# INTRODUCTION

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1. INTRODUCTION

1.1. Development of Cereal Agriculture

In the past 3 to 4 decades, there have been dramatic increases in the yield of grain crops throughout the world. Mackey (1982) has reviewed the situation in the major grain producing countries of the world, where the average yield of grains per unit land area has been very high and found that from the year 1950, the yield has increased almost steadily with time up to 1980 in rice (Japan), wheat (U.S.A. and Netherlands), barley (World average) and maize (World average). The situation in a developing country like India, has been also much encouraging. Agricultural economy has been the backbone of India, as nearly half of the gross national product is generated in agriculture and more than half of all consumer expenditure is for food—(Mellor 1976). In the year 1950-51, the total food grain production in India was a meagre 55.9 million tonnes, which rose to 155.3 million tonnes in 1984-85 (Goud, 1986) and stabilized thereafter till now (1986-87) with no further increase. During this period, the gross national product of the country increased at an average of 3.5% per annum (the rise in G.N.P. in 1986-87 has been 5%—All India Radio News broadcast on 06 06 1987), whereas the rate of population growth was about 2.2% (Ghosh 1987). These remarkable achievements in increasing the yield of grains in food crops have been possible due to the innovative research conducted in
the use of plant breeding, uses of chemicals as fertilizers, pesticides and insecticides, irrigation and water management techniques. In India, the adoption of these novel production technologies, has been the backbone of the success of green revolution.

1.2. Scope for increasing productivity

With so many achievements made in agricultural production throughout most of the countries of the world, one should feel satisfied and happy. However, there is no room for complacency. Economic surveys have revealed that, biological demand for food has not been expressed in the consumption of food due to the poor economic conditions of small and marginal farmers and landless labourers leading to periodical starvation (Dogra 1985). Ms Joan Holms, Global Executive Director of Hunger Project, in her Live Aid Global broadcast for ending hunger reported (The Telegraph, Calcutta dated 30.5.1987) that as many as 750 million people in the world go to bed hungry every night due to want of food. These horrifying reports have been the consequences of inclement weather conditions prevailing in certain developing countries of the world (such as drought in Kalahandi (India) and Ethiopia in the years 1985 to 1987). The increase in prices of the petroleum products has also contributed much to the misery of the poor people by increasing cost of transportation for distribution of food grains. Therefore despite
the recent success of the green revolution, another quantum jump in the yield of grains has been necessary.

There has been wide gap in between the potential and the actual yield of grains in different cereal crops. The average grain yield obtained from different grain crops in the highly developed countries has been about 6 tonnes per hectare (rice - Japan, wheat - Netherlands, barley - Belgium and maize - U.S.A.), which has been far below that of the best national average (rice - 10 tonnes, wheat - 14 tonnes, barley - 11 tonnes and maize - 24 tonnes) (Wittmer 1975). The situation in rice, which has been the major cereal crop in India, has been more precarious. The national average yield has been 1.46 tonnes per hectare, whereas the potential yield calculated with available solar energy of 300 Cal. m$^{-2}$ day$^{-1}$ during the traditional wet season has been 12 tonnes per hectare (Venkateswara 1985). The report of IRRI (1978) also suggested that the average national yield in rice in India has not been more than 15% of the potential yield.

1.3. Importance of rice

Rice has been a major cereal crop of the world and as much as 40% of the total population use it as the primary source of food (De Datta and Mikkelsen 1985). The crop has been cultivated in 111 countries, spread over different continents of the world (De Datta 1981) and the total area under rice cultivation has been 145 million hec-
tates, consisting 11% of the arable lands of the world (Swaminathan 1984). However, the major rice growing areas of the world are located in the south and South East Asia, which are frequented by the monsoonal rainfall. Rice has been the only cereal crop which can be grown at different moisture regimes. The plant has an efficient system of air passage from the shoot to the root to tolerate flooding (Swaminathan 1984). Therefore it has been suitable for the low lying wet lands of Asia, which has a thick growth of population (De Datta, 1981). Apart from the wet land crop, several varieties of rice, are grown as upland crop - in a large number of countries, but the yield of grains has not been so high. In contrast to other cereals, rice plant is very sturdy and has high temperature tolerance (Indica variety). The traditional tall indica varieties require significantly less fertilizer for optimum growth. These qualities make it suitable for cultivation in the tropics, where temperature is high and heavy monsoonal rainfall depletes the essential mineral elements from the soil surface. The traditional varieties are also resistant to some diseases. In the field condition, its natural competitors are the weeds, which compete with the plant for light and nutrition. The plant has wide diversification of varieties and is adapted to different climatic and soil conditions of the tropical and temperate countries in between the latitudes 40° S and 50° N of the equator.
1.4. **Climatic factors and seasonal variation in the yield of grains.**

