippines at the International Rice Research Institute, tungro like malady was observed in the experimental fields of the Institute (IRRI 1963). They observed various shades of orange to yellow colour in the leaves depending upon the varieties. They further observed that some varieties became stunted and ultimately died if infected early. The IRRI workers subsequently conducted experiments under glass house conditions and transmission studies on this disease and established the virus nature of the disease which cause discoloration of leaves and stunting of rice plants in the experimental fields and in other areas of Philippines (IRRI 1963).
Rivera and Ou (1965) made detailed study of the transmission of the causal virus of the tungro disease by *Nephotettix impicticeps* Ishihara and proposed to name the disease as 'tungro'. Lamey *et al.* (1967) later confirmed the observations of Rivera and Ou (1965). They established the destructiveness of this rice virus through transmission studies. According to them, individual male, female and nymph could transmit the virus. Virus free adult population was capable of transmitting the disease after feeding on infected plants. They did not find any transmission through the eggs of viruliferous leaf hoppers.

After the establishment of virus nature of the tungro disease of rice, the so-called physiological disorders showing discoloration of leaves and stunting of plants in different countries were reinvestigated. Ou and Goh (1966), Ou *et al.* (1965b) studied 'penyakit merah' of Malaysia and transmitted the disease by *Nephotettix impicticeps* Ishihara. From the symptoms, the insect vector involved and varietal reaction, he found it to be a disease caused by tungro virus. Singh (1969), Ting and Paramsothy (1970), confirmed the findings of Ou and Goh (1965). The 'mentek' disease of Indonesia was studied by Ou (1965) and Rivera *et al.* (1968). According to them 'mentek' disease was also caused by tungro virus. Lamey *et al.* (1967a, 1967b) studied 'Yellow-orange leaf' disease in Thailand and observed the similarity of this disease in symptomatology and transmission characteristics; particularly, vector species, acquisition feeding period, inoculation feeding period, retention of the virus in the vector and varietal reaction, with those of tungro. The leaf
yellowing disease of India when reported by Raychaudhuri et al. (1967b), presence of tungro virus was suspected. Later it was confirmed by John (1968).

Besides the reinvestigation of the tungro like disease found in Philippines, Indonesia, Thailand, Malaysia and India, many workers have also attempted to study the incidence of tungro disease in several other countries. Nuque and Miah (1969), and Lippold et al. (1970), Galvez and Miah (1969) reported the incidence of the disease in East Pakistan (Bangladesh).

Baldacci et al. (1970) also suspected the presence of this disease in Italy. Baldacci et al. did not suspect the presence of tungro in Italy.

After the scientific establishment of tungro virus of rice by Rivera and Ou (1965), many workers have studied the identifying characters of this virus (Ou et al., 1965; IRRI, 1963, 1964, 1965, 1966). It has been reported that symptomatology and transmission characteristics were the primary criteria for identifying the tungro virus disease. The typical symptoms as described by the IRRI workers (IRRI, 1964-1966) are as follows:

"The tungro virus infected plants, especially in case of susceptible varieties, are stunted, leaves become yellow orange in colour and less number of tillers per hill. The discolouration of leaves starts from the tip and may cover the entire leaf blade. When infection occurs at the early stage, number of tillers per hill reduces markedly. Infected plants take longer period to mature and have fewer spikelets and higher percentage of empty grains. The weight of 1000 grains from
infected plants are less than that of the healthy one.

As regards to the transmission characteristics of the *Nephotettix impicticeps* Ishihara, Ling (1966, 1968b, 1969); Sing (1969); Rivera and Ou (1968); John (1968) observed the minimum acquisition feeding period, minimum incubation period and maximum retention period of the virus in the vector as 30 minutes, 2 hours and 5 days respectively. As regards to the use of other technique for identifying tungro virus, such as, purification and electronmicroscopy, no extensive efforts have been made so far, Galvez (1967, 1968), Galvez et al. (1971) made an attempt to purify the virus and studied the electron micrograph. According to them tungro virus particles were polyhydral being 30-33 m/μ in diameter.

Although information in relation to the chemical and physical properties of tungro virus are very limited, extensive works have been done on epidemiological aspect of the disease, such as, source of the virus in nature, transmission of the disease in the fields and various other relevent aspects.

