The present investigations were conducted in field tanks and pots under simulated condition of excess water situations, at Central Rice Research Institute, Cuttack, during wet season (kharif) of 1980 and 1981. They were designed to find out the physiological basis of the tolerance of rice plant to partial (waterlogging)/complete submergence. The major findings involving the impact of excess water situations on the diverse parameters of growth and development, productive efficiency, nutrient status (N, P and Fe content), biochemical changes, stem anatomy and the pattern of endogenous growth regulators (IAA and GA) are briefly summarised below.

Partial submergence (waterlogging)

(1) The immediate effect of waterlogging, irrespective of the stature of the cultivars, was the rapid longitudinal growth of the plant accompanied by the culm elongation due to early extension growth of the basal internodes, especially the second one. In comparison to semi-tall, Jagannath, the plant height at each growth stage from vegetative to harvest was found to be higher in the tails like CR 1030, FR 13A, IET 6205 etc., though the former had the highest elongation coefficient. The tails, on the other hand were found to be more tolerant to waterlogging than the semi-tall Jagannath referred above.
(2) All cultivars irrespective of their stature (tall or semi-tall) were found to be affected by appreciable reduction of tillers, due to mortality of some tillers under waterlogging and also impaired production of new ones. The gradual decline in the number of tillers was mostly apparent up to 45 days of submergence (70 DAP). Tiller reduction, the most adverse effect of waterlogging, was however, found to be the highest in the semi-tall Jagannath, especially at the highest water depth (55-60 cm).

Almost similar to the pattern of impaired tillering, reduced dry matter/m² (about 50% of the normal plants) and also crop growth rate (CGR) under waterlogging were observed up to 70 days after planting (DAP) or 45 days of submergence treatment. However, in comparison to normal plants, waterlogged plants showed enhanced production of dry matter and CGR, subsequent to 70 DAP. Regarding these two traits, the most adversely affected cultivar was the semi-tall Jagannath. Among the talls, enhanced dry matter production after 70 DAP was found to be marked in cvs. Janaki (C 64-117) and IET 6205. Waterlogging did not impair CGR of C 64-117 even at initial stages of submergence, while it had very little impact on cvs. IET 6207, IET 6205 and CR 1030 at this growth stage.

Within three weeks of the submergence treatment, the leaf area index (LAI) under waterlogging was reduced by 69%. While leaf area (LA) and dry weight (D.Wt)/tiller decreased by only 58 and 12 per cent respectively
in comparison to normal plants. Thereafter, the difference between the normal and waterlogged plants, with respect to those characters narrowed down even in the most vulnerable semi-tall Jagannath, due to subsequent near normal growth under waterlogging. Comparatively less reduction of those characters in tall at the initial stage of submergence and appreciable increase, especially of the LA and D.Wt./tiller afterwards, appeared to be responsible for higher tolerance capacity of tall cultivars to waterlogging.

(3) Though the average reduction of grain yield even at the highest water depth of 55-60 cm was found to be only 20%, the decline among the cultivars ranged from 4-65 per cent. In IET 6205, C 64-117 and CN 643, the grain yield was even found to be higher than the normal plants. The grain yield of the semi-tall Jagannath, which was at par with that of the best tall under normal situation declined considerably (by 65%) under waterlogging resulting in very low yield of only 0.9 tons/ha. under waterlogging. IET 6205 and CR 1030 were found to be the highest yielders among the tall recording grain yields of 2.5 and 2.4 tons/ha respectively.

Relatively less average reduction of grain yield (by 20%) in comparison to 30% reduction of panicle number, was found to be mainly due to increase (by 24%) in grain number/panicle under waterlogging. Grain yield under waterlogging was found to be highly associated with LAI
(r = 0.79***) and total dry matter/m² (r = 0.765***) at flowering and number of panicles/m² (r = 0.778**) at harvest. The high grain yield of IET 6205, C 64-117 and CN 643 under waterlogging was associated with greater LAI, TDM/m² and grains/panicle.

(4) Nitrogen content was higher in waterlogged than in normal plants, particularly in semi-tall Jagannath, after 20 days of submergence. Although protein nitrogen in the cultivars was also higher under waterlogged treatment, a greater portion of the total nitrogen was in non-protein form, especially in cultivar Jagannath. High total and protein nitrogen under waterlogging contributed to increased leaf chlorophyll as observed under the present study, while high soluble nitrogen, which is toxic to plant induced high tiller mortality.

Phosphorus and iron contents were also higher in waterlogged plants, especially in the susceptible semi-tall type Jagannath. High stem phosphorus might precipitate excess iron, which otherwise could have exerted toxic effect. On the otherhand, high iron content is likely to be responsible for predominance of soluble nitrogen and reduced carbohydrate content in the waterlogged plants.

The percentage of total leaf chlorophyll, as well as the fractions 'a' and 'b' was found to be higher under waterlogging, which might have resulted from high leaf nitrogen content.
All the fractions of carbohydrate (starch, non-reducing and reducing sugars) were reduced in the cultivars after 20 days of submergence. In short statured Jagannath, the impaired carbohydrate metabolism continued even up to 45 days (70 DAP) of submergence. Thereafter, the carbohydrate fractions in the cultivars increased rapidly in the waterlogged plants. Increased dry matter production in the plants actually occurred at this growth stage as a result of higher carbohydrate production. Higher carbohydrate status might have contributed to the production of enhanced number of spikelets and grains/panicle in the waterlogged plants.