Climatic factors, such as rainfall, solar radiation, temperature and relative humidity influence rice crop. The crop is mostly cultivated twice in a year in the tropics, i.e., the wet cultivation and the dry cultivation. Sometimes, a third crop is raised in between the two, which is called the semi-drug cultivation. Rice, being a semi-aquatic plant, has large requirement of water, which is obtained from the atmospheric precipitation during the wet season or by irrigation during the dry season. The facilities of irrigation remaining largely confined to the developed or semi-developed countries, rice is mostly cultivated during the rainy season by adjusting the growth period of the crop to the period of rainfall.

After the primary requirement of the plant for water is satisfied, the other climatic factors determine the yield of grains at a particular locality. Chatterjee and Maiti (1981) stated that the average yield of grains of the crop increased with increase in distance of the location from the equator. The countries nearer to equator, were reported to have average grain yield of 560 to 1120 Kg per hectare, whereas, India, China and Egypt, lying between latitude 21 to 30°N had average yield ranging in between 1640 to 4898 Kg per hectare and the yield in Japan, Italy and Spain, lying at latitude over 30°N, was from 5209 to 6295...
Kg per hectare. Keeping aside the poor farming techniques used in the countries nearer to the equator, the high temperature during day and night coupled with poor incidence of solar radiation in the wet season has been primarily responsible for the low yield of grains (De Datta 1981).

When irrigation water is available, rice is cultivated in the dry season, but in this case adjustment to favourable temperature has been necessary. In the tropics, the dry cultivation is initiated during the winter months and harvesting is done in the summer. During the winter months the temperature generally does not go below 13°C and the crop is not affected by any low temperature stress in the tropics. In Japan, which remains within the temperate zone, the irrigated cultivation starts in the spring season, when the temperature remains in between 13°C to 20°C and the plants are harvested in the autumn before the temperature recedes below 13°C (Yoshida 1981). The japonica rice varieties, which prefer the cooler environment of the temperate region are used for cultivation in Japan, in contrast to the temperature loving indica varieties of the tropical countries.

In India, rice occupies nearly 40% of the land area under cereal cultivation, which has been countrywise the biggest in the world. It ranks second in the world in total production of rice grains (Chatterjee and Maiti 1981). However, the average grain production per hectare has been
one of the lowest in the world. The average yield of grains has not been uniform throughout the country and sharp differences exist in between the states located in various parts of the country due to variations in climatic conditions, irrigation facilities and agricultural investments. About 60% of the rice growing regions of the country (1986-87 data) being rainfed, the wet season has been the main cultivating season for the crop. During this season, especially in between the months of July and September, the eastern part of the country (consisting the major rice growing area) is subjected to unfavourable agroclimatic conditions in the form of occasional drought, flooding and low solar radiation due to the cloudy condition of the sky (Murty and Venkateswarlu 1978). The Eastern part consists of the states of U.P. (eastern part), Bihar, Orissa, West Bengal, Tripura, Assam, and the hill states where the average yield of grains per hectare has been much below that of the national average (Table 14). In the year 1986-87, the national target of 160 million tonnes of food grains was not achieved due to natural calamities and the situation in 1987-88 is going to be worse than that of the previous year due to the unprecedented drought. The yield of grains in the states like Punjab, Haryana, Andhra Pradesh and Tamil Nadu has been much higher than that of the national average, because of better irrigation facilities and high investment in the crop. The poor socio-economic conditions of the farmers in the eastern
Table 1.1. - Area of production and yield of rice and consumption of fertilizers in some States of India (1981-82).

