REVIEW OF LITERATURE
Effect of waterlogging/submergence

Wide adaptability of the rice plant as a result of its special intrinsic mechanism of survival under most adverse situations made its cultivation possible in an ecological continuum i.e. from upland drought situation to deep waterlogged conditions. Highly reduced condition of the soil and low light stress under waterlogged situations restrict the growth of root and shoot which may affect the existence of the rice plant under such conditions. However, cultivars adapted to such conditions are said to have modification of normal morphological, anatomical and physiological processes leading to fast elongation of shoot, more ear bearing tillers per unit area and comparatively healthy root growth than the cultivars of low tolerance capacity under this condition. Thus the biological characters of rice plant, which get influenced by waterlogging/submergence determine its survival under such conditions are reviewed in following heads.

1. **Survival rate of rice plant**

The adverse effect of waterlogging is mostly apparent to seedlings or tillers mortality, which vary among the rice cultivars. Various factors i.e. the quality and temperature of water in crop canopy, height of seedlings before and after submergence, age of seedlings
at the time of submergence, depth and duration of waterlogging and the nitrogen and carbohydrates content of seedlings govern the survival rate of seedlings/plant are reviewed here.

The seedlings survival of rice decreased with higher temperature and increased with lower temperature. Hence under lower temperature of water the number of functional leaves were found more (Kondo and Okumura, 1932). The survival per cent of rice seedlings was considerably reduced under turbid water as compared to clean water. Precipitation of soil particles on the leaf surface by turbid water during recession of water level induced plant mortality (Kondo and Okumura, 1934). Palada and Vergara (1972) found that the survival of rice seedlings increased with light intensity and low water temperature and reduced with high water temperature and turbid water condition. Low light transmittance in crop canopy under turbid water adversely affected photosynthesis and carbohydrate reserve in the plant.

Ramaih (1953) reported that initial height of the seedling is not an index of their tolerance capacity to submergence. Lack of correlation between seedling height before submergence and tolerance capacity to submersion has also been reported by Mazaredo and Vergara (1982). However, Palada (1970) found positive correlation between plant height at the end of submergence and their survival
rate. Karin (1980) and Karim and Vergara (1981) also found higher survival rate of taller plant at the end of submergence than shorter ones. However, the higher tolerance capacity to submergence in tall plant than short ones has been reported by Palada and Vergara (1972), Karin and Vergara (1981) and Mazaredo and Vergara (1982). De et al. (1981) also reported that 70-75 per cent seedlings of tall cultures could survive at their very early growth stage due to their rapid elongation under submergence. There was significant varietal differences in their survival rate under submergence (Sulaiman and Anwarhan, 1982). Seedling age showed positive influence on submergence tolerance. The aged seedlings showed more tolerance capacity to submergence than younger ones (Kondo and Okamura, 1932; Ramaih, 1953; Alim et al., 1962; Palada, 1970; Choudhury and Zaman, 1970). Several reports indicates that the plant must be at least 3-6 weeks old before advent of flood (Richharia and Misro, 1960; Alim et al., 1962; Singh, 1962; Choudhury and Zaman, 1970; Vergara et al., 1976). Datta and Banerjee (1973) studied the behaviour of 25 winter rice varieties under flooded and nonflooded condition and concluded that seedlings age up to 35 days was most susceptible to flood water. Under waterlogged condition, the plants of 6 weeks age or above recorded higher percentage of survival and more grain yield than the younger plants (Barooah and Uzir, 1962).
Survival of rice seedlings after complete submergence decreased with duration and depth of submergence (Richharia and Parasuram, 1963; Palada and Vergara, 1972; Datta and Banarjee, 1976b; Sulaiman and Anwarhan, 1982; Lambers and Vergara, 1982), temperature and turbidity of water and increased with light intensity and initial content of carbohydrate in seedlings (Palada and Vergara, 1972). The survival rate of seedlings under submergence was significantly higher in low than in high nitrogen level (Palada and Vergara, 1972).