(5) Waterlogging induced increased biosynthesis of endogenous auxin (IAA), almost at similar levels in the stem of both tall (IET 6205) and semi-tall (Jagannath) cultivars. This was found to be accompanied by the reduced activity of IAA-oxidase. GA concentration increased especially in the semi-tall Jagannath.

Exogenous spray of GA and IAA alone or in combination, prior to submergence treatment, remarkably increased grain yield particularly in short statured Jagannath. However, application appreciably increased plant height prior to submergence and also number of panicles and grains/panicle at harvest resulting in enhancement of grain yield.
(6) Internodes of the waterlogged plants, in general, were of the higher diameter. Anatomical observations on the cross section of the internodes indicated reduction in the thickness of ground tissue, particularly in cvs. Jagannath and FR 13A. However, thickness of the ground tissue and the number of vascular bundles were found to be higher in tolerant cv. IET 6205. Area of the air cavities, the possible route for the passage of ambient oxygen to root increased under waterlogging, as evidenced by the anatomical study and the determination of stem porosity. The increase, however, was found to be the highest in cv. Jagannath followed by CR 1030 and FR 13A.

Prolonged duration of submergence and increase in water depth impaired the oxygen excretion power of the root and also the activity of enzymes catalase and peroxidase, ascribed to be involved in the mechanism of oxygen release by the root. The greater decline of oxygen release or reduced enzymatic activity in the roots of short statured Jagannáth and CR 1009 probably indicates their poor performance due to decreased oxygen in the rhizosphere.

Impact of seedling age on the complete submergence for different duration

(1) Remarkable increase of seedling height (6-93% more than the normal seedlings) took place within 5 days of submergence, mostly by the fast extension growth of the
leaf sheath (125-217%). The final length of the seedlings was higher in the proven submergence tolerant cultivars, which were normally taller than the susceptible cultivars at the initial stage of submergence. In the seedlings of all age group (15, 30 and 45 days) prolonged submergence treatment declined the initial rapid elongation rate. Although the dry weight of the submerged seedlings of any age group at a particular interval of submergence was much less than the corresponding normal seedlings; it was normally found to be higher than that prior to submergence treatment, indicating thereby continued dry matter production even under submergence. The dry matter production, however, was much less in the seedlings of 15 days old, which practically succumbed after 15 days of submergence.

(2) The per cent survival of the seedlings markedly improved with the increased age of the seedlings, even though appreciable decrease was noticed with prolonged submergence treatment. The initial as well as final length of seedlings/leaf sheath and dry weight/seedling had high positive association with survival rate of seedlings after 10 and 15 days of submergence.

(3) In pot experiment seedlings of 30, 45 and 60 days old with respect to nine promising cultivars were submerged for a period of 15 days. Highest survival was recorded in seedlings of 60 days old. Such aged seedlings submerged at early growth stages recorded higher
grain yield as well as dry matter at harvest. The higher grain yield was found to be mainly due to more panicle number/pot and also grain number/panicle.

(4) Total nitrogen in the submerged seedlings was higher than the normal ones even after five days of submergence. The difference was found to widen, particularly in the susceptible Jagannath on prolongation of the treatment. Much less protein nitrogen in the submerged seedlings, on the other hand indicated the presence of large quantity of soluble nitrogen, the factor considered as harmful for the growth of the rice plant.

Carbohydrate fractions (sugars and starch) in the seedlings, prior to submergence treatment gradually declined with advancing duration of submergence. The decline, however, was found to be the highest in the short statured Jagannath. Aged seedlings (45 days old) had higher carbohydrate content both prior to and after the submergence treatment.

From the results, the following general conclusions may be drawn on the tolerance of rice plant to partial/complete submergence.

(i) Maintenance of optimum plant height by elongation ability, higher tiller and panicle number/m² more dry matter/m² at flowering, optimum leaf area index, high leaf area and dry matter/tiller and more grains/panicle as seen in the cvs. IET 6205, CR 1030, IET 6207
etc. under waterlogging are desirable parameters for tolerance to waterlogged situations.

Keeping up the rhizosphere relatively oxidative by excretion of oxygen through the root, maintaining optimum level of nitrogen, phosphorus and iron and high carbohydrate in the shoot are also desirable for proper growth and development under waterlogging.

For improved plant type under waterlogging, it is desirable to combine the traits of high tiller number and low tiller mortality as in CR 1030, with heavy panicle weight of cvs. like IET 6205.

(ii) Tall statured cultivars and aged seedlings are more tolerant to complete submergence, because of their greater initial height, dry matter and carbohydrate content before submergence and also higher protein nitrogen content after the submergence treatment.

Since complete submergence of the seedlings of 45 days old for 15 days showed considerable differences in survival rate among the cultivars (12-90%), the technique can be used as a rapid selection criteria for assessing tolerance to early submergence by rice varieties.