PTIMIZATION OF AGRONOMIC RESOURCES FOR MAXIMIZING GRAIN AND MILL YIELD OF RICE

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This thesis entitled " Optimization of agronomic resources for maximizing grain and mill yield of rice " is submitted by Shri Kannan Mukundan to the Indian Institute of Technology, Kharagpur, for the award of the degree of Doctor of Philosophy in Agronomy. The experiments described in the thesis are the record of bonafide research work conducted by him under our supervision. Shri Kannan Mukundan has worked for his thesis for more than four years, and the thesis is, in our opinion, worthy of consideration for the award of the degree of Doctor of Philosophy in accordance with the regulations of the Institute. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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CHAPTER I.

INTRODUCTION

The importance of rice, the major cereal food for nearly three fourths of the country's population, need not be over emphasized. Water and soil fertility are the important determinants of productivity in rice farming, and nitrogen and phosphate are known to be two of the major important constituents of soil fertility. Judicious use of these agronomic resources holds the key to possible increase in the yield potential of the crop and thereby the profit of the farmer.

Aims for richer harvest by adoption of scientific methods in crop production need to include quality of the produce as much as its quantity. Production of high quality paddy is imperative to realise quality rice after processing. Quality in rice involves, among other characters, fully developed grains. Any production practice, therefore, which can minimize susceptibility of grain to sun checks and maximize head rice on processing would be very desirable. The production practices to be considered for high outturn of quality rice include timely planting, water and fertility management and harvesting of the crop at a suitable grain moisture content.

The right time of harvesting is directly linked with the maturity and ripening of the grains. Even today, the farmers in our country decide maturity of the crop only by visual judgement, involving appearance of golden yellow colour of the panicle. This may result in delayed harvesting of the crop having grain moisture ranging from 19 - 15 per cent. Recent investigations seem to show that there are considerable losses in field due to shattering of the grain and damage by birds and rodents. Further, there is reduction in milling outturn when the harvesting is delayed and the grain is allowed to dry in the field. On the other hand, timely harvest of the crop helps in reducing the field losses and provides opportunity for field preparation and timely sowing of the subsequent crop. This is an important factor in multiple cropping for efficient land utilisation and high cropping intensity.

The time of harvest for rice could be identified based on the number of days after heading/flowering or on the grain moisture content at harvest. The latter criterion appears to be more practicable and appropriate, since the physical manifestations indicating moisture content of the grain vary from variety to variety (Wikramanayake and Wimberly, 1975). However, it would be desirable to consider the moisture content of the grain with a conventional index, like number of days after heading/flowering, to give an appropriate idea of the maturity of the crop so as to ascertain and facilitate timely harvesting.

The post harvest milling process includes removal of hull and polishing, which may be done in one operation by using huller or by improved procedure of shelling and polishing separately. The different by-products like husk, bran and brokens can thus be separated for economic and industrial uses, in addition to bringing out the desired quality of rice. The bran oil obtained from the rice bran may be used for edible purposes and the deoiled bran may be used as a valuable animal feed. The husk is utilized for making hard panel boards, particle boards and as fuel. The brokens which include protein-rich germs are highly nutritious and can be used in certain food preparations like idly and also used in the brewing industry.

The market value of paddy, when sold immediately after harvest is less remunerative compared to selling it as milled rice. Moreover, the values of by-products are seldom included in economic assessment. Hence, the economic evaluation of these by-products along with that of milled rice is essential in judging the actual value of the total produce.

As already stated, the yield of milled rice and the by-products are considerably influenced by the inputs like variety, water, fertility, plant protection and management. It is useful, therefore, to study their interaction effects as well. Further, inspite of a suitable management practice, it is a problem to produce quality paddy in 'aman' (Kharif) season due to climatic limitations. In addition to this, information on economic evaluation of by-products is also scanty. Hence, a systematic investigation was planned during the problem period, that is during 'aman' (Kharif), with the following objectives,

(i) to identify the effect of major inputs - fertiliser, water and management - on grain yield and milling quality,

(ii) to optimize the above factors for augmenting production for quality paddy and rice,

(iii) to evaluate the economic viability of the inputs in production and processing of rice, and

(iv) to identify a suitable variety under specific management of production and processing.

CHAPTER II.

REVIEW OF LITERATURE

Rice yield as well as milling quality are well known to be influenced by agronomic factors such as fertiliser, water and grain moisture at harvest. Further, the net return from a rice crop depends on proper management of resources at an optimum level. The available literature pertaining to the said aspects is, therefore, reviewed in brief under the following heads.

I. Effect of nitrogen, phosphate, water and grain moisture at harvest on yield and yield attributes.

II. Effect of fertiliser and grain moisture at harvest on mill yield.

III. Economic evaluation of inputs.

Effect of Nitrogen :

Among the major essential nutrient elements, nitrogen has received more attention in rice cultivation. Many fertilizer experiments in various rice growing areas have demonstratedthe variable response to nitrogen application due to different soil type, climatic conditions, water management practices and like factors. Positive response to nitrogen application has been reported by several workers of the country and abroad.

<u>Grain yield</u> Increase in grain yield of dwarf indica has been reported by Chandler (1966), Padhi and Misra (1968), Bathkal and Patil (1970), Bhaskaran (1970) and Rego (1973). Kumara and Takeda (1962) observed that under low level of nitrogen, grain yield was increased remarkably with the increment in nitrogen though the rate of increase in yield diminished with increase in the supply of nitrogen.

Regarding response of rice varieties to different levels of nitrogen, Chowdhry *et al*. (1969) found that there was no significant difference among the varieties Taichung Native 1, IR 8 and Kaushung. However, Padhi and Misra (1968) noticed marked differences in the response among different cultivars to various levels of nitrogen. Biswas and Chowdhury (1971) worked out the grain yield per kilogramme of nitrogen for different varieties. They found that all the varieties showed maximum response at lowest level of fertilization. Each kilogramme of nitrogen addition increased about 10 - 12 kg of grain in Taichung Native 1 and Ponlai varieties. Varieties - IR 8, Padma and IR 262 gave about 10 - 14 kg of grain per kg of nitrogen at 50 kg N/ha. They noted that the efficiency of grain production per kilogramme of nitrogen declined sharply at higher level of nitrogen applications.

Variation in nitrogen response was also noted due to growing season of the crop. It has been reported that the optimum nitrogen level was far high in dry season than in wet season (Tanaka *et al.* 1964; De Datta *et al.*; 1968; Lenka 1969; Anon 1970; Kanwar and Mahapatra 1971; Mahapatra and Leelavati 1971; Tandon, 1971 and Sinha *et al.*, 1973).

Yield attributes   Oshima (1962) reported significant increase in tiller production in the early stages of growth due to nitrogen application. Similar results were also reported by De Datta *et al.* (1966), Bathkal and Patil (1968) and Varma (1974).

Lenka (1969) observed that nitrogen addition increased the number of panicles and the number of grains per panicle. Pande and Singh (1970), Place *et al.* (1970), Ishizuka (1971) and Koyama *et al.* (1973) also reported ~~the~~ similar observations. Tanaka *et al.* (1964) indicated that the number of spikelets per panicle and percentage of grains decreased with high nitrogen application and mutual shading of leaves. It was further opined (Tanaka, 1972) that, with heavy nitrogen application, even though many tillers and panicle primordia per unit land area were produced, number of spikelets per panicle would be less, since there were many sinks as compared to the capacity of the source.

Increase in grain weight due to more nitrogen supply was reported by Kumara (1957). Ghosh *et al.* (1971) observed that thousand grain weight of rice varieties showed appreciable increase over the control at 50 kg N and thereafter, the increase in weight was marginal and did not show much variation.

(from 100 - 150 kg N) in all the 15 varieties studied. Bollich and Miers (1959) found that the nitrogen levels were inversely related to thousand grain weight, the weight decreased with increase in Nitrogen. However, they found this relation was slight and did not apply to all varieties. Baba (1961) emphasized that plants produced grain number per unit area only to the extent of availability of carbohydrate, hence thousand grain weight did not increase with nitrogen dressing. Whereas, Ghosh et al. (1971) observed decrease in thousand grain weight at higher levels of nitrogen.

Effect of Phosphorus :

The role of phosphorus in fertilizing rice was not properly understood till recently. Although reports are available on the response of phosphorus application to rice, ~~but~~ the magnitude of its response is much lower than that of nitrogen (Kalam et al., 1966). Moreover, positive response was obtained when phosphorus was applied with other elements like nitrogen.

Grain yield Significant increase in yield has been reported by Mariakulandai (1957), Moolani and Sood (1967). While Mahapatra (1961) reported no response to phosphorus by eight indica varieties during the main season, Russel (1961) suggested that an excess of phosphorus over the actual requirement may depress crop yields.

Yield attributes   It has been reported by Srinivasulu and Pawar (1965) that phosphorus has no significant influence on the number of tillers, length of panicle, percentage of filled grains and the yield of grain and straw.

Srinivasulu and Pawar (1965) observed no significant influence on the weight of thousand grains by phosphorus. Similar results were also noted by Reddy (1967) and Gately (1968).

No effect of phosphorus on panicle length and number of grains per panicle was observed by Suseelan (1969) and Place et al. (1970).

Effect of Water Management Practices :

Rice is known to favour a submerged soil condition and reported to have very high water requirement. However, there are differences in opinion about the suitable depth of submergence and variation in depth have been attributed to the difference in the degree of tolerance among the rice varieties and the season in general.

Grain yield   Nojima et al. (1962), Nojima and Tanaka (1967) and Chandramohan (1970), recorded a high grain yield from 5 cm submerged plots. Singh and Singh (1966) also observed that dry matter production was maximum under 5 cm depth. Bhatia and Dastane (1971) indicated that a depth upto 4 cm seemed to be optimum for high yielding dwarf varieties. Satyanarayana and Childyal (1970) have observed that plants grown under flooded conditions produced best shoot growth and higher grain yield. The findings of Hall and Jackett (1968), Pande and Mittra (1969 and 1970) Naphade and Childyal (1971) were also similar.

Dastane *et al.* (1970) stressed the importance of shallow submergence on the growth and yield of rice. According to them, the standing water, 0 – 4 cm was adequate for high yielding dwarf varieties. Deeper submergence was found to be an unnecessary and wasteful practice. Pillai (1958) concluded that maintenance of 5.08 cm standing water with frequent change by fresh water resulted in highest rice production. Ghosh *et al.* (1960) stressed the beneficial effect of intermittent irrigation by giving small quantities of water at frequent intervals. Tanaka *et al.* (1965) concluded that when rainfall is adequate and evenly distributed, continuous submergence was always not necessary for rice cultivation. Moolani and Sood (1967) reported that application of frequent light irrigations at field capacity to keep the soil moist all the time gave highest paddy yield, and the excessive depth of water on land did not influence the transpiration and yield. Similar observation was made by Nojima and Tanaka (1967). Hatta (1967) observed that the yields were similar in continuous flooding and intermittent irrigation plots. De Datta (1970) emphasised that continuously saturated soil supplied enough moisture to rice crop and gave yield equal to that obtained from a continuously submerged plot. Mane and Dastane (1971) and Rao (1971) did not get any difference between 0 to 4 cm depth of submergence and saturation to 0.5 atmospheric tension under shallow ground water table conditions. Childyal (1971) opined that water use by rice crop depended not only upon soil water regime and plant growth phases, but also on the environmental conditions and evaporative demand. Under situations of medium evaporative demand, the yield obtained under saturation was almost on par with that of flooded condition. Saturation appeared to be significantly superior to flooding when evaporative demand of the atmosphere was low. Similar results were reported by Yadav (1970-71) from the results of co-ordinated projects on water management and salinity at Kharagpur.

Yield attributes The number of tillers decreased with the increase in depth of submergence has been reported by Pande and Singh (1969) and Lenka (1971). Nojima et al. (1962) recorded more tillers, less panicles, less dry matter per hill in water logged soil with no standing water than 5 cm submergence. Similar effect on tillering was also obtained by Lenka (1971). Pande and Singh (1969) reported that yield was adversely affected in the absence of standing water. Limited moisture supply caused reduction in leaf area, number of effective tillers and ratio of sound to unsound grains.

<u>Water requirement</u>   Rice has higher water requirement than any other cereal crop of similar duration, because the crop is grown mostly under submerged field condition.

The water requirement of rice has been reported by different workers. Narasingha Rao (1951) observed that the water requirement of rice was 102 cm whereas, Vamadevan and Dastane (1967) reported it to the extent of 168 cm . According to Kung <u>et</u> <u>al</u>. (1965) the water requirement of rice ranged from 80 to 120 cm with the extremes of 52 cm and 255 cm in a crop season depending upon the agroclimatic conditions of the locality and duration of the crop.