Survival rate of rice seedlings was largely decreased with top dressing of N fertilizer before flooding (Yamada, 1959). Yamada and Ota (1956) reported that tolerance to submergence bear a high positive correlation with total carbohydrate or starch content of rice plant tissue and they could not find any significant correlation between resistance and sugars or insoluble nitrogen content. The resistance of seedlings to submergence has negative relationship with respiratory rate (Yamada and Ota, 1957). Rai and Murty (1976) reported that the high sugar content, chlorophyll stability and nitrate reducing ability of rice seedlings appeared to be some physiological parameters associated with better survival rate under submergence.

2. **Morphological characters of rice plant**

Morphological changes is the main external effect of submergence/waterlogging in rice. The growth of leaf blade,
sheath and internode of floating rice plant considerably increases with the rise of water level (Yamaguchi and Sato, 1961; Yamaguchi, 1973). However, the increase in plant height as a result of increase in number and length of internodes and formation of nodal tillers and nodal roots are the main morphological changes induced by deep waterlogging (Datta and Banerjee, 1973; Haque, 1974; Maurya, 1975; IRRI, 1977, 1979; Datta, 1982). The height of the plant increased by submergence (Yamaguchi and Sato, 1961, 1963; Yamaguchi, 1973; Alim et al., 1962; Chowdhury and Zaman, 1970; Haque, 1974; Vergara et al., 1974; Setabutara and Vergara, 1979; De et al., 1981; Mazaredo and Vergara, 1982) and waterlogging (Vamadevan, 1971; Roy, 1972; Rai and Murty, 1976). The height of the plant increased consistently with increase in water level was reported by (Nasiruddin et al., 1982; Singh, 1982). The elongation rate of rice plant have been reported as much as 20-25 cm/day under submergence treatment (Alim et al., 1962; Chowdhury and Zaman, 1970). The marked increase in plant height under early submergence was due to elongated internodes and increase in internode number from 6-10 (Rao and Rao, 1974). Karin and Vergara (1981) observed that seedlings height before submergence and recovery, the tolerant cultivars were higher than that of susceptible types and they also found that tolerance cultivars generally had longer primary leaves and greater overlapping of the first leaf sheath than susceptible ones.
Vergara and Mazaredo (1979) reported that the rice plant of less than 4 weeks old under deep water showed very poor internode elongation. The main distinguishing feature of deep water or floating rice is that the internode, leaf sheath and blade elongate with rising water level (Nasiruddin et al., 1977). Datta and Banarjee (1976a) reported that the varietal performance and survival under deep water condition related to the number of elongated internodes and total stem length that too a particular variety capable of attaining is one of the important criteria of selecting varieties for different water depths. They also observed that Jaladhi-1 showed better performance than Jaladhi-2 in relation to stem elongation (10% greater) because Jaladhi-1 had 18 internodes in comparison to 17 internodes in Jaladhi-2. IRRI (1976) reported some semi-tall cultures to be tolerant against submergence because of their elongation ability.

Reduction in the tiller number is the most detrimental effect of waterlogging/submergence (Ghosh, 1954; Ghosh and Bhattacharjee, 1959; Tsunoda and Matsushima, 1963; Vamdevan, 1971; Rai, 1974). The number of tillers reduced consistently with depth of waterlogging (Nasiruddin et al., 1982; Kupkanchankul et al., 1982). Sen and Datta (1967) reported reduced growth of tillers under deep submergence in ordinary rice cultures and further stated that basal tillering of rice is inversely proportional to water depth.
Emergence of new tillers does not take place during internode elongation or increase in water level (Kondo and Okamura, 1932) and faster elongating shoot prevents the production of new tillers (Chowdhary and Zaman, 1970). Submergence up to 75% of the rice plant height was found to cause more tiller mortality than that up to 50% of the plant height (Pande et al., 1979). Shattacharjee et al. (1980) has indicated that early developed basal primary or secondary tillers, that attain a minimum height of about 40 cm and age of 10-12 days at the time of submergence, generally become ear bearing under waterlogged condition of 50-60 cm.

The increase in depth of water level in rice fields influence particularly all the characters related to lodging. More water depth produce maximum fresh weight in upper parts, test grain weight and also higher nitrogen content in the plant parts than lower water depth, resulting lodging susceptibility (Singh and Singh, 1966). The increased internode length of deep water rice varieties favoured lodging at maturity stage of growth (IRRI, 1979).