As regards to the source of virus in nature, it has been reported that root debris or stubbles of infected plants may act as primary source of the virus (Ling and Palomar, 1966; IRRI 1964). Besides this, occurrence of many alternate and co-lateral hosts have also been reported. Wathankul (1964), found *Echinochloa crusgalli* (L.) Beauv and *E. colonum* (L.) Linn and *Eleusine indica* Gaertn as alternate hosts of tungro. *E. crusgalli* and *E. colonum* were suspected by him as a symptomless carriers of the virus and similar observation have also been
made at IRRI (1964). Recently, it has been demonstrated that 63 species in 26 genera and 8 tribes of wild grasses can be infected by tungro virus (IRRI 1968). Sporadic infection of *Ischaemum rugosum* Salisb, *Dactyloctenium aegyptium* (L.) Beave, were also observed by them. In 1970 two more grasses, *Leersia hexendra* Sw and *Cynodon dactylon* Pers, have been reported which can act as collateral host of tungro virus.

The transmission of tungro virus have been studied at IRRI and in many other places (IRRI 1963, 1964, 1965, 1966, 1967, 1968; John, 1968; Ling 1969b). Before the separation of taxonomic group of *Nephotettix* by Ishihara (1964) *Nephotettix bipunctatus* or *apicalis* were considered to be the vector for tungro virus (IRRI 1963). Later it was recorded that only *N. impicticeps* acts as a vector for this virus (Rivera et al., 1969; IRRI, 1964, 1965). Ling (1970); AICRIP (1971) demonstrated that both *Nephotettix impicticeps* and *N. apicalis* can transmit the tungro virus but the transmitting capability of *N. impicticeps* is much higher than that of *N. apicalis*. The percentage of active transmitters in *N. apicalis* and *N. impicticeps* have been found to be 45 per cent and 83 per cent respectively. Retention of the virus in *N. impicticeps* is also higher than that in *N. apicalis* (Ling, 1970; John, 1968), observed that female species of *Nephotettix* are more efficient in transmitting the virus than the male species. Recently another two species *Recilia* (Inazuma) *dorsalis* and *N. parvus* was reported as vectors of this virus but their transmitting capability has been found to be very low (IRRI, 1968, 1969, 1971; Rivera et al., 1969a).
Thus *N. impicticeps* and *N. apicalis* are still considered to be the primary vectors for tungro virus of rice. Although Ghauri (1971) recently revised the genus *Nephotettix* and changed the name of *N. impicticeps* to *N. virescens* and *N. apicalis* to *N. nigropictus*, the names *N. impicticeps* and *N. apicalis* have been used in the text for the sake of convenience.

As regards to the influence of environmental factors upon the incidence of the tungro virus it has been reported that temperature and other climatic factors may directly or indirectly influence the incidence of the disease, as optimum temperature for virulification of leaf hoppers is 26°C (IRRI, 1970). Lippold et al. (1970) reported that the disease spreads in East Pakistan (Bangladesh) primarily during monsoon. They also observed that incidence of the disease is related with the population of *Nephotettix* spp in the fields and the population build up in the fields again, is related with the existing environmental condition. Harikwa (1951), observed that high temperature and low rainfall increased the population of *Nephotettix* spp. Besides the environmental factors, it has been reported that certain host factors also influenced the incidence of the disease. It has been found that the susceptibility of the plant to tungro virus disease decreased with the increase of the age of the plants at the time of infection (IRRI, 1966, 1967; Ling and Palomar, 1966). They also observed that the susceptibility of tungro virus varied with the variety, and the virus was widely distributed in various plant parts such as leaf blade, leaf sheath, root, stem, rachis, young panicle and partially in mature
The interactions between the environmental factors, vector species, virus and host factors have, however, not yet been properly studied to present a comprehensive picture on their relation with the incidence of the disease.

So far as the relationship between the virus and the vector, studies have been made by a large number of workers (Rivera and Ou, 1965; Ling, 1966, 1968b; and IRRI, 1968). According to them *N. impicticeps* Ishihara is the active transmitter of the disease and minimum acquisition and inoculation feeding periods are 30 and 15 minutes respectively. No definite incubation period in the insect was detectable. They observed gradual decrease of infectivity of the vectors with the time. *N. impicticeps* can only retain the tungro virus for 5 days and more than 50 per cent of the insect lost their ability to transmit the virus within 24 hours after acquisition of feeding. From these observations Ling (1966) reported that the relationship between tungro virus and its vectors may be non-persistent or stylet-borne. Although extensive works are now being carried out in different laboratories on tungro virus disease, the virus vector relationship or in other words the exact mechanism of virus uptake, relationship of the uptake with the probing behaviour of the leafhopper, the exact localization of the virus on the stylet and mechanism of ejection of the virus particles during inoculation feeding have not yet been properly studied.