The water requirement in the submerged field condition increases because of the continuous positive hydraulic head over the soil surface, resulting in the increased hydrostatic pressure gradients, leading to increased losses of water through percolation. Catambe <u>et</u> <u>al</u>. (1959) showed that under 5, 10, 15 and 20 cm depths of submergence, the total water requirement was 110, 192, 230 and 240 cm respectively for the entire growth period. Choudhury and Pande (1969) reported that the water requirement was 257, 129 and 162 cm under continuous submergence, alternate wetting - drying and alternate wetting - drying plus 5 - 8 cm deep flooding during flowering respectively.

Sahu and Rout (1969) reported that the low-land rice gave maximum yield when the soil was kept submerged with 15 cm water. The quantity of water used from transplanting to harvest was 1560 mm under submergence, 812 mm under field capacity and 200 mm at 75 per cent available soil moisture, while Chandramohan (1970) observed that the total water requirement of rice ranged between 935 mm to 2650 mm for different varieties and seasons for the soil and climatic conditions of Coimbatore, Tamil Nadu.

Effect of Grain Moisture at Harvest :

In determining the optimum time of harvest, for shattering loss, grain yield, milling quality, and seed quality should all be considered as these factors were important to the farmers. Returns per hectare depend on both the quantity and quality of the product harvested. Seed quality is important since Indian farmers wish to use part of the harvested crop for seed. Ideally, therefore, transplanted rice should be harvested when it will give the highest grain yield, with maximum milling and seed qualities.

Grain yield   Malabuyoc *et al.* (1966) reported that no significant differences in grain yield were observed when transplanted rice was harvested in the wet season at 20,25,30 and 35 days after heading. Bhole *et al.* (1970) observed that optimum harvest moisture content for ADT-27 variety in Kuruvai season was between 20 to 23 per cent at which average field yield of 3,475 kg/ha was obtained. The yield was reduced to an average of

2,730 kg/ha when the crop was harvested at 10 per cent grain moisture content. The percentage reduction in field yield due to field losses was 25 per cent. During Kuruvai season the optimum harvest moisture content for the cultivar IR-8 was found to lie between 21 to 24 per cent. The average field yield at optimum harvest moisture level was 6,740 kg/ha was reduced to 5,550 kg/ha when the crop was harvested at 15 per cent moisture content. The per cent reduction in field yield was 21.6 per cent.

Nangju and Datta (1970) observed that maximum grain yield occurred between 28 and 38 DAH (days after heading) in the dry season. They opined maximum grain yield, head rice, and germination percentage to be obtained when the transplanted rice was harvested between 28 and 34 DAH during the dry season. During this period, the moisture content of the grain was between 19 and 22 per cent. The optimum time of harvest in the wet season was between 32 and 38 DAH. During this period, the moisture contents of the grain were between 18 and 21 per cent. Govindaswami (1972) reported that ADT 27 rice variety could be safely harvested between 20 to 25 days after flowering without any reduction in the field yield and total milling yield. While Seetanun and De Datta (1973) observed that the grain yield was highest when the crop was harvested between 30 and 42 DAH during the wet season and 28 and 34 DAH in the dry season. The period of 28 to 36 days after flowering was found to be an optimum harvest period for ~~the~~ Jaya variety in Aman season (Anon., 1973). For IR 22 rice, highest field yield was obtained when it was harvested 26 DAH in Aman season (Anon., 1975).

Shedding or shattering of grain from the panicles at the time of harvest is one of the factors contributing to loss of yield in rice. It is important in areas where rice is extensively cultivated and when the harvesting extends over long periods. The loss due to shattering is likely to be greater in an over ripe crop. A rice crop subjected to alternate heat in day and heavy dew in the night also gave increased amount of shattering (Ramiah and Rao, 1953). Apart from this, the shattering is also a varietal characteristic as reported by Shrinivasan and Balasubramanian (1959). They observed that fine and slender grain varieties, displayed shattering to a greater degree than coarse grain ones.

Milling Quality of Rice :

The milling quality of rice is based on the yield of head rice obtained, because it is usually the milled product having greatest monetary value. Yields of head rice vary widely, depending on variety, grain type, cultural methods and other environmental factors, and drying, storing and milling conditions. The yield of total milled kernels (head rice and all sizes of broken kernels) is important too, and this yield is influenced by the proportion of hulls and the amount of fine particles of broken kernels unavoidably included in the bran fraction during the milling process (Anon., 1966).

Effect of fertilizers   Rhind (1962) reported that nitrogen fertilizers have an adverse effect on the milling quality of rice while Koster (1959) observed that no specific effects. Bollich and Miears (1959) observed highly significant differences in total milled rice existed among varieties within maturity groups but not among nitrogen levels. No interactions were significant. In 1960 they found a slight inverse relation between per cent total milled rice and nitrogen level for the average of all varieties where the three lowest nitrogen levels produced slightly higher yields than the three highest levels. On variety basis, ignoring maturity groups, an inverse relation between total mill yield and nitrogen level was observed in some of the varieties, while other varieties did not show any consistent relation between the total mill yield and nitrogen levels.

Miears and Harell (1959) reported that lowest head rice per cent was obtained from the plots which did not receive any application of nitrogen. The difference between the lowest, 62 per cent, and highest 65 per cent, was so small that very little emphasis could be placed on the effect of nitrogen on the milling quality with reference to head rice. They opined that the milling quality might have been indirectly affected by the nitrogen application, as the crop was delayed in maturity and might have been at a more optimum moisture content at the time of harvest. Similar observations were made by Ghosh et al. (1971). At Rice Experiment Station Corwley(Anon., 1960), it has been observed that the average head rice per cent for all the varieties showed no consistent relation to nitrogen levels. The head rice yield of Lacrosse increased with levels of nitrogen through the 90 kg/ha level, and decreased at higher levels. Nangju and De Datta (1970) found that when the nitrogen level was increased from 0 to 150 kg/ha,an increase of about 7 per cent in head rice was obtained in the Chalky varieties IR 8, IR 5 and 'Peta' and practically no increase in head rice over the no-nitrogen control was observed in the non-chalky varieties.

Miears and Narell (1959) observed that phosphorus and potash applications had no measurable effect on the milling quality of rice. It was found that the moisture at the time of harvest was significantly higher in the rice from those plots which did not received any application of phosphorus. Even though the lowest total mill yield and head yield were obtained from those plots which did not receive phosphorus, the difference when compared with the milling yield, from those plots receiving phosphorus, were not significant (Anon., 1960).

Effect of grain moisture at harvest   Henderson (1954) reported that reduction of head rice yield at later harvest dates was caused by the alternate wetting and drying of the grains, which caused sun checking. McNeal, (1950) and Kester (1959) opined that optimum time of harvest depends on the varieties cultivated and the prevailing local climatic conditions. Faulkner (1967) and Halick (1960) observed that a variety which ripened under lower temperatures, generally produced higher head yields than that which ripened under higher temperatures.

Govindaswami and Ghosh (1969) opined that moisture content of the grain was the major factor which was responsible for the breakages in rice. They reported that the moisture content of paddy between 18 to 23 per cent at 27 to 39 days after flowering was the most desired time for head yield recovery. Tenhave (1963) and Huysman (1965) also reported 18 to 23 per cent as optimum moisture for best milling yield. They noticed varietal difference in the case of total milled rice in relation to time of harvest. In all the five varieties examined by them, it was found that the yield of total milled rice increased very slightly with harvest time. They have also observed that the total milled rice was found to increase by an average of 0.05 per cent per day from 24th day to 36th day after flowering. Bhole et al. (1970) reported that head rice yield recovery was 64 per cent when harvesting was made at 24.2 per cent harvest moisture content and only 55 per cent recovery at 15 per cent harvest moisture content. Mangju and Datta (1970) observed that maximum head rice was obtained between 24 and 34 days after heading, and between 32 and 38 days after heading in the dry and wet seasons, respectively. The corresponding moisture contents of the grains during these optimum stages were between 19 and 25 per cent for the dry season and between 18 and 21 per cent for the wet season. Harvesting outside these optimum periods resulted in significant head rice losses due to either under-ripening or over-ripening of the grains. Govindaswami (1972) reported that rice varieties, harvested at an early stage from 27 to 33 days and 33 to 39 days for late varieties gave higher recovery of unbroken kernels. Seetanun and De Datta (1973) observed in both dry and wet seasons the bushel weight and the germination percentage were increased to about 22 days after heading and ~~the~~ remained constant throughout the later harvests. The maximum head rice percentage was obtained when the crop was harvested 26 and 42 days after heading (average of cultivars and nitrogen treatment). They suggested rice should be harvested between 30 and 42 days after heading in the wet season (moisture content 20 - 22 per cent) and 28 and 35 days after heading in the dry season (moisture content 18 - 21 per cent).

Economic Evaluation of Inputs :

The production function approach in analysing economic aspects of fertilizer use for rice is relatively a recent development in India. Some interesting studies have been made by various workers in and outside the country.

Herdt and Mellor (1964) reported contrasting response of rice to nitrogen by using the data of a large number of experimental trials on various levels of nitrogen in the State of Texas and Arkansas in the U.S. and the States of Orissa and West Bengal in India. They estimated that the optimum level of nitrogen application were 122 kg, 124 kg, 33 kg and 35 kg per hectare for Arkansas, Texas, Orissa and West Bengal. The corresponding rates of return on total cost at these optimum levels were 305, 217, 86 and 35 per cent.

Abraham (1965) reported the optimum fertilizer requirements of different crops by using the data of the fertilizer trials conducted by ICAR on cultivators fields in various states of India. He fitted quadratic response curves and studied the response of nitrogen to paddy for different zones of India. It was observed that the response to nitrogen do not show appreciable difference among different zones of rice. He reported that optimum dose for nitrogen varied from 30 kg to 50 kg per acre in different regions. Maximum response was indicated in south zine. The optimum doses of P_2O_5 for rice were also estimated. The optimum doses were 50 kg, 30 kg, 35 kg and 35 kg per hectare for north-eastern, northern, central and southern zone respectively. These levels were some what lower than those of nitrogen. The author also calculated the net profit per hectare and percentage of profit on investment in fertilizer at the optimum level. Percentage of profit on investment in fertilizer was highest in souther zone. Per cent of profit on investment in nitrogen was much higher than the corresponding profit on investment in phosphorus.

Parikh (1965) fitted quadratic type of production function with the data on fertilizer trials of wheat and paddy conducted at Burdwan in West Bengal and Bhagwai in Madhya Pradesh. He computed the optimum units of N and P under various assumptions. He found that phosphatic fertilizers were not effective in increasing the response of paddy because the acid soils might have reacted unfavourably to phosphate.

Seth and Abrahamm (1965) worked out the quadratic response curve for N on different crops. They used the data of simple fertilizer experiments coverying most of the crops in about 170 districts in India. They found that the optimum N dressing for paddy was 44.5 kg per hectare and the percentage return per rupee invested at the optimum dose was 272.

Parikh (1966) attempted to measure the quantitative significance of chemical fertilizers in increasing the yield of various crops in few selected districts of the country where package programme was launched. Data of the demonstration programme carried out on cultivators plots were utilised for economic analysis. The rate of return for paddy grown in Thanjavur as "Samba" crop in 1962-63 Rs.2.46 per additional rupee invested while the corresponding figure for 1963-64 was Rs.0.79. In Sahabad district, the additional return on chemical fertilizer was Rs.0.86 per additional rupee invested on paddy during 1962-63. But for rabi 1963-64 the rate of return turned out to be Rs.2.22 per additional rupee invested. Inadequate rainfall is said to be one reason that might have led to such low rate of return on chemical fertilizers for paddy crops in the year 1962-63 kharif as compared to 1963-64.

Mukundan (1966) fitted Cobb-Douglas type to different levels of bullock labour and seeds and manure for irrigated and non-irrigated paddy in Kerala as given below.

The function for the irrigated farms :

$$Y = 241.51 X_1^{.58} X_2^{-.41}$$

Y = Gross return in rupees

X_1 = Bullock labour in pair day units

X_2 = Seeds and manures in rupees

The function for the non-irrigated farms :

$$Y = 177.69 X_1^{-0.046} X_2^{.52}$$

He inferred that the gross return can be increased by 0.58 per cent with an increase of 1 per cent in bullock labour in the irrigated holdings. As the elasticities of capital (seeds and manures) showed less than zero, the addition of these input resource would result in a decrease in the gross income of the farm. For non-irrigated farms, the gross returns can be increased by 0.52 per cent with an increase of 1 per cent in capital. The addition of bullock labour input would result in a decrease in the gross income in the non-irrigated farms.

Verma and Thakur (1968) derived the N response equations separately for each of the five different methods of transplanting from the pooled grain yield data of paddy for consecutive three years.

Singh et al. (1968) reported the economic analysis of the response of three varieties of paddy viz., IR-8, Tainan-3 and China-4 to various levels of N application. The quadratic production functions were developed for the three varieties separately. The values of R^2 were quite high (0.99) in all the cases. The study showed that IR-8 was highly responsive to higher levels of N application followed in order by Tainan-3 and China-4. At the most profitable levels of N application, net profit per hectare due to N application was also higher from IR-8 than other two varieties. However, net profit per kg. of N applied was the highest from Tainan-3.