Nodal tillers generally developed 4-8 weeks after submergence of 6 weeks old plant in 85 cm of water and the
elongation of internode decreased after stable water level, thereafter the nodal tillers developed immediately from the nodes of main, primary culm just below the water level (Setabutara and Vergara, 1979).

Production of adventitious root from the aerial nodes of rice under deep water condition helps in the absorption of water and nutrients from the water and after receding the water level, those roots set in the muddy soil and support the plant for growth up to ripening stage (Haque, 1974).

Deep water rice usually lodge during the receding of water level because of elongated internode. Thus the cultures for deep water situations must have the ability to bend (kneeling ability) towards the vertical axis, which helps to keep the first three leaves above the water surface, preventing them from decaying, providing better leaf arrangement by keeping the panicle above the water and thereby prevent grain damage (IRRI, 1977).

3. Growth and yield of rice varieties

The reduction of growth and yield of rice plant under waterlogging/submergence depends upon the varietal reaction with adverse situation, growth stage of the crop, depth and duration of waterlogging/submergence (Nishikawa, 1956; Datta and Banerjee, 1972, 1973, 1976; Yamaguchi, 1973, 1978; Haque, 1974; Rai, 1974; Rai and Murty, 1976; Pande
et al., 1979; Panda et al., 1980; Singh, 1982; Nasiruddin et al., 1982; Kupkanthajkul et al., 1982). Nishikawa (1956) reported reduced dry weight of rice seedling under flooding. Thomas and Stewart (1969) working with growth and development of rice plant under 0, 8, 16, 24 and 32 cm depth of water, found that dry weight of plant decreased by water depth of <8 cm and >110 cm. Yamdevan (1971) reported that under standing water depth plant height, panicle length, number of sound grain per panicle, test grain weight and yield increased. Datta and Banerjee (1972) observed that deep water rice varieties showed significantly better performance under deep water for growth traits like plant height, stem length, number of internodes, etc. and yield attributes, number of panicle, length of panicle, grains per panicle, grain and straw weight than normal ones. But flood resistant varieties gave better result under normal field condition in most of the characters i.e. number of main tillers, number of panicles, grain and straw yield, indicating clear distinction between deep water and flood resistant cultures. They concluded that deep water varieties may be suitable for the areas of waterlogging and flood resistant cultures for flash flood prone areas. Yamaguchi (1973a) observed a reduction in the dry matter of non-floating rice with raising water level, while it was increased in floating rice under same situation. Datta and Banerjee (1973) studied the effect of flooding on growth and yield of 25
water floating cultures and found that only FR-13A, FR-43B and Gabuna could tolerate flood (250 cm) for 16 days and some more cultures showed better growth and gave higher grain yield under both normal and flooded soil condition.

Datta and Banerjee (1974b) further reported that the seedlings of deep water rice varieties showed a greater degree of tolerance to anaerobic condition than other types of rice cultures. They found the presence of larger air cavities, which store the air for respiration under submerged condition and their growth was higher under deep water than in aerated condition. However, IRRI (1977) reported that the photosensitive tall cultures were less affected in yield with increase in the depth of water level, but the cultures which have no elongation ability were unable to produce grain yield under semi-deep water condition. Rai (1974) observed that the dry matter production and leaf area index was lower in susceptible cultures under waterlogged condition throughout the growth period, whereas in tolerant cultures (NC-1281) the dry matter production during early growth stage was lower but from flowering onwards the dry matter and leaf area index were similar to that of normal field condition. He also observed higher SLW under waterlogging than under normal field condition. Rai and Murty (1976) found significant reductions in grain yield (10%) of rice cultures under waterlogging caused by reduction in both panicle number (4%) and grains...
per panicle (6%). However, the test weight was remained constant. They also observed marginal increase of grain yield (7%) in selection T(N)1 x T-65 even under submergence, while MTU-15 sustained no grain loss. The dry matter production at flowering and harvest was severely reduced by 4 and 10% respectively over the control treatments (Rai and Murty, 1976).