<table>
<thead>
<tr>
<th>State</th>
<th>Area (1000 ha)</th>
<th>Production (1000 tons)</th>
<th>Yield (Kg ha(^{-1}))</th>
<th>Nutrient Consumption (Kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>3 824</td>
<td>7 868</td>
<td>2 050</td>
<td>50</td>
</tr>
<tr>
<td>Assam</td>
<td>2 259</td>
<td>2 236</td>
<td>989</td>
<td>3</td>
</tr>
<tr>
<td>Bihar</td>
<td>5 368</td>
<td>4 257</td>
<td>793</td>
<td>18</td>
</tr>
<tr>
<td>Gujarat</td>
<td>499</td>
<td>737</td>
<td>1 477</td>
<td>39</td>
</tr>
<tr>
<td>Haryana</td>
<td>506</td>
<td>1 250</td>
<td>2 470</td>
<td>46</td>
</tr>
<tr>
<td>Karnataka</td>
<td>1 168</td>
<td>2 384</td>
<td>2 041</td>
<td>34</td>
</tr>
<tr>
<td>Kerala</td>
<td>807</td>
<td>1 340</td>
<td>1 660</td>
<td>33</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>4 850</td>
<td>3 830</td>
<td>789</td>
<td>11</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>1 515</td>
<td>2 435</td>
<td>1 607</td>
<td>27</td>
</tr>
<tr>
<td>Orissa</td>
<td>4 159</td>
<td>3 853</td>
<td>925</td>
<td>10</td>
</tr>
<tr>
<td>Punjab</td>
<td>1 270</td>
<td>3 755</td>
<td>2 956</td>
<td>124</td>
</tr>
<tr>
<td>Tamilnadu</td>
<td>2 467</td>
<td>5 607</td>
<td>2 272</td>
<td>67</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>5 389</td>
<td>5 898</td>
<td>1 094</td>
<td>52</td>
</tr>
<tr>
<td>West Bengal</td>
<td>5 210</td>
<td>5 832</td>
<td>1 119</td>
<td>33</td>
</tr>
<tr>
<td>All India</td>
<td>40 708</td>
<td>53 248</td>
<td>1 308</td>
<td>35</td>
</tr>
</tbody>
</table>

part of India has inhibited high input in the crop, in the form of irrigation, fertilizers and pesticides or usage of modern farming techniques. It has been observed by Ghosh (1987) that there has been negligible improvement in production of food grain crops in the eastern part of India in the recent years, although the population growth has increased at par with rest of the country. Therefore, a decline in rural income in this part has been forecast (Rath, 1986).

1.5. Major yield constraints

1.5.1. Irrigation

The gap between potential and average farm yield can be reduced by manipulation of some of the environmental factors influencing the growth and development of the plant. In the field conditions crop growth should be adjusted to rainfall pattern and suitable temperature regime. However to escape from severities of drought condition due to the erratic rainfall, irrigation water has been most essential. Herdt and Barker (1977) published a list of the factors that influence crop growth and yield in rice and suggested that the depth of water in the field to be the most important determinant of grain yield. Without the support of irrigation, water management in the form of maintenance of appropriate depth of water can never be done. Therefore irrigation assumes greater importance than other environmental factors and there has been attempts in developing countries to bring more rice growing areas under irrigation to increase produ-
ctivity (Swaminathan 1984). Adequate water treatment of the plant ensures proper utilization of the chemical fertilizers applied to the basal medium of the plant (the chemical transformations of the fertilizers have been described in the next chapter). The crop uses too much water as transpiration losses are considered very high in comparison to other cereals. In the wetland condition, a shallow submergence of the soil has been considered essential for growth and development of the plant (De Datta 1981). Statistics collected by various international agencies (De Datta 1981) have also emphasized adequate water management to be the most essential factor in achieving high yield of grains in the tropical countries. The average national yield of various countries in south and South East Asia, has been closely related to the irrigation rate (Colombo et al 1977).

Lack of irrigation facilities has been the major constraint for optimum yield of grains in the eastern part of India. Sen Committee (1984) found that, institutional, technological and economic reasons obstructed agricultural growth in this area and recommended massive investment for improvement of irrigation, water management and drainage of water for increasing productivity per hectare and per cultivator in this region. The national commission on agriculture of Government of India (1976) has also suggested extension of irrigation facilities in this area to achieve a national average of 3.04 tonnes per hectare by 2000 A.D. (Arakeri 1981).
1.5.2. Fertilizers

Rice is grown in different ecological conditions of the world and growth of the plant in these conditions has been possible due to the variation in the physico-chemical properties of the soil (Mahapatra et al. 1985). These authors (Mahapatra et al. 1985) further proposed that, water being the primary requirement for the growth of the plant, grain yield is possible in presence of adequate supply of water in any of the soil type, but optimum yield can be achieved only when there is proper management of water and soil conditions. De Datta (1981) compared the yield gap in between the farmer's field and experimental plots with high inputs of fertilizer, insecticide and weed control in six Asian countries and revealed that fertilizer management was the most crucial factor in determining grain yield in the dry season and in the wet season it was of identical importance with the insect control.