Bose (1970) reported six different production functions from three field experiments. He obtained fourth order production function for rice as a best fit to the grain yield data when different levels of lime and ammonium sulphate were applied. He has also observed 1.3 power function, square root function, quadratic function and Mitscherlich - Spillman function as best fitted function for rice when different types of organic manures were used in combination with different levels of ammonium sulphate.

CHAPTER III.

MATERIALS AND METHODS

Four field experiments were conducted during 'aman' season (June-November) of 1972 and 1973 on a plot of Abhoy Ashram farm, Balarampur, about 3 km from the Institute. Through these experiments, the response of high yielding rice varieties to different levels of nitrogen, phosphate and water management practices was studied in order to find out the optimum level of each of the inputs for a particular variety. Studies were also made to find out the optimum grain moisture at which rice should be harvested in order to minimize field losses and increase the milling outturn of rice.

<u>Geographical location</u> The farm under reference is situated in the laterite belt of the south western region of the state of West Bengal, India. The place is intersected by 22° North latitude and 88° East longitude. The altitude is 44 m above M.S.L. and is about 115 km interior, westward, from the eastern sea coast of the Bay of Bengal.

<u>Climate</u> The region receives on an average 1300 to 1500 mm of rains per annum, eighty per cent of which is received during the monsoon from June to October. Data on daily

distribution of rainfall and the weekly averages of maximum and minimum temperatures, humidities, sunshine hours and wind velocity during the experimental period are depicted through Figures 3.1, 3.2, 3.3, 3.4 and 3.5.

<u>Soil</u> The soil is lateritic silty-clay-loam. The physical and chemical properties of the farm soil are given in Table 3.1.

The particle size distribution was determined by Pipette method (Kilmer and Alexander 1949). Maximum water holding capacity (Keen Raczkowski method), the permanent wilting percentage and field capacity were estimated by following the methods described by Piper (1942). The bulk density was calculated following the methods given in U.S.D.A. Hand Book No.60.

The pH of the soil was determined at 1:2.5 soil to water ratio using Toshniwal Universal pH meter. The cation exchange capacity was estimated by ammonium acetate (Schollenberger, 1927), the organic carbon content was found out by Walkley Black method, the total nitrogen of the soil was determined by modified Kjeldhal and total and available phosphorus by Trug and Meyer method. Total and available potassium and exchangeable calcium and magnesium were determined by flame photometric method (Chapman and Pratt, 1962). All the methods were followed as described in 'Soil Chemical

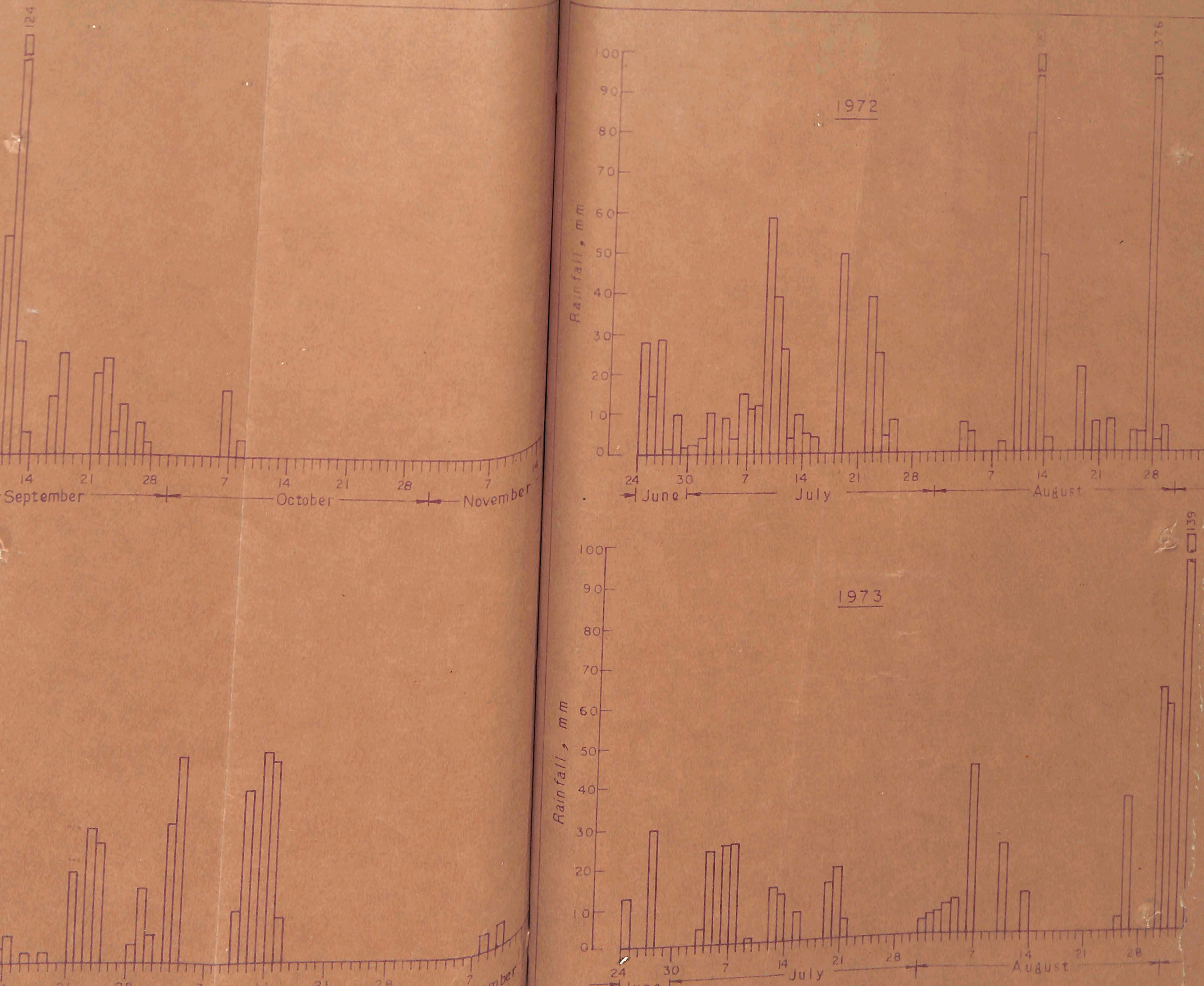


FIG. 3.1. DISTRIBUTION OF RAINFAL[L DURIN]G THE EXPERIMENTAL PERIODS.

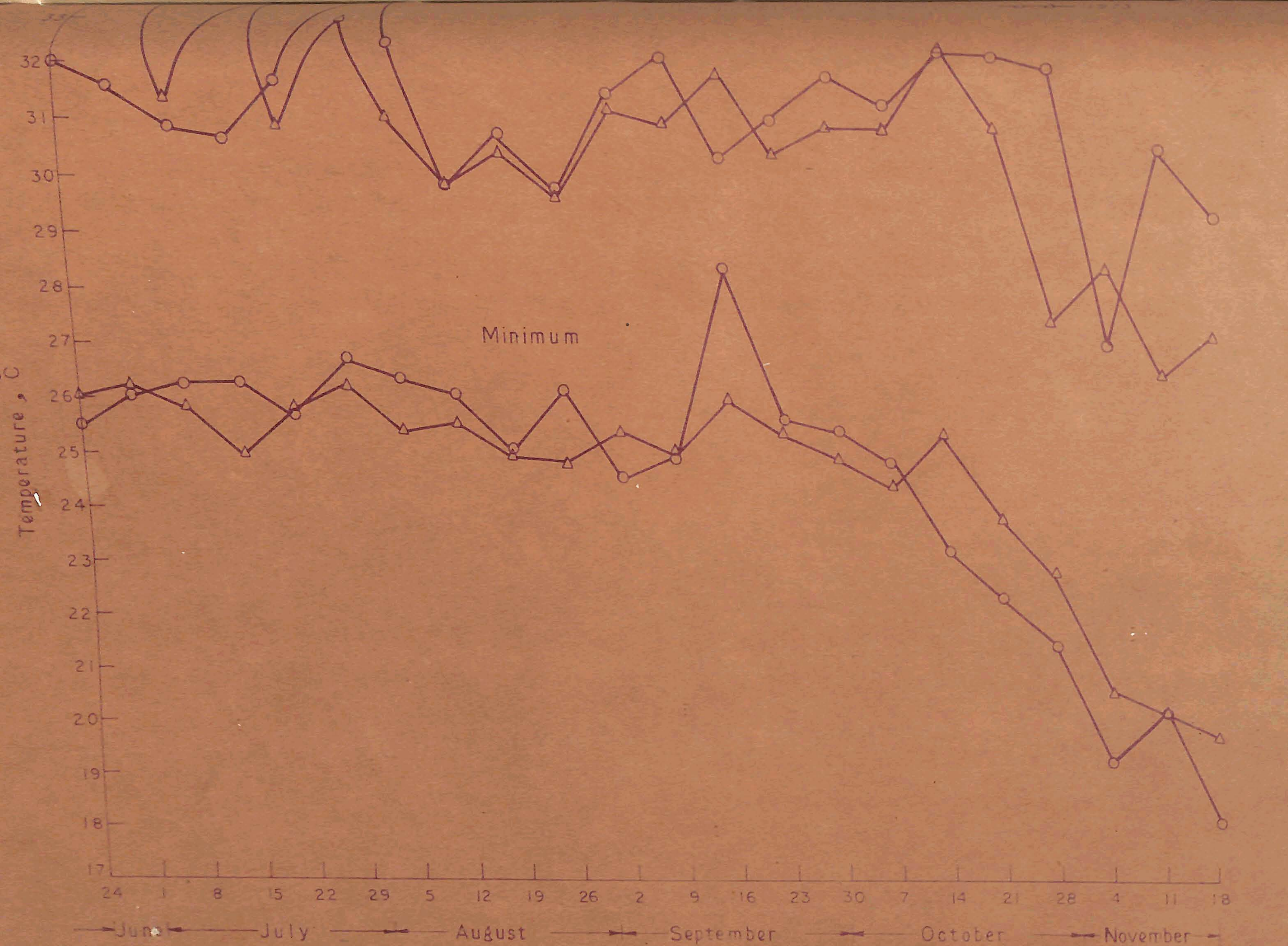


FIG. 3.2 VARIATION IN MAXIMUM AND MINIMUM TEMPERATURE DURING THE EXPERIMENTAL PERIODS.

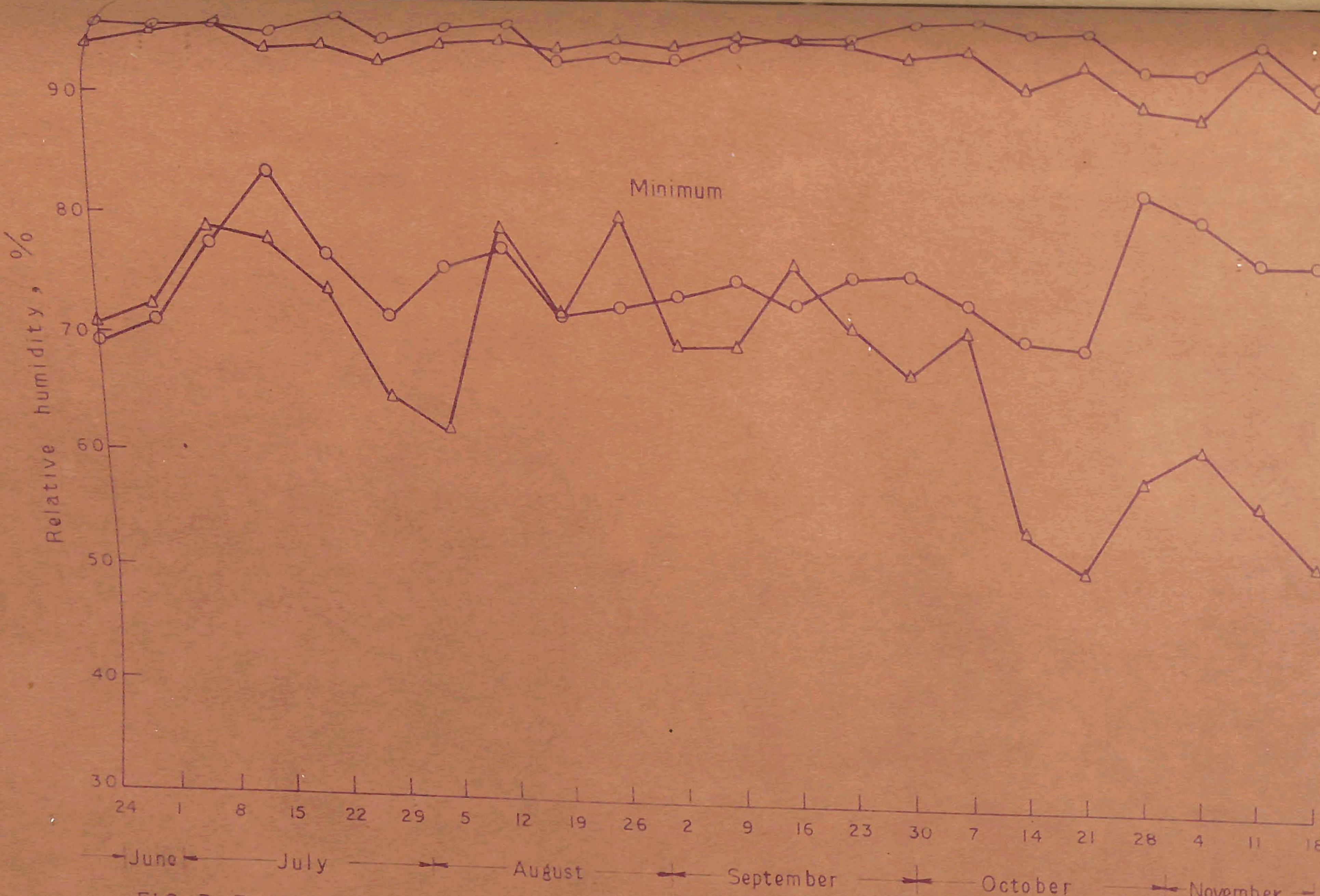


FIG. 3. 3. VARIATION IN MAXIMUM AND MINIMUM RELATIVE HUMIDITY DURING THE EXPERIMENTAL PERIODS.