Venketswaralu and Rao (1976) observed a linear relationship between LAI and panicle number and grain number with grain yield. Panicle number and grains/panicle were found to be compensated by each other. Catling et al. (1979) found maximum grain yield under 1.5 - 1.8 m depth of flooding in deep water rice varieties. The grain yield of rice varieties reduced with depth (Haque, 1974; Pande et al., 1979; Panda et al., 1980; Singh, 1982; Nasiruddin et al., 1982; Kupkanchankul et al., 1982) and duration (Haque, 1974) of submergence; while increased with age of seedling at the time of submergence (Haque, 1974; Hasanuzzaman, 1974; Pande et al., 1979).

4. Nutrient content at various growth stages in rice plant

Submergence/waterlogging also affect the absorption of nutrients in rice crop by means of changing the status and balance of nutrients in the flooded soil solution. Due to change in chemistry of soil by waterlogging, the
availability of nutrients is altered in the soil, which ultimately hampered their absorption by the rice plant.

Takahashi et al. (1955) found rapid absorption of NPK at tillering stage and during elongation period the absorption of N and K was reduced but phosphorus and manganese increased remarkably. There was also found the variation of nutrient absorption in relation to their growth duration in early, medium and late varieties (Tanaka, 1957). Shapiro (1958) observed that flooding increases the grain yield through higher phosphorus and nitrogen uptake by rice plant. Ali and Morachan (1963) reported high nitrogen and phosphorus content in IR-8 and IR-20 rice varieties under flooded soil condition. Mehrotra et al. (1968) also reported higher nitrogen and phosphorus uptake in cereals during tillering stage than other stages. Nitrogen content in the rice plant just after establishment determines the ear bearing tillers and at reproductive and heading stage, determines the number of spikelets per panicle and sterility percentage respectively (Matsushima, 1964). Tanaka (1964) again observed more nitrogen uptake during early growth stage in Peta than Tainan-3 but reduced later in Peta while in Tainan-3 its uptake continued. Patnaik and Nanda (1969) noticed that the nitrogen and phosphorus absorption in high yielding rice varieties was high from planting to flowering stage whereas potassium absorption was high from flowering to dough stage. Rai (1974) reported higher
concentration of total nitrogen in submerged rice plants than normal ones.

Shapiro (1958) found that the availability of phosphorus in the soil was increased, whereas no apparent effect on availability of nitrogen was noted by flooding soil. He also observed that the utilization efficiency of these elements was increased under flooded condition. Similar results were found by Datta and Shinde (1965). Ota and Yamada (1960) observed that the Eh and pH of the reduced soil is always lower than the normal soil and these values depend upon the iron content of the soil. The lower Eh and pH affect the availability and uptake of nutrients especially nitrogen, phosphorus, potassium, iron and manganese. Nitrogen and K₂O content in the plant increased under high iron status of the soil whereas the absorption of phosphorus drastically reduced. Iron toxicity in the plant was recorded in the form of Akagara disease. Sankaram (1969) also found higher phosphorus absorption under flooded soil than nonflooded but its availability in the soil depends upon the reduction intensity and iron content of the soil. Recently Bora and Goswami (1980) reported 3-4 times more phosphorus uptake under submerged than non-submerged soil. The uptake under flooded condition was maximum at tillering stage, while it continued up to ripening stage under unflooded soil.
Clark et al. (1957) observed higher iron and lower manganese absorption by the rice plant under flooded than nonflooded soil. The Mn content in the plant grown under submerged condition for 74 days were high, ranging from 800-3300 ppm. The cultures grown under low land produced more yield when accompanied by high Mn uptake (more than ten fold of that of upland rice). He also stated that rice is exceptional crop and has high tolerance capacity against Mn. Baba and Tajima (1960) reported that higher availability of ferrous ions under flooded soil reduced the level of protein nitrogen, starch and sugar and increased non-protein nitrogen content of the rice plant. However, Weeraratna (1969) reported higher absorption of Mn and dry matter production in rice plant under flooded soil. Tanaka et al. (1966) stated that iron toxicity increased in rice plant under flooded soil because of high uptake of ferrous ions in the root. The entrance of ferrous iron into the root increased because of reduced rooting activity under flooded soil, due to production of H₂S and butyric acid in the soil, which oxidize the ferrous ions into ferric ions on the root surface. Charien et al. (1968) observed that in flooded soil, rice seedlings produced more foliage growth and absorbed more phosphorus and manganese but less Ca and Mg than in non-flooded soil.