With the introduction of high yielding varieties of rice, the demand for commercial fertilizers has increased in several folds. The semidwarf high yielding rice varieties respond to fertilizer treatment better than the traditional tall varieties and the yield of grains has been enhanced significantly. However, the escalation of fertilizer prices, due to the global crisis for energy, has induced agronomical and physiological research for efficient
use of fertilizers to minimize the cost of investment. Therefore, Graswell and De Datta (1980) emphasized the need for identification of the right stage of plant development for fertilizer application and discouraged treatment throughout the whole life cycle of the plant to rationalize the use of these sparsely available resources.

The rice growing soils are broadly classified into two types, upland and lowland soils. In both these conditions, the soil is supplemented with nitrogen, phosphorus and potassium to increase the yield of grains. The modern varieties of rice, remove a substantial amount of these elements from the soil during growth and the soil gets depleted. To replenish the stock, the soil is supplemented with the fertilizers before cultivation.

Out of the inputs required for the cultivation of the rice crop, fertilizer has been the most expensive. The poor socio-economic conditions of the small and marginal farmers and lack of institutional facilities in the eastern part of India has therefore substantially inhibited the extensive use of the fertilizers for increasing the yield of grains and the overall grain yield in India has been unsatisfactory. The demand for fertilizers has been very high as the average soil condition in the country has been poor in major essential elements. Mahapatra et al (1985) observed that out of millions of samples tested, a vast
majority was found to be poor in nitrogen and phosphorus. In comparison to the nitrogen and phosphorus, the potassium deficiency was moderate and nearly 40% of the land area was reported to have high concentration of the element.

1.5.2.1. **Nitrogen**

Nitrogen deficiency occurs in almost all parts of the world and therefore supplementation has been most essential. Rice plant has high demand for nitrogen, but the recovery of the element in the plant has been poor (De Datta et al 1968, Craswell and Vlek 1979). Substantial amount of the fertilizer applied to the field is lost through the processes of leaching, volatisation, surface run off, denitrification and immobilisation (Mahapatra et al 1985, De Datta et al 1974 Savant and De Datta 1982). Therefore, a number of experiments have been done in both low land and upland conditions about the method of fertilizer treatment of the soil and plant to minimize the loss. The rice plant can absorb nitrogen in the form of ammonia, nitrate, urea and amino acids. In the submerged condition of the tropical low lands, it is usually taken up in the form of ammonia, whereas in the upland condition nitrogen is preferred in the form of nitrate ion (Yoshida 1981).

In the tropical low lands of Asia, a number of methods are adopted to increase the nitrogen use efficiency of the crop. Apart from the identification of proper stage
for fertilizer application, good water management, deep placement of urea and controlled release and slow release nitrogen fertilization are necessary (De Datta 1986). Nitrogen is mostly applied to the soil in the form of urea (Stangel 1979) and placed deep in the soil at the time of puddling to minimize loss in transformation. Recently Craswell et al (1985) experimented upon different forms of modified urea products in order to compare utilization and loss of the element in the low land condition of Philippines and suggested that urea can be used as sulphur coated urea (SCU), urea supergranules (USG) and sulphur coated urea supergranules - (SCUSG). It has been estimated that quantitatively about four million tonnes of nitrogen fertilizers are applied to rice to increase production of food grains (Martinez and Diamond 1982, Koyama et al 1977).

1.5.2.2. Phosphorus

Phosphorus is taken up by the plants in the form of phosphate anion, $H_2PO_4^-$, $HPO_4^{2-}$ or $PO_4^{3-}$. Oxidised phosphorus compounds are absolutely necessary for the plant as it has been a component to ATP, NADP, nucleic acids and proteins. Phosphorus deficiency occurs in the soil with high or low pH. Millions of hectares of rice soils in the tropics have been reported to be deficient in phosphorus (De Datta 1983). To supplement the soil, phosphorus is applied in combination with calcium, as mono, di or tri substituted calcium phosphate. Like nitrogen, the nature of water regime of the soil also determines the availability of phosphate
ion to the roots of the plant. In the low land condition, submergence creates a reducing atmosphere due to deficiency of oxygen in the soil. In the reducing condition, the ferric phosphate is reduced to ferrous phosphate which is soluble in soil water. In the soluble condition, the phosphate ion is displaced by organic anions and becomes available for absorption by the roots (Ponnamperuma 1965). The high yielding rice varieties have large requirement for phosphorus. Its removal has been as large as 14.6 Kg P per hectare in the wet season (De Datta and Gomez 1982) and the demand has been expected to be more than this in the dry season (De Datta et al 1980) as the yield of grains is higher in this season. Therefore it has been necessary to find out a method for rational utilization of the element.