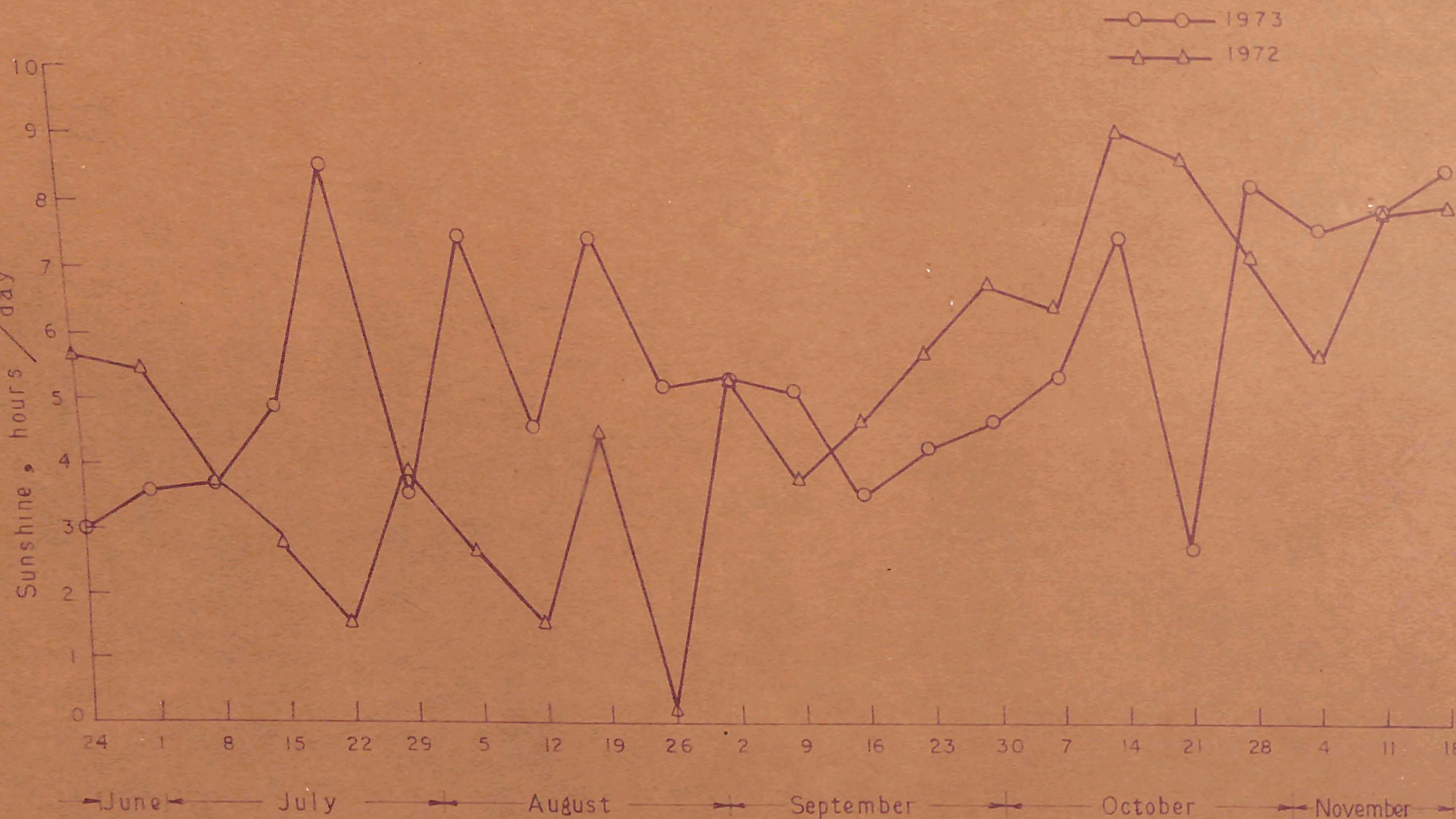


FIG.3.4. VARIATION IN BRIGHT SUNSHINE HOURS DURING THE EXPERIMENTAL PERIODS.

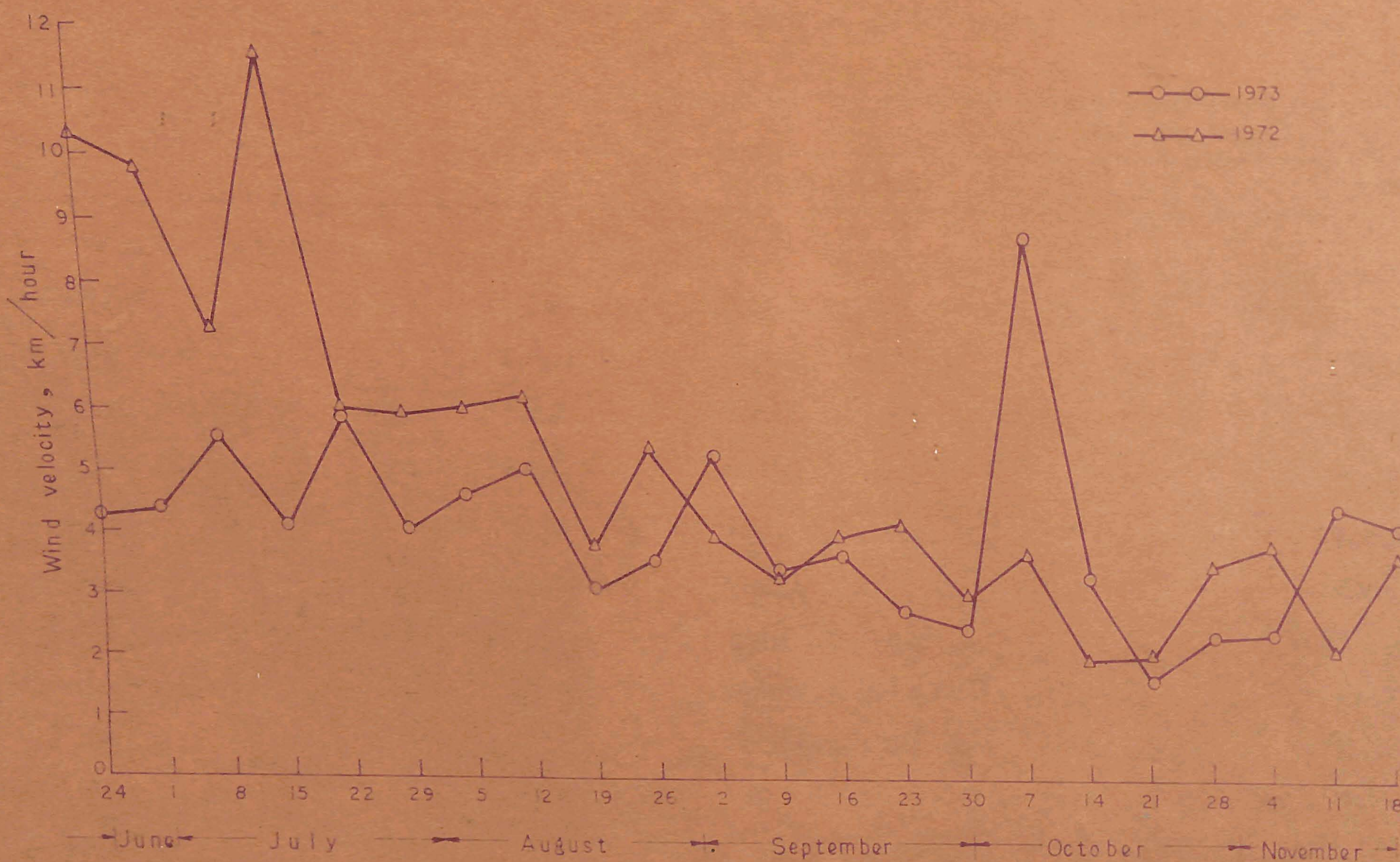


FIG 3.5. VARIATION IN WIND VELOCITY DURING THE EXPERIMENTAL PERIODS.

Table 3.1 Physical and chemical properties of soil of experimental field(0 to 30 cm)

Physical properties		Chemical properties	
Particulars	Values	Particulars	Values
Particle size distribution			
(a) Course sand	27.28%	Cation exchange capacity	15.4 me./100 g
(b) Fine sand	8.34%	Organic carbon	0.268%
(c) Silt	31.4%	Total nitrogen	0.045%
(d) Clay	32.5%	Total P_2O_5	0.047%
Bulk density	1.46 g/cc	Available P_2O_5	0.001%
Field capacity	16.42%	Total K_2O	0.401%
Permanent wilting point	6.28%	Available K_2O	0.408%
Water holding capacity	39.80%	Exchangeable Ca^{++}	0.197%
		Exchangeable Mg^{++}	0.079%
		pH	8.1

analysis' by Jackson (1962).

Test crops In Experiment 1 and 2, IR 22 variety was used as test crop while in Experiment 3 and 4, Sona, Jayanti, Pankaj and IR 22 were grown. The details on the individual varietal characteristics are given as follows.

(i) Sona (IET-1991) : It is a cross between G.E.B. 24 and Taichung Native two designated as semi-dwarf, photo-insensitive, medium duration (120 - 125), lodging resistant and comparatively disease susceptible. The grains are long and slender.

(ii) Jayanti (IET-1039) : It is a cross between T 90 and IR 8, designated as semi-dwarf, photo-insensitive, medium duration (125 - 130), lodging-resistant and comparatively disease resistant. The grains are long and slender.

(iii) Pankaj : It is a cross between Peta and Tongkai Rotan, designated as semi-dwarf, photo-insensitive, long duration (140 - 148) lodging resistant and comparatively disease resistant. The grains are long and bold.

(iv) IR 22 : It is a selection from a cross between IR 8 and Tadukan (A Philippine variety), designated as semi-dwarf, photo-insensitive, medium duration(130-135) lodging resistant and comparatively disease resistant. The grains are long and slender.

Experimentation :

Experiment 1 This was conducted during 1972 'aman' (June to November) and consisted of the treatment of three levels each of nitrogen, phosphate and submergence. The details regarding the treatments are given in the layout plan (Fig.3.6). The experiment was laid out in a 3 x 3 x 3 confounded design where 27 treatment combinations were allocated. In the layout plan, additional plots were included to accommodate zero levels of nitrogen and phosphate, which were used only for fitting the functions.

Experiment 2 Experiment 1 was repeated with some changes in the levels of nitrogen and phosphate during 'aman' (June to November) and the details are given in the layout plan (Fig. 3.6).

Experiment 3 This consisted the treatments of four levels each of nitrogen and phosphate with four high yielding rice varieties in a 4 x 4 x 4 confounded design. The details regarding the treatments are given in the layout plan(Fig.3.7). The experiment was conducted during 1972 'aman' (June to November).

Experiment 4 Experiment 3 was repeated with some changes in the levels of nitrogen and phosphate during 1973 'aman' (June to November) and the details are given in the layout plan (Fig.3.7).