Jugsujinda and Patrick (1977) reported that the absorption of nutrients was severely affected by the pH of
soil. Under anaerobic condition of the soil at pH 5, the uptake of iron was higher than aerobic condition with pH more than 5. He again observed that the uptake of iron was lower under aerobic condition because of low solubility of iron. Thus the uptake of Fe and Mn decreased with increase in pH above 5-8 under aerobic condition. Phosphorus uptake was also found higher under lower than higher pH of the soil.

5. Physiological characters of rice plant

Occurrence of anaerobic condition as a result of submergence or waterlogging, brings the plant under oxygen stress situation. Under stress condition, rice plant modify its normal physiological behaviour for the existence. Plant and agrophysiologists proposed various physiological mechanism to explain the tolerance capacity of rice plant under oxygen deficiency stress situation. Erygin (1936) for the first time observed anaerobic respiration in rice plant and found R.Q. values for barley, upland and lowland rice were 1.40, 3.80 and 4.50 respectively. Tayler (1942) observed superiority of rice plant in germination and growth under low oxygen concentration than wheat and suggested that rice plant possesses efficient fermentation mechanism and tolerance against ethyl alcohol (end product of fermentation). Okajima and Kimura (1952) supported these results with similar findings. Yamada (1959) reported that the internal content of oxygen is
reduced in rice plant when it is submerged, due to insufficient oxygen supply to the plant. Crawford (1967) reported that plant species whose growth was reduced under flooding, produced large amount of ethanol and showed higher alcohol dehydrogenase activity in roots, whereas the plant whose growth was not adversely affected by flooding did not increase their ethanol concentration and also there was no induction of ADH activity during anaerobic condition of flooding. Vorobev and Aleshin (1979) stated that the death of rice seedlings in flooded soil is associated with accumulation of toxic level of ethanol by higher ADH activity during alcohol fermentation.

The other mechanism of survival of rice plant under oxygen stress situation was that the methane (end product of anaerobic decomposition) is converted into CO₂ by the anaerobic bacteria, which is utilized by hydrophytes or algae and liberate molecular oxygen, which is utilized by the higher plants during respiration (Harrison and Iyer, 1913).

Rice plant itself passed the oxygen downward (Vlamis and Davis, 1944). It has ability to transport oxygen from its aerial parts to the root zone through its ventilating system in stem and root (Roalte, 1944). He get similar concentration of oxygen in air channel of root cortex under normal and reduced conditions but after removing the shoot and sealing with wax, the O₂ concentration was dropped
immediately. Lin (1946) and Aimi (1960) confirmed the necessity of O\textsubscript{2} by the rice root transported through air spaces from leaves. Rapid internal diffusion of O\textsubscript{2} from the foliage parts to roots was also confirmed through \textsuperscript{15}O tracer technique by Barber et al. (1962). Arikado (1959) observed that the rate of O\textsubscript{2} transport from aerial to root portion of rice plant increased with the progress of plant growth up to primordial initiation and after this stage to maturity the rate of O\textsubscript{2} transport declined due to reduction in the active green leaf area. He further stated that the ventilating system in upland rice was found less than lowland rice.

The secretion of oxygen from the rice root was first demonstrated by Roalte (1941, 1944) and Mitsui (1955). Dai (1952) reported stronger oxidizing power of rice root than other cereals. Mitsui et al. (1962) further proposed a mechanism of O\textsubscript{2} liberation by rice roots through glycolate respiratory pathway. The root oxidising power of younger rice seedlings was found superior to that of older ones, because of higher nutritional status of younger seedlings (Okajima, 1960). The rooting activity of rice plants reduced with age of plant due to increase in the number of older roots (Mitsui and Tensho, 1952; Okajima, 1960; Ota, 1970).