Considering the economic significance of the disease, extensive work has been done in many laboratories on the varietal panicle also.

susceptibility of rice plants to the virus. A few varieties of rice, namely Kamod, Kataribhog, Tilakkachari and Pankhari, have been found which are resistant to tungro virus (IRRI, 1964-1969, AICRIP, 1968-1970, Raychaudhuri and John, 1970). While studying the varietal resistance, it has been found that a set of varieties reacted differently with different isolates of the virus. From these observations, at present three strains of tungro virus have been established (IRRI, 1970). Regarding the effect of the virus infection on the yield characteristics of rice, much information is not available. Workers at IRRI have observed low yield, low grain weight in infected plants, (IRRI, 1966; Ling, 1969a). Ling and Palomar (1966) reported tungro virus caused 74 per cent damage of the crop when infected in an early stage.

As for biochemical changes induced in the rice by the tungro virus infection, it is very little understood. Raychaudhuri et al. (1969), IRRI (1966) and AICRIP (1970) reported accumulation of excess starch in the rice leaves due to tungro virus infection. They further observed reduction in chlorophyll and increase of ribonucleic acid in the infected leaves.

In India, studies on tungro virus disease of rice have been started when Raychaudhuri et al. (1967a, 1967b), first suspected the occurrence of it in Orissa, West Bengal, Bihar, Delhi and Andhra Pradesh. John (1968) confirmed the occurrence of tungro virus disease in Andhra Pradesh. Govindu et al. (1968) suspected the occurrence in Mysore. Mukhopadhyay and
Chowdhury (1971), Chowdhury and Mukhopadhyay (1972), Mukhopadhyay (1971) confirmed the incidence of this disease in West Bengal previously reported by Raychaudhuri et al. (1967). According to them the infected plants reduced in plant height, panicle length, number of panicle, number of filled grain per panicle and grain weight. Raychaudhuri and his associates (1969, 1970) and WCRIP (1969, 1970, 1971) found some alternate host in the grass family for tungro virus. They also found that in addition to high yielding variety, two local varieties of West Bengal namely Badkalamkati and Churnakati may be infected by tungro virus. In this study of varietal resistance against the virus they found Pankhari 203, Intan, T 47 (Faizabad), NSJ 198 as resistant. They also observed the incidence of this disease in aus (autumn rice) in addition to the aman (winter rice) in West Bengal.

Raychaudhuri and his associates (1969, 1970) also partially purified the virus and performed electron microscopic studies and confirmed the observation of Galvez (1967). They also observed difference in virulence among different isolates of tungro virus, and in producing different kinds of disease syndromes such as leaf yellowing, interveinal chlorosis, mild mottling and stunting. They also studied the leafhopper incidence in different areas, and observed the population of Nephotettix impicticeps was more common than N. apicalis particularly from September onwards. In the study of virus-vector relationship they found that in certain areas 70-80 per cent leafhoppers were active transmitters and the disease
could be transmitted even by a single hopper.

In the studies conducted at All India Coordinated Rice Improvement Project it has been observed that the degree of leaf symptoms of tungro virus disease such as orange-yellow to yellow coloration of the leaves, vein clearing and stunting depend upon the variety of rice. Inoculating large number of varieties they observed different shades of coloration ranging from orange yellow, orange, brown, rusty and black colour of the leaves. Vein clearing became prominent only in certain varieties. As for stunting, they observed different grades of percentage depending upon the susceptibility and resistance of the varieties concerned to tungro virus (AICRIP, 1968, 1969).

The AICRIP workers through their studies on varietal reaction to tungro virus established four different strains (AICRIP 1970) which differ in their virulence and reaction to certain indicator varieties. In another experiment they observed that the application of nitrogen fertilizer at a very high rate marked tungro symptoms (AICRIP 1970) in pot culture experiments.