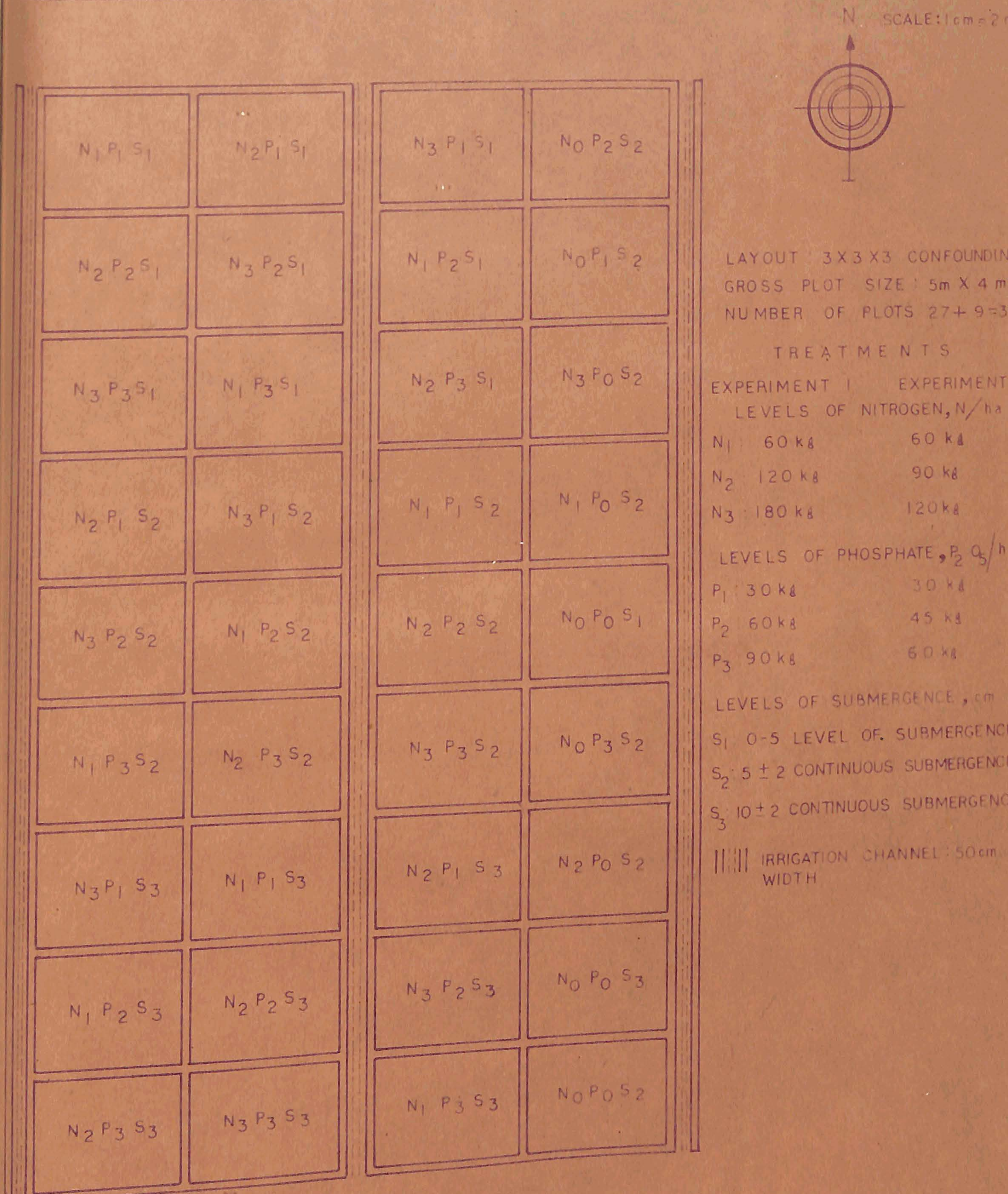
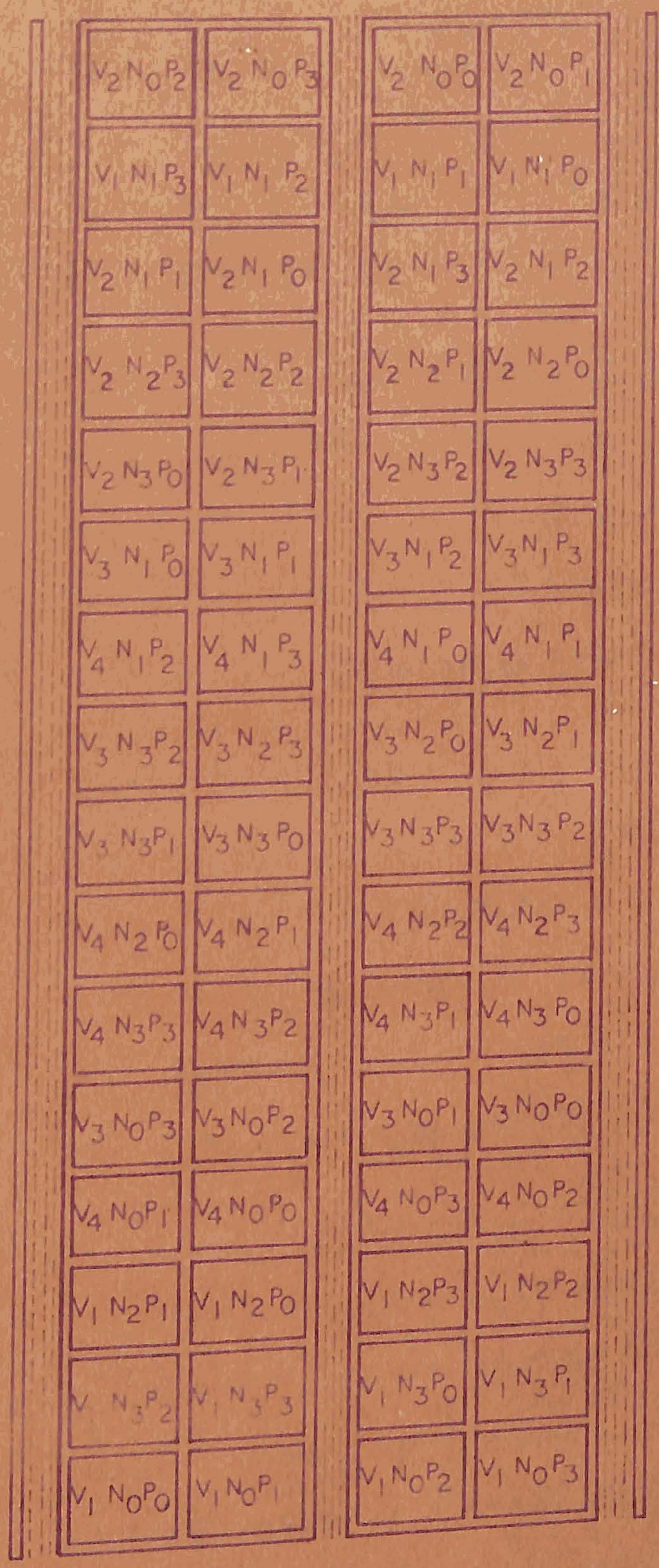


FIG. 3.6. PLAN OF FIELD LAYOUT OF EXPERIMENTS 1 AND 2.

SCALE : 1cm = 4m



LAYOUT: 4X4X4 CONFOUNDING
GROSS PLOT SIZE : 5m X 4 m
NUMBER OF PLOTS : 64

TREATMENTS
VARIETIES

V_1 : SONA　V_2 : JAYANTI
V_3 : PANKAJ　V_4 : IR - 22

LEVELS OF NITROGEN, N/ha

	EXPERIMENT 3	EXPERIMENT 4
N_0	0 kg	0 kg
N_1	60 kg	60 kg
N_2	120 kg	90 kg
N_3	180 kg	120 kg

LEVELS OF PHOSPHATE, P_2O_5/ha

	EXPERIMENT 3	EXPERIMENT 4
P_0	0 kg	0 kg
P_1	30 kg	30 kg
P_2	60 kg	45 kg
P_3	90 kg	60 kg

IRRIGATION CHANNEL : 50 cm WIDTH

FIG. 3.7. PLAN OF FIELD LAYOUT OF EXPERIMENTS 3 AND 4.

Cultural Operations : The schedule of cultural operations are given in Table 3.2.

Seed selection and nursery The seeds were dipped in brine solution to remove partially filled grains and chaffs. The sound seeds were collected, washed with fresh water and treated with a solution of Ceresan wet (1 gm in 500 cc water). The treated seeds were sown in the raised seed beds.

Land preparation The fields were ploughed and harrowed twice and then levelled. The experimental plots, each measuring 5m x 4m were prepared manually and were separated from each other by bunds 20 cm high and 30 cm wide. The soil in each plot was puddled to a similar degree as far as possible by equal number of passes and depth of the implement.

Fertilizer application Nitrogen and phosphate were applied through urea and single superphosphate respectively. Half of the total nitrogen and full dose of phosphate were applied as basal dressing at the time of puddling. The remaining half dose of nitrogen was applied in two equal splits as top dressing, one at the time of active tillering and the other at flag leaf stage of the crop. A basal application of 40 kg K_2O/ha through muriate of potash was given at the time puddling in all the treatments. At the time of top dressing of nitrogen the plots, under the treatments of submergence, were drained and refilled after the application of fertilizer.

Table 3.2 Schedule of cultural operations followed in the different experiments conducted during 1972 and 1973.

S. No.	Particulars	Date of operation			
		Experiment 1 1972	Experiment 2 1973	Experiment 3 1972	Experiment 4 1973
1.	Nursery seeding	June 27th	June 27th	June 27th	June 27th
2.	Preparation of plots				
	(i) Demarcation and bunding	July 14th to 18th		July 14th to 18th	
	(ii) Puddling and levelling	July 20th	July 19th	July 21st and 22nd	July 20th
3.	Fertilizer application				
	(i) Basal dressing	July 20th	July 19th	July 20th	July 19th
	(ii) First top dressing	August 24th	August 21st	August 24th	August 21st
	(iii) Second top dressing	Sept. 15th Sept. 21st*	Sept. 9th Sept. 20th*	Sept. 15th Sept. 21st*	Sept. 9th Sept. 20th*
4.	Transplanting	July 21st	July 20th	July 22nd	July 21st
5.	Weeding				
	First	August 24th	August 21st	August 25th	August 22nd
	Second	Sept. 15th	Sept. 10th	Sept. 16th	Sept. 11th

* Date of top dressing for Pankaj only

contd.../

(contd. Table 3.2)

6.	Plant protection				
	Spraying with streptocyline	July 20th	July 19th	July 20th	July 19th
	Spraying with rogor				
	First	August 9th	July 30th	August 9th	July 30th
	Second	Sept. 9th	August 26th	Sept. 9th	August 26th
	Dusting with B.H.C.				
	First	Oct. 1st	Sept. 29th	Oct. 1st	Sept. 29th
	Second	Oct. 8th	Oct. 9th	Oct. 8th	Oct. 9th
7.	Harvesting				
	(i) First (IR 22 Exp.1 & 2)	Oct. 27th	Oct. 27th		
	(ii) Second "	Oct. 31st	Oct. 31st		
	(iii) Third "	Nov. 8th	Nov. 6th		
	(iv) Fourth "	Nov. 15th	Nov. 12th		
	(v) Sona (Exp.3 & 4)			Oct. 28th	Oct. 30th
	(vi) Jayanti			Oct. 30th	Nov. 2nd
	(vii) Pankaj			Nov. 16th	Nov. 15th
	(viii) IR 22			Nov. 8th	Nov. 6th

Transplanting In the puddled plots 3 seedlings of 23 days age were transplanted per hill at 20 cm x 15 cm spacing.

Irrigation After transplanting, the field was maintained at near saturation for a week and then the treatments of water management were started and maintained upto full maturity of the crop.

Levels of submergence For maintaining 0 - 5 cm level of submergence, 5 cm depth of water was allowed to recede completely and refilling to that depth was done only after two days of complete recession. Whereas, the low and high levels of continuous submergence were maintained throughout the growth period i.e. seedling establishment till maturity of the crop, by keeping 5 ± 2 cm and 10 ± 2 cm depths of water respectively.

Measured quantities of water were applied as and when required to maintain the treatments. However, the crop being grown in the rainy season, the irrigation applied was supplemental. The source of irrigation was a tank. The desired level of water was maintained with the help of graduated pegs which were fixed at four different places in the plots. Any excess water over the mark, during the rains, was drained out.

In Experiment 3 and 4 only 5 ± 2 cm of submergence was maintained throughout the growth period of the crop.

Plant protection A schedule of insecticide and fungicide application was followed as preventive measure against pests and diseases. The details are given in Table 3.2.

Harvesting In Experiment 1 and 2, each net plot was divided into 4 subplots of 2 m x 1.5 m size. This was done to harvest the paddy from the plots at different moisture contents. The grain moisture content was determined daily by Osaw Universal Moisture Meter. The samples were collected from the border row plants. The crop was harvested at four different grain moisture levels of 25.5 - 22.5, 22.5 - 19.5, 19.5 - 16.5 per cent and 16.5 - 13.5 per cent. When the paddy moisture level reached the desired test level in the plots, the crop was harvested and carried to the threshing yard. The paddy was then threshed and the grain from each subplot was weighed and dried to the level of 12 to 13 per cent moisture. Thereafter, each sample was weighed and packed separately in polythene bags with proper label. These samples were taken for the processing studies. The final yield of grain was reported at 12 per cent moisture.