Armstrong (1969) found more oxygen flux from the root of Norin varieties, which showed high resistant
capacity to waterlogged conditions. Ota and Nakayama (1970) and Nishiyama et al. (1980) found improvement in germination of rice seeds coated with calcium peroxide ($\text{CaO}_2$) under submerged condition. The oxygen release character of rice roots was recently proved by putting the rice plant in ferrous sulphate solution, which altered the oxidation reduction potential by changing the ferrous into ferric ions in solution (Yanatori, 1981). Mazaredo and Vergara (1982) reported higher rooting activity in submergence tolerant rice seedlings than susceptible ones. They also observed the reduction in rooting activity under submergence, but the reduction was found much lower in tolerant than susceptible ones.

A drastic reduction in respiratory and photosynthetic rate was observed after submerging the rice plant under water. After three days of submergence there was reduction of 70 and 50 per cent in respiratory and photosynthetic rate respectively (Yamada and Ota, 1951). Very recently Mazaredo and Vergara (1982) observed higher respiratory rate in submergence tolerant varieties than susceptible ones after 6 days of complete submergence of 10 days old rice seedlings. They also reported lower reduction in photosynthesis in tolerant than susceptible ones under submergence treatment. When the rice plant was submerged under water, sugars such as reducing as well as non-reducing both were used rapidly, while the acid hydrolysable polysaccharides including starch and hemicellulose
were also reduced to some extent while protein hydrolysis was inhibited due to deficiency of $O_2$. The soluble nitrogen fraction increased soon after flooding the plants, reached to a peak and then decreased (Yamada et al., 1954, 1955). Submergence of rice plant induced reduction in total available carbohydrate content of plant (Palada and Vergara, 1972). Yamaguchi (1973c) critically reviewed the concentration of carbohydrate and nitrogen fractions in floating and non-floating rices under ordinary and deep water condition. Under ordinary conditions, the content and concentration of reducing and non-reducing sugars were higher and that of crude starch lower in floating rice than in non-floating rice. However, the content of reducing sugars (RS) was high in floating rice under submergence when the raising water level was slow and remained constant at further increase in the rate of raising water level as compared to the ordinary condition. In the non-floating rice, the content of RS dropped remarkably when the rate of raising water was rapid. It is further reported that the content and concentration of non-reducing sugar and crude starch decreased under submerged condition, but the rate of reduction was lower in floating than in non-floating rices. The content of protein nitrogen in non-floating rice was reduced; while in floating rice its content increased under submergence. However, the concentration of protein nitrogen got reduced in both type of rice under submergence. Both the content
and concentration of total and soluble nitrogen was reduced in non-floating rice while no appreciable change was seen in floating rice. The concentration of soluble nitrogen increased markedly in non-floating than floating rice. Among the different plant parts leaf sheath and internode were affected more than leaf blade and the ratio of NPN to TPN was found higher in non-floating than floating rice under submergence. Rai and Murty (1976) reported that the contents of sugars and chlorophyll were reduced under submergence in rice seedlings, but the reduction percentage was much lower in tolerant (NC 1281) than susceptible culture (IR 8 and Jagannath).

Yamaguchi and Sato (1963) reported that floating rice varieties had no higher content of carbohydrate but showed higher amylase and invertase activity than non-floating ones. These evidence may suggest that there is the latent ability for the vigorous elongation of floating rice. The activity of catalase and cytochrome oxidase in rice seedling was higher under anaerobic than aerobic condition, whereas the peroxidase activity showed almost similar trend under both condition and these catalase and peroxidase activity showed some relation with coleoptile elongation (Ito and Hayashi, 1961). Activity of rice root was reduced under submergence due to production of hydrogen sulphide and butyric acid under same condition (Tanaka et al., 1966, 1968). Arikado (1967) surmised that the rice
plant can perform almost normal respiration and nutrient absorption even under poorly oxygenated medium, so far as no substance harmful to respiration is present, because the rice root can receive enough molecular oxygen to sustain aerobic respiration from the top through the well developed ventilating system. The reduction of sugars and starch content in rice seedlings with duration of submergence have been reported by Palada and Vergara (1972).

Submergence treatment of rice plant for 6 days reduced the activity of nitrate reductase, ribulose biphosphate carboxylase and respiratory rate (Rai and Murty, 1976, 1979, 1980). Rai and Murty (1980) reported the reduction of total phenols by 19% in leaf blade after 6 days of submergence, whereas in leaf sheath the concentration of phenols increased by 43 and 78 per cent after 3 and 6 days of submergence respectively.