1.5.2.3. Potassium

In addition to nitrogen and phosphorus, the modern high yielding varieties of rice also require application of large amount of potassium (De Datta and Gomez 1982). In a low land rice crop in Philippines, producing 9.8 tonnes of grains per hectare in 115 days, the total uptake was found to be 219 Kg of N, 31 Kg of P and 258 Kg of K (De Datta and Mikkelsen 1985). However, in comparison to nitrogen and phosphorus its response on the yield of grains is low (Mahapatra and Panda 1972). Excepting a few cases in the low land conditions, the soil is generally not deficient in
potassium. However, considering the high requirement of the element for vegetative growth of the plant, the soil is supplemented with potassium in the form of muriate of potash. Potassic fertilizers are readily soluble in water and potassium is easily absorbed in the form of K⁺. After application to the soil, the cation is exchangeably adsorbed to the soil particle and not easily available to the roots unless displaced. Soil submergence creates a reducing atmosphere due to deficiency of oxygen and soluble ferrous and manganous ions displace the potassium ion and increase its availability in the soil solution (De Datta and Gomez 1982).

1.6. **Physiological approach to increase productivity**

Development of high yielding indica varieties of rice by exploitation of hybrid vigour was mainly responsible for the break through in the green revolution of late sixties and seventies (Swaminathan 1984). The stiff strawed, non-lodging, photo insensitive, semidwarf varieties with erect leaves were highly responsive to the treatment of fertilizers. The morphological design of the plant was conducive for efficient interception light energy (erect leaves) and transport of photosynthetic assimilates from the source (leaves) to the sink (panicles) without much hindrance (non-lodging character). Apart from these, the most important factor, which has been the major determinant of the high grain yield of the plant, is the increased efficiency
for partitioning of dry matter from the vegetative parts to the reproductive parts.

As has been discussed previously, the cultivation of the high yielding varieties has increased the yield of grains from the plant significantly but the gap between average and potential yield is still very high, due to the adverse ecological conditions in many of the tropical countries. To keep pace with the rise in population growth Swaminathan (1984) has proposed effective dissemination of modern technology and agronomic advances throughout the rice growing areas of the world, which has not been possible so far due to various reasons. In this connection alleviation of the yield constraints in the growing medium by bringing more area under irrigation and better fertilizer management has been given high priority. However, even in the areas of advanced agronomy, the grain yield has been stable over the last couple of years, as it has been in the states of Punjab and Haryana in India. Also it has been absolutely difficult to manage agronomical conditions in the field on a large scale to achieve 100% yield potential for the plant. Therefore physiological research has been most essential to break the yield barrier in the areas of advanced agronomy and to suggest method to increase yield in those areas frequented by ecological stresses (Murty, 1986).

There are two possibilities to improve the yield of grains from the plant by the manipulation of physiological
characters. The first is to improve the photosynthetic efficiency of the plant to increase the total assimilation and growth. Majority of the plant physiologists believe that the crop productivity can be increased by increasing efficiency of photosynthesis through the manipulation of processes of light harvesting, carbon assimilation, photorespiration and translocation of the assimilates (Bassham, 1977, Coombs 1984). The second view is to give more emphasis on the process of partitioning of higher quantities of assimilates from the vegetative to the reproductive parts. It is believed that the gross photosynthesis of the plant has always been in far more excess than the capacity to produce grains resulting in extra vegetative growth unrelated to the yield of grains. Therefore increasing the photosynthetic efficiency of the leaf (source) may not necessarily enhance translocation of dry matter to the reproductive parts and may be used in alternative sink, such as the unproductive tillers. It may also be possible that the extra assimilates produced by increased efficiency of the source may not be consumed in the reproductive parts with poor sink activity and may precipitate in feedback inhibition of the source activity. In contrast to this, high sink activity disproportionate to the source, may lead to premature senescence of the source. Thus, Yoshida (1981) has concluded that more attempts be made to understand and control the mechanism of partitioning of assimilates in
between the vegetative and reproductive parts in order to maintain a perfect balance between the two for optimum yield of grains. In view of this, the physiological control of inflorescence growth in rice should be studied properly.

Finding out methods of improving yield in unfavorable physico-chemical environment has been a big problem. In the field-condition no effective control can be made on the climatic factors and varieties must be screened for important physiological characters helpful in the survival of the plant in the presence of the stress. The wide spectrum of the traditional rice varieties adapted to the physico-chemical stresses of the locality can be used for this purpose. However, losses incurred due to inefficient management of the soil fertility and water can be very high (Boyar 1982). Therefore, it has been necessary that a rational method for use of these materials be found out.
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