Observations Recorded :

Yield The grain and straw yield were recorded by weighing each sample. The moisture content of the grain was determined and the yield has been reported at 12 per cent moisture content.

Number of productive tillers per hill   Before harvesting, 5 hills were selected at random from each of the plots and all the ear-bearing tillers of the five hills were counted. The average was calculated, giving the number of productive tillers per hill.

Number of grains per panicle   The five hills which were selected for counting the number of productive tillers, were threshed and the number of grains were counted to get the average number of grains per panicle.

Thousand grain weight   One thousand grains were counted from the total grain produced from each net plot and were finally weighed. The weight thus obtained was reported at 12 per cent moisture content.

Processing   The samples were cleaned in the Dockage Tester (Plate I.A) to remove all foreign matter other than good sound marketable paddy grains. Moisture content was determined using Universal Moisture Meter (Plate I.B) taking 50 g of paddy sample. The cleaned sample was divided into two equal parts by the Sample Divider(Plate I.C). Two samples of 250 g each were taken for the study. The samples were shelled in the Satake Laboratory Sheller(Plate I.D). Weight of shelled rice and husk were recorded to determine the husk content.

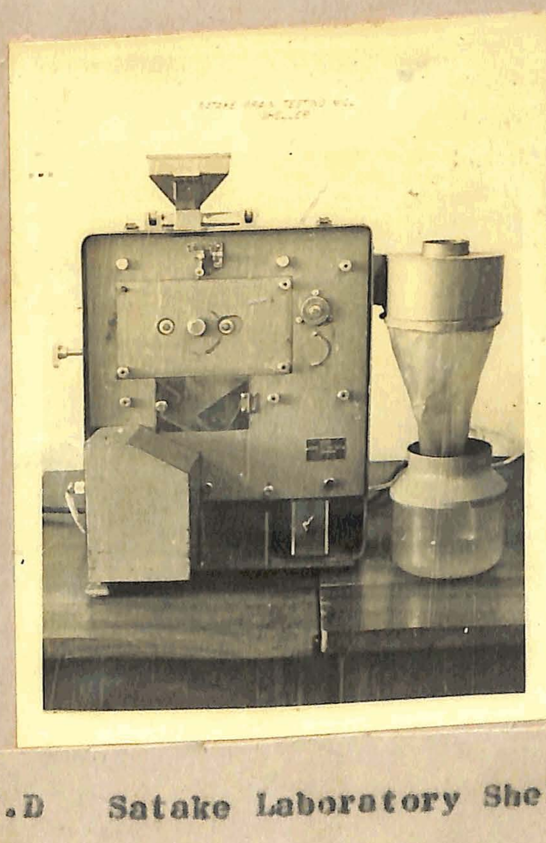
Husk $= W - W_s$

Husk per cent $= \frac{W - W_s}{W} \times 100$

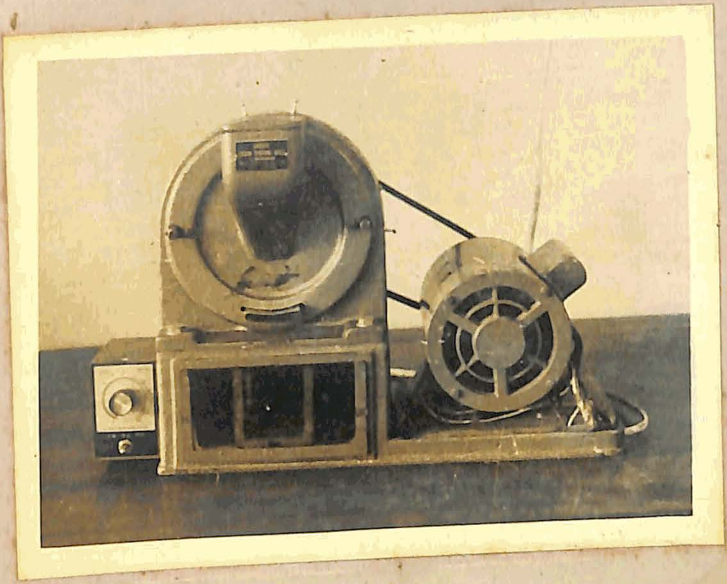
I.A Dockage Tester

I.B Universal Moisture Meter

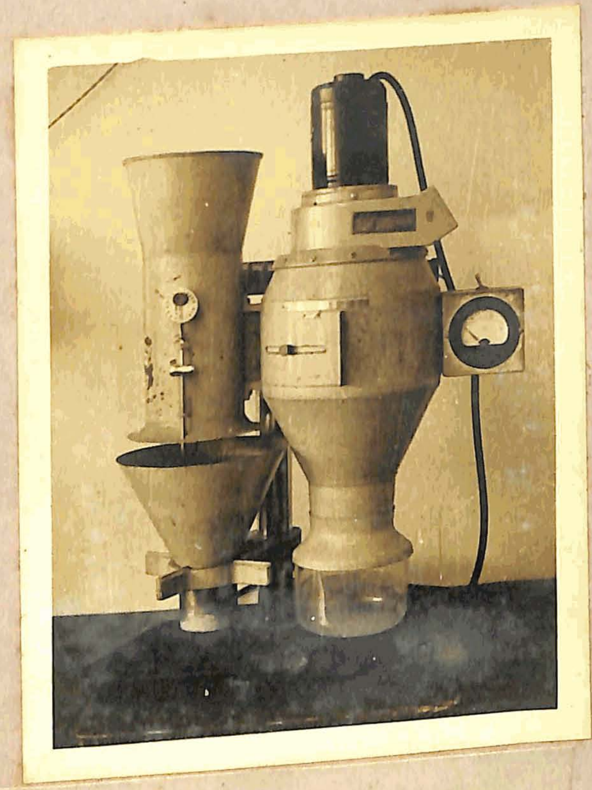
I.C Sample Divider



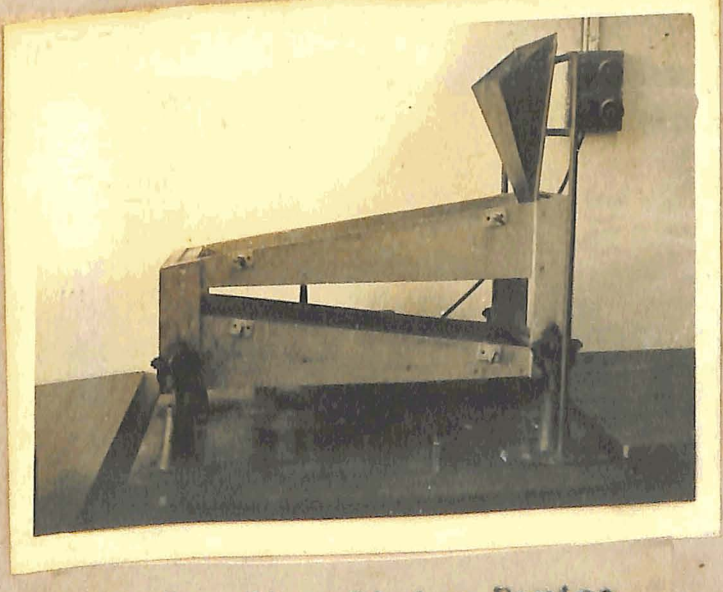
I.D Satake Laboratory Sheller



II.A Satake Laboratory Polisher



II.B Laboratory Aspirator



II.C Rice Sizing Device

Where W is the sample taken for milling and W_s is the weight of shelled rice.

Shelled rice (brown rice) was polished in Abrasive Type Satake Laboratory Polisher (Plate II.A). A constant polish time of 45 seconds was given to each sample by the electronic timer. Bran from the polisher was collected in a sample pan and was aspirated in a Laboratory Aspirator (Plate II.B) to separate fine brokens and germs from the bran. The polished rice was aspirated separately to remove bran which may be adhearing to the surface of the kernels. Fine brokens which were previously separated from the bran were added into the aspirated rice samples and the whole quantity was weighed to account for the total weight of milled rice. Total yield of rice or total outturn was determined by weighing the milled rice

$$\text{Total mill yield per cent} = \frac{\text{Wt. of milled rice}}{\text{Wt. of paddy sample}} \times 100$$

The weight of bran was calculated by the difference in weight between brown rice and milled rice. Degree of polish given to the rice was then calculated from the ratio of weight of bran to weight of brown rice originally taken for polishing

$$\text{Polish per cent} = \frac{\text{Wt. of bran}}{\text{Wt. of brown rice}} \times 100$$

Milled rice was then graded by a Rice Sizing Device (Plate II.C) to remove brokens from the rice sample. This rice is known as whole rice or head rice. Brokens equal to greater than 3/4 length of the whole kernel were treated as whole rice.

$$\text{Head yield recovery per cent} = \frac{\text{Wt. of head rice}}{\text{Wt. of paddy sample}} \times 100$$

The percentage of broken was calculated from the ratio of weight of broken grains to the weight of milled rice.

$$\text{Broken rice per cent} = \frac{\text{Wt. of broken rice}}{\text{Wt. of milled rice}} \times 100.$$

Statistical analysis and data presentation The data recorded were analysed following the method of analysis of variance described by Yates (1937) and the level of significance was tested by 'F' test. The mean values of the treatment effects along with the standard error of means (S.Em.) and least significant difference (L.S.D.) at 5 and 1 per cent probability levels are given in the form of summary tables. The corresponding analysis of variance tables are given in Appendices I and II. The coefficient of correlation and regression among the various characters have been calculated by using the methods given by Snedecor and Cochran (1967).

The data were analysed with the help of the IBM 1620 and EC-1030 Digital Computers.

Determination of Production Functions :

The following forms of functions have been derived using the computer programme as given in the Appendix V.

$$Y = b_0 + b_1N + b_2M + b_3N^2 + b_4M^2 + b_5NM \quad \ldots (3.1)$$

$$Y = b_0 + b_1P + b_2M + b_3P^2 + b_4M^2 + b_5PM \quad \ldots (3.2)$$

$$Y = b_0 + b_1S + b_2M + b_3S^2 + b_4M^2 + b_5SM \quad \ldots (3.3)$$

$$Y = b_0 + b_1N + b_2P + b_3S + b_4M + b_5N^2 + b_6P^2 + b_7S^2 + b_8M^2 + b_9NP + b_{10}NS + b_{11}NM + b_{12}PS + b_{13}PM + b_{14}SM \quad \ldots (3.4)$$

$$Y = a\,N^{b_1}\,P^{b_2}\,S^{b_3}\,M^{b_4} \quad \ldots (3.5)$$

Where:

Y = grain yield, kg/ha
N = nitrogen, kg/ha
P = phosphate, kg/ha
S = water, cm/ha
M = grain moisture at harvest, %
b = regression coefficient
a = constant

The grain yield Y is a function of two variables N and M.

Grain yield is maximized when the elasticity of production = 0

or when $\frac{\partial Y}{N}$ and $\frac{\partial Y}{M}$ = 0 ... (3.1a)

$$\frac{\partial^2 Y}{\partial N^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial N . \partial M}\right)^2 > 0 \text{ and} \qquad \text{... (3.1b)}$$

$$\frac{\partial^2 Y}{\partial N^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \text{... (3.1c)}$$

The grain yield Y is a function of two variables P and M.

Grain yield is maximized when the elasticity of production = 0

or when $\frac{\partial Y}{\partial P}$ and $\frac{\partial Y}{\partial M}$ = 0 and ... (3.2a)

$$\frac{\partial^2 Y}{\partial P^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial P \partial M}\right)^2 > 0 \text{ and} \qquad \text{... (3.2b)}$$

$$\text{when } \frac{\partial^2 Y}{\partial P^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \text{... (3.2c)}$$

The grain yield Y is a function of two variables S and M.

Grain yield is maximised when the elasticity of production = 0

or when $\frac{\partial Y}{\partial S}$ and $\frac{\partial Y}{\partial M}$ = 0 and ... (3.3a)

$$\frac{\partial^2 Y}{\partial S^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial S.\partial M}\right)^2 > 0 \text{ and} \qquad \dots (3.3b)$$

$$\text{when } \frac{\partial^2 Y}{\partial S^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \dots (3.3c)$$

The grain yield Y is a function of four variables N, P, S and M.