The major physiological change induced by submergence was the accumulation of ethylene in the submerged plant. Ethylene accumulation in root and shoot of sunflower subjected to partial submergence was observed by Kawase (1974). It is pointed out that the concentration of ethylene increased in plant if the water was not drained and exhibited flood damage symptoms as hypertrophy of hypocotyl, new root formation from hypocotyl, leaf epinasty (droopy) and chlorosis of leaf. Very recently, Tang and Kozlowski (1982) reported the acceleration of ethylene production by the stem of plantanus accidentalis during
flooding for 40 days.

Other physiological change in plant subjected to submergence is modification in the concentration of growth hormones in the plant tissue. Evidence is available regarding increase in the length of plant by means of increasing the concentration of growth promoter i.e. indole acetic acid and gibberellic acid under submergence (Kramer, 1951; Jant Waidt and Hagan, 1957). Although the mechanism involved in the action of auxin is still doubt, the auxin content in the plant is clearly related to the survival power of rice plant under waterlogged situations. Carr (1961) suggested that estimation of mesocotyl elongation under waterlogged condition permit identification of varieties tolerant to oxygen stress conditions. Keeford (1962) observed that the deficient oxygen concentration to the rice seedlings increases the cellular concentration of phenolic inhibitor of IAA oxidase, which in turn increases the IAA concentration in the cells and auxin induced plant height.

The other view of plant elongation under submergence may be due to increase in the concentration of IAA as a result of less the loss of IAA through photo-oxidation under low light intensity in the submerged crop canopy. Another view of plant elongation under submergence/waterlogging may be due to increase in gibberellic acid synthesis in low light intensity under submergence (light inhibition of GA; Lockhart, 1961), because the light intensity under
submergence is reduced (Westlake, 1966; Palada and Vergara, 1972). Murty and Murty (1981) reported high concentration of GA in shaded plant than in normal ones. In view of inter-relationship between auxin and GA in plant growth, effect of deficient aeration of tissue may ultimately be linked to high gibberellic acid and its influence on extension growth.

6. **Anatomical characters of rice plant**

Besides changes in morphology of rice plant, some anatomical changes are also brought by the submergence/waterlogging. Parija (1941) for the first time reported the development of schlerenchymatous tissue in leaf sheath of rice plant during submergence for longer period. Basu et al. (1970) observed significant difference in relation to structural changes in rice plant when subjected to lower water depth irrespective of varieties. They observed increase in air cavity size and diameter of cortical cells, with phloem thickness remain constant, and metaxylem size decreased under higher water depth. Roy (1972) observed, no change in the number of Vascular bundles in the culm, reduction in the number of parenchyma layer and development of prominent air cavity under waterlogged condition. Datta and Banerjee (1974) observed hydrophytic nature of rice plant in deep water condition and found significant difference in structural changes between submerged and normal field condition. Irrespective of varieties, number, length and diameter of internode,
number and diameter of air sac, diameter of lumen, thickness of stem and diameter of cortical cells were found remarkably larger in respect to the plant under deep water than under normal field condition. They also observed the presence of air sac up to 16-17th internode of rice plant under deep water condition, whereas, it was present only up to 4-7th internode under normal field condition. The size of air sac increased by 3-4 times under deep water to that under normal condition, which enable the plant to float and utilize air for tissue respiration under deep water condition (Datta and Banarjee, 1974). Maurya (1978) reported that the cultures which showed high resistance to intermittent flooding had thick sclerenchymatous hypodermis layer with lignified cells, profused starch granules in the cortical cells and additional sclerenchymatous band around vascular bundles. The presence of 26-32 air spaces in the first internode of deep water rice varieties viz., CR 63G, IR 442-2-58 and Leb Mue. Nahn 111 except BKN 6986 was reported by IRRI (1979). The diameter of air space in these four cultivars was twice than that of ordinary cvs. The greater occurrence of air space in deep water cultivars was considered to enrich O2 transport from aerial parts to submerged plant parts (ventilation system) (IRRI, 1979). Plant tolerance to excess water depends upon the root porosity and length (Peter et al., 1969). The maximum value of root porosity was found to be 26-30% for rice and 7-11% for maize (Jensen et al., 1969).