Grain yield is maximized when the elasticity of production = 0

$$\text{or when } \frac{\partial Y}{\partial N}, \frac{\partial Y}{\partial P}, \frac{\partial Y}{\partial S} \text{ and } \frac{\partial Y}{\partial M} = 0 \qquad \dots (3.4a)$$

$$\frac{\partial^2 Y}{\partial N^2}, \frac{\partial^2 Y}{\partial P^2}, \frac{\partial^2 Y}{\partial S^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \dots (3.4b)$$

$$\begin{vmatrix} \frac{\partial^2 Y}{\partial N^2} & \frac{\partial^2 Y}{\partial N \partial P} \\ \frac{\partial^2 Y}{\partial P \partial N} & \frac{\partial^2 Y}{\partial P^2} \end{vmatrix} > 0 \qquad \dots (3.4c)$$

$$\begin{vmatrix} \frac{\partial^2 Y}{\partial N^2} & \frac{\partial^2 Y}{\partial N \partial P} & \frac{\partial^2 Y}{\partial N \partial S} \\ \frac{\partial^2 Y}{\partial P \partial N} & \frac{\partial^2 Y}{\partial P^2} & \frac{\partial^2 Y}{\partial P \partial S} \\ \frac{\partial^2 Y}{\partial S \partial N} & \frac{\partial^2 Y}{\partial S \partial P} & \frac{\partial^2 Y}{\partial S^2} \end{vmatrix} < 0 \qquad \dots (3.4d)$$

$$\begin{vmatrix} \frac{\partial^2 Y}{\partial N^2} & \frac{\partial^2 Y}{\partial N \partial P} & \frac{\partial^2 Y}{\partial N \partial S} & \frac{\partial^2 Y}{\partial N \partial M} \\ \frac{\partial^2 Y}{\partial P \partial N} & \frac{\partial^2 Y}{\partial P^2} & \frac{\partial^2 Y}{\partial P \partial S} & \frac{\partial^2 Y}{\partial P \partial M} \\ \frac{\partial^2 Y}{\partial S \partial N} & \frac{\partial^2 Y}{\partial S \partial P} & \frac{\partial^2 Y}{\partial S^2} & \frac{\partial^2 Y}{\partial S \partial M} \\ \frac{\partial^2 Y}{\partial M \partial N} & \frac{\partial^2 Y}{\partial M \partial P} & \frac{\partial^2 Y}{\partial M \partial S} & \frac{\partial^2 Y}{\partial M^2} \end{vmatrix} > 0 \quad \ldots (3.4e)$$

The cost of production was calculated by taking into consideration the following variable cost items as land preparation, seed, nursery, labour, plant protection, water, miscellaneous items and interest on working capital. Fixed cost as land tax was also included while calculating the production cost. Net return was calculated by deducting the total cost from the gross return (value of grain and straw). The cost of each input and the market value of rough rice, polished rice and the by-products - broken, bran and husk are given in the Appendix III. The value of straw has been kept common for estimating gross and net returns from rough rice as well as polished rice with broken bran and husk.

CHAPTER IV.

RESULTS

To find out the optimum level of agronomic resource utilization in the production and processing of rice, four field experiments were conducted during 'aman' (June-November) 1972 and 1973. The response of four varieties of rice to different levels of nitrogen, phosphate and water management practices was studied, in order to find out the optimum level of each of the inputs. Experiments 1 and 2 were conducted only with the rice variety IR 22, while Experiments 3 and 4 were conducted with four rice varieties, Sona, Jayanti, Pankaj and IR 22. The influence of the different grain moisture contents at harvest on the yield and milling quality of rice was studied only in Experiments 1 and 2.

Effects of Nitrogen, Phosphate and Water Management Practices on Rice Variety IR 22

The performance of rice variety IR 22 in grain yield and milling quality was studied by growing it under different levels of nitrogen and phosphate during 'aman' (June-November) 1972 and 1973. During 1972 (Experiment 1), the levels of nitrogen were 60, 120 and 180 kg/ha and the phosphate levels were 30, 60 and 90 kg/ha whereas, during 1973 (Experiment 2), the levels of nitrogen were 60, 90 and 120 kg/ha and the levels of phosphate were 30, 45 and 60 kg/ha. The levels of submergence and the grain moisture contents at harvest were common in both the experiments. The levels were 0 - 5 cm, 5 ± 2 cm and 10 ± 2 cm for submergence and 25.5 - 22.5, 22.5 - 19.5, 19.5 - 16.5 and 16.5 - 13.5 per cent for the grain moisture at harvest.

<u>Grain yield and yield attributes</u> In Experiment 1, where 60, 120 and 180 kg N/ha levels were tried, there was significant increase in grain yield with the increase in the level of nitrogen from 60 to 120 kg/ha and a significant decrease was noted when the level was raised from 60 to 180 kg/ha. In other words, the increase in yield was noted only upto 120 kg N/ha. The significant increase in grain yield at 120 kg N/ha was associated with the significant increase in number of grains per panicle and number of productive tillers per hill(Table 4.1) In Experiment 2, where 60, 90 and 120 kg N/ha levels were tried, the increase was significant only upto 90 kg N/ha and no significant increase was noted by increasing the level from 90 to 120 kg N/ha (Table 4.2).

In Experiment 1, with the application of phosphate, the grain yield was significantly increased under 60 kg P_2O_5 level as compared to that at 30 and 90 kg/ha. On the other hand, between 30 and 90 kg/ha levels of phosphate, significant decrease noted under the latter (Table 4.1). In Experiment 2, where three levels of phosphate, 30, 45 and 60 kg/ha were tried, significant increase in yield was noted only upto 45 kg/ha. Further increase in the level did not benefit the crop.

Table 4.1 Grain yield and yield attributes of the cultivar IR 22 as influenced by the levels of nitrogen, phosphate and submergence - Experiment 1.

Treatment	Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/ panicle	1000 grain weight, g
Levels of nitrogen, kg/ha				
60	3908	10.27	100.53	22.63
120	4256	10.93	106.42	22.68
180	3775	10.34	85.64	22.57
	**	*	**	NS
Levels of phosphate, kg/ha				
30	4013	10.38	99.36	22.67
60	4094	10.75	98.06	22.63
90	3832	10.41	95.17	22.58
	**	NS	*	NS
Levels of submergence, cm				
0 - 5	3895	10.55	94.86	22.68
5 ± 2	4118	10.75	98.89	22.63
10 ± 2	3926	10.24	98.84	22.57
	**	NS	*	NS
S.Em. ±	30.24	0.25	1.45	-
L.S.D.(P=0.05)	74	0.61	3.54	-
L.S.D.(P=0.01)	112	0.92	5.36	-

* Significant at (P=0.05); ** Significant at (P=0.01);
NS = Not significant.

Table 4.2 Grain yield and yield attributes of the cultivar IR 22 as influenced by the levels of nitrogen, phosphate and submergence - Experiment 2.

Treatment	Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/panicle	1000 grain weight, g
Levels of nitrogen, kg/ha				
60	4459	9.85	108.08	22.92
90	4798	10.89	109.56	22.96
120	4818	10.81	110.67	22.91
	**	NS	NS	NS
Levels of phosphate, kg/ha				
30	4630	10.50	108.39	22.89
45	4744	10.37	111.92	22.99
60	4701	10.68	108.00	22.91
	**	NS	*	NS
Levels of submergence, cm				
0 - 5	4593	10.12	107.97	22.88
5 ± 2	4820	10.97	111.26	22.90
10 ± 2	4662	10.46	109.05	23.01
	**	NS	**	NS
S.Em.±	22.48	-	1.14	-
L.S.D.(P=0.05)	55	-	2.78	-
L.S.D.(P=0.01)	83	-	4.21	-

* Significant at (P=0.05); ** Significant at (P=0.01);
NS = Not significant.

The significant increase in yield at 45 kg P_2O_5/ha was found associated with the signficant increase in the number of grains per panicle (Table 4.2).

Under the three levels of submergence in both the Experiments 1 and 2, significant increase in yield was noted where continuous submergence of 5 ± 2 cm was maintained throughout the crop growth period, i.e. from seedling establishment to maturity, as compared to that under the other two levels of submergence, 0 - 5 cm and 10 ± 2 cm (Table 4.1 and 4.2). In Experiment 2, significant increase in yield was found to be associated with the significant increase in number of grains per panicle.

<u>Milling yield</u> In Experiment 1, with the increase in level of nitrogen from 60, 120 and 180 kg/ha, there was significant increase in total mill yield upto 120 kg N/ha; thereafter, at 180 kg N/ha level, significant reduction was noted. Whereas, in Experiment 2, significant increase was noted only up to 90 kg N/ha (Table 4.3 and 4.4).

Significant increase in the total mill yield was noted at 30 and 60 kg P_2O_5/ha than at 90 kg P_2O_5/ha level in Experiment 1. But, in the Experiment 2, significantly higher total mill yield was obtained at 45 kg P_2O_5/ha than at 30 kg P_2O_5/ha level. Further increase in phosphate level to 60 kg/ha did not bring any appreciable increase in yield over that of

Table 4.3 Milling yield of the cultivar IR 22 as influenced by the levels of nitrogen, phosphate and submergence - Experiment 1.

Treatment	Total mill yield		Head yield		Broken rice		Bran		Husk	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%+	kg/ha	%
Levels of nitrogen, kg/ha										
60	2855	73.00	2369	60.04	485	18.00	125	4.22	927	23.75
120	3102	73.04	2490	57.95	619	20.76	140	4.31	1005	23.63
180	2746	72.69	2113	55.30	632	24.02	121	4.21	907	24.07
	**	NS	**	**	**	**	**	NS	**	NS
Levels of phosphate, kg/ha										
30	2931	72.98	2295	56.62	634	22.46	133	4.35	949	23.65
60	2979	72.91	2428	58.71	558	20.41	132	4.23	974	23.85
90	2793	72.84	2249	57.76	544	20.61	121	4.16	916	23.95
	**	NS	**	NS	*	NS	**	NS	*	NS
Levels of submergence, cm										
0 - 5	2839	72.83	2216	56.14	621	23.13	129	4.23	926	23.84
5 ± 2	3000	72.99	2413	58.08	595	20.67	134	4.24	976	23.72
10 ± 2	2864	72.91	2343	59.07	520	18.98	123	4.17	937	23.89
	**	NS	**	*	*	*	*	NS	*	NS
S.Em.±	20.84	0.31	41.28	0.91	29.83	1.21	2.45	-	15.94	-
L.S.D.(P=0.05)	51	0.77	101	2.23	73	2.96	6	-	39	-
L.S.D.(P=0.01)	78	1.16	153	3.38	111	4.48	9	-	59	-

*Significant at(P=0.05);Significant at(P=0.01);NS=Not significant; + Polish per cent.

Table 4.4 Milling yield of the cultivar IR 22 as influenced by the levels of nitrogen, phosphate and submergence - Experiment 2.

Treatment	Total mill yield		Head yield		Broken rice		Bran		Husk	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%+	kg/ha	%
Levels of nitrogen, kg/ha										
60	3240	72.56	2866	64.08	373	11.65	161	4.74	1058	23.71
90	3498	72.94	3099	64.49	394	11.63	178	4.84	1118	23.29
120	3497	72.59	3118	64.64	378	10.83	180	4.83	1148	23.61
	**	NS	**	NS	NS	NS	**	NS	**	NS
Levels of phosphate, kg/ha										
30	3378	72.90	3013	64.88	365	11.03	170	4.73	1083	23.37
45	3446	72.59	3050	64.15	395	11.59	174	4.80	1123	23.67
60	3412	72.60	3020	64.18	385	11.49	175	4.83	1118	23.57
	**	NS	NS	NS	NS	NS	NS	NS	*	NS
Levels of submergence, cm										
0 - 5	3340	72.65	2945	63.93	394	12.01	173	4.93	1078	23.48
5 ± 2	3510	72.81	3127	64.73	383	11.06	176	4.73	1140	23.41
10 ± 2	3385	72.63	3011	64.55	368	11.04	170	4.75	1106	23.72
	**	NS	**	NS	NS	NS	NS	NS	**	NS
S.Em.±	16.76	-	23.29	-	-	-	3.27	-	11.03	-
L.S.D.(P=0.05)	41	-	57	-	-	-	8	-	27	-
L.S.D.(P=0.01)	62	-	86	-	-	-	12	-	41	-

* Significant at(P=0.05); ** Significant at(P=0.01); NS=Not significant; + Polish per cent

45 kg P_2O_5/ha (Table 4.3 and 4.4). Significant increase in the total mill yield was noted with the increasing level of phosphate up to 45 kg/ha only at the nitrogen level of 120 kg/ha in Experiment 2 (Table 4.5).

In both the Experiments 1 and 2, the total mill yield was significantly increased under 5 ± 2 cm continuous submergence, as compared to 0 - 5 and 10 ± 2 cm submergence levels (Table 4.3 and 4.4).

Regarding total mill yield per cent, it remained unaffected due to the varying levels of nitrogen, phosphate and submergence in both the Experiments 1 and 2 (Table 4.5 and 4.4).

<u>Head yield</u> In Experiment 1, head yield per hectare was significantly increased with the increase in nitrogen level from 60 to 120 kg/ha and significant decrease was noted when the level was increased to 180 kg/ha. On the other hand, the head yield recovery per cent was maximum at 60 kg N/ha and thereafter, with the increasing level of nitrogen, there was reduction which was signficant only at 180 kg N/ha (Table 4.3). In Experiment 2, though the maximum head yield was obtained at the level of 120 kg N/ha, there was no significant difference between 120 and 90 kg N/ha levels. In this experiment, the head yield recovery percentage did not vary appreciably under the three levels of N (Table 4.4).

Table 4.5 Total mill yield of the cultivar IR 22 as affected by interaction between nitrogen and phosphate - Experiment 2.

Levels of nitrogen kg/ha	Total mill yield, kg/ha		
	Levels of phosphate, kg/ha		
	30	45	60
[illegible]	3236	3235	3250
[illegible]	3454	3517	3525
120	3446	3587	3461
S.Em.±		32.69	
L.S.D. (P=0.05)		80	
L.S.D. (P=0.01)		121	

Under the different levels of phosphate in Experiment 1, significant increase in head yield was noted with the increase in phosphate level from 30 to 60 kg/ha. Beyond this level, at 90 kg P_2O_5/ha, the head yield was significantly reduced. However, in Experiment 2, no such difference was observed between the three levels of P_2O_5, 30, 45 and 60 kg/ha. In both the experiments, the phosphate levels did not bring any appreciable variation in head yield recovery percentage.

At 60 kg N/ha, the head yield and its percentage recovery were significantly increased when the level of P_2O_5 was raised from 30 to 60 kg/ha. Thereafter, a significant decrease was noted at 90 kg P_2O_5/ha level. But, this decrease was arrested by increasing the level of nitrogen from 60 to 120 kg/ha (Table 4.6).

Significantly higher head yield was obtained under 5 ± 2 cm and 10 ± 2 cm levels of continuous submergence as compared to 0 - 5 cm level in both the experiments. Only in Experiment 2, significant increase in head yield was noted under 5 ± 2 cm submergence as compared to 10 ± 2 cm level. The head yield recovery percentage was increased significantly at 10 ± 2 cm level of submergence as compared to 0 - 5 cm level and no appreciable difference was noted between the former and 5 ± 2 cm levels in Experiment 1 only (Table 4.3).

Broken rice It was noted that the broken yield and its percentage under the different levels of nitrogen, phosphate and

Table 4.6 Head yield of the cultivar IR 22 as affected by interaction between nitrogen and phosphate - Experiment 1.

Levels of nitrogen, kg/ha	Head yield, kg/ha		
	Levels of phosphate, kg/ha		
	30	60	90
60	2322 (58.1)	2574 (63.6)	2210 (58.4)
120	2416 (56.0)	2512 (57.1)	2543 (60.7)
180	2149 (55.8)	2199 (55.4)	1993 (54.7)
S.Em.±		71.11(1.59)	
L.S.D.(P=0.05)		174(3.9)	
L.S.D.(P=0.01)		264(5.9)	

The values under parentheses represent the head yield recovery per cent.

water management practices had almost an opposite trend as that of head yield and its percentage. In other words, with the increase in head yield and its percentage there was decrease in broken yield and its percentage and vice-versa (Table 4.3 and 4.4).

Bran The bran yield was found associated with the grain yield under the different levels of nitrogen, phosphate and submergence. However, in Experiment 2, the bran yield was found unaffected due to the levels of phosphate and submergence. Further, the polish percentage was not influenced by the different levels of nitrogen, phosphate and submergence in both the experiments (Table 4.3 and 4.4).

Husk The increase or decrease in husk yield was associated with the increase or decrease in grain yield under the different treatments of nitrogen, phosphate and submergence. However, the husk percentage did not show any significant variation due to the different levels of nitrogen, phosphate and submergence in both the Experiments 1 and 2 (Table 4.3 and 4.4).

Effect of Different Grain Moisture Content at Harvest of Rice Variety IR 22

Grain yield and yield attributes Considerable difference in grain yield was noted when the crop was harvested at different grain moisture contents. The grain yield showed significant increase when harvested at moisture content between 25.5 - 22.5 and 22.5 - 19.5 per cent. Significantly higher grain yield was also noted when the crop was harvested at 22.5 - 19.5 per cent grain moisture as compared to that harvested at 25.5 - 22.5 per cent moisture(Table 4.7 and 4.8).

In Experiment 1, while there was no significant difference in grain yield between 25.5 - 22.5 and 22.5 - 19.5 per cent ranges of grain moisture at 60 and 120 kg N/ha levels, significant increase was noted at the latter harvest grain moisture when the level of nitrogen was 180 kg/ha. However, significant decrease in yield was noted by decreasing the grain moisture below 19.5 per cent under all the levels of nitrogen (Table 4.9).

In Experiment 2, the crop raised with 60 and 90 kg N/ha and harvested at 25.5 - 22.5 per cent moisture content of the grain showed similar yield performance as that at 22.5 - 19.5 per cent moisture level. But when it was allowed to dry further to 19.5 - 16.5 or 16.5 - 13.5 per cent moisture levels, there was significant decrease in grain yield. However, the trend under 120 kg N/ha was different and the crop at this level of nitrogen yielded higher when harvested at 22.5 - 19.5 or 19.5 - 16.5 per cent moisture level as compared to that harvested at 25.5 - 22.5 per cent grain moisture. In other words, by increasing the level of nitrogen from 90 to 120 kg/ha, the crop could be harvested with some delay without any loss in yield rather appreciable increasing was noted (Table 4.10).

Table 4.7 Grain yield and yield attributes of the cultivar IR 22 as influenced by the grain moisture at harvest - Experiment 1.

Grain moisture at harvest, %	Grain yield, kg/ha	Number of grains/ panicle	1000 grain weight, g
25.5 - 22.5	4134	101.67	22.59
22.5 - 19.5	4185	102.81	22.72
19.5 - 16.5	3920	95.70	22.56
16.5 - 13.5	3679	89.93	22.63
	**	**	NS
S.Em.±	18.41	0.62	-
L.S.D.(P=0.05)	38	1.27	-
L.S.D.(P=0.01)	51	1.72	-

** Significant at (P=0.01);
NS = Not significant.

Table 4.8 Grain yield and yield attributes of the cultivar IR 22 as influenced by the grain moisture at harvest - Experiment 2.

Grain moisture at harvest, %	Grain yield, kg/ha	Number of grains/ panicle	1000 grain weight, g
25.5 - 22.5	4824	112.59	22.80
22.5 - 19.5	4871	113.56	23.01
19.5 - 16.5	4712	109.96	22.94
16.5 - 13.5	4359	101.63	22.96
	**	**	*
S.Em.±	23.26	0.56	0.05
L.S.D.(P=0.05)	48	1.16	0.10
L.S.D.(P=0.01)	65	1.57	0.13

* Significant at (P=0.05); ** Significant at (P=0.01)

Table 4.9 Grain yield of the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 1.

Levels of nitrogen, kg/ha	Grain yield, kg/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	4123	4101	3826	3580
120	4431	4492	4148	3956
180	3849	3961	3787	3503
S.Em.±		31.98		
L.S.D.(P=0.05)		66		
L.S.D.(P=0.01)		89		

Table 4.10 Grain yield of the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 2.

Levels of nitrogen, kg/ha	Grain yield, kg/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	4626	4645	4429	4137
90	5035	4986	4735	4431
120	4811	4982	4990	4510
S.Em.±	40.70			
L.S.D.(P=0.05)	84			
L.S.D.(P=0.01)	114			

<u>Milling yield</u> The total mill yield followed almost similar trend as that of grain yield under the four harvest grain moisture contents. There was significant increase in total mill yield when the crop was harvested either at 25.5 - 22.5 or 22.5 - 19.5 per cent grain moisture as compared to that which was harvested at 19.5 - 16.5 and 16.5 - 13.5 per cent. The total mill yield percentage, did not show appreciable decrease when the grain moisture was decreased from 25.5 to 16.5 per cent in Experiment 1 while in Experiment 2, no particular trend was noted under the different levels of harvest grain moisture. However, the total mill yield per cent was found maximum under 25.5 - 22.5 per cent harvest grain moisture in both the experiments (Table 4.11 and 4.12).

In Experiment 2, under all the four grain moisture contents, the total mill yield was significantly increased with the increase in nitrogen levels from 60 to 90 and 60 to 120 kg/ha. But with the increase in nitrogen levels from 90 to 120 kg/ha decrease in total mill yield was noted in case of the crop harvested at 25.5 - 22.5 and 22.5 - 19.5 per cent grain moisture. This decrease in total mill yield at 120 kg N/ha was significant only at the harvest grain moisture content of 25.5 - 22.5 per cent. Further, at grain moisture content below 19.5 per cent, there was increase in total mill yield with the increase in nitrogen level from 90 to 120 kg/ha (Table 4.13).

Table 4.11 Milling yield of the cultivar IR 22 as influenced by grain moisture at harvest - Experiment 1.

Grain moisture at harvest, %	Total mill yield		Head yield		Broken rice		Bran		Husk	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%+	kg/ha	%
25.5 - 22.5	3039	73.49	2831	68.45	207	6.82	125	3.89	970	23.48
22.5 - 19.5	3071	73.38	2801	66.91	269	8.78	120	3.71	994	23.74
19.5 - 16.5	2868	73.42	2330	59.48	548	18.74	132	4.34	909	23.21
16.5 - 13.5	2626	71.36	1335	36.21	1290	49.38	140	5.03	912	24.84
	**	**	**	**	**	**	**	**	**	**
S.Em.±	21.80	0.21	28.59	0.73	25.68	0.98	3.88	0.12	7.27	0.20
L.S.D.(P=0.05)	45	0.43	59	1.50	53	2.02	8	0.25	15	0.41
L.S.D.(P=0.01)	61	0.58	80	2.03	72	2.74	11	0.34	20	0.55

** Significant at (P=0.01); + Polish per cent.

Table 4.12 Milling yield of the cultivar IR 22 as influenced by grain moisture at harvest - Experiment 2.

Grain moisture at harvest, %	Total mill yield		Head yield		Broken rice		Bran		Husk	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%+	kg/ha	%
25.5 - 22.5	3533	73.25	3349	69.45	226	5.14	160	4.28	1139	23.33
22.5 - 19.5	3507	71.97	3235	66.35	261	7.74	171	4.62	1193	24.50
19.5 - 16.5	3421	72.48	2953	62.82	486	13.57	185	5.11	1105	23.44
16.5 - 13.5	3187	73.09	2576	59.01	559	19.21	176	5.18	996	22.87
	**	**	**	**	**	**	**	**	**	**
S.Em.±	22.29	0.26	27.62	0.43	15.55	0.47	3.89	0.08	15.02	0.25
L.S.D.(P=0.05)	46	0.55	57	0.89	32	0.97	8	0.17	31	0.51
L.S.D.(P=0.01)	62	0.71	77	1.21	43	1.31	11	0.23	42	0.69

** Significant at (P=0.01); + Polish per cent.

Table 4.13 Total mill yield of the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 2.

Levels of nitrogen, kg/ha	Total mill yield, kg/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	3412	3311	3218	3019
90	3679	3620	3454	3242
120	3509	3589	3591	3301
S.Em.±		38.76		
L.S.D.(P=0.05)		80		
L.S.D.(P=0.01)		109		

<u>Head yield</u> Highest head yield per hectare and its recovery per cent were obtained when the crop was harvested at 25.5 - 22.5 per cent grain moisture. Significant reduction was noted with the decrease in the harvest grain moisture below 22.5 per cent. However, in Experiment 1, the head yield under 25.5 - 22.5 and 22.5 - 19.5 per cent was found on par with each other (Table 4.11 and 4.12).

With the increase in nitrogen level from 60 to 120 kg/ha in Experiment 1 and from 60 to 90 kg/ha in Experiment 2, significant increase in head yield was noted when the harvesting was done at grain moisture above 19.5 per cent. Further, in Experiment 2, at the lower levels of harvest grain moisture, below 19.5 per cent, significant increase in head yield was noted even at 120 kg N/ha (Table 4.14 and 4.15). Further, it is apparent from Table 4.15 that there was appreciable increase in head yield recovery percentage with the increase in the level of grain moisture content at harvest under all the levels of nitrogen. By increasing the nitrogen from 60 to 90 kg/ha appreciable increase in head yield recovery was noted only at 22.5 - 19.5 per cent harvest grain moisture(Table 4.14 and 4.15).

It is revealed from Experiment 1 (Table 4.16) that there was significant increase in head yield when the crop was grown under continuous submergence of 5 ± 2 cm and harvested at 25.5 - 22.5 and 22.5 - 19.5 per cent grain moisture as compared to the crop grown under 10 ± 2 cm and 0 - 5 cm

Table 4.14 Head yield of the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 1.

Levels of nitrogen, kg/ha	Head yield, kg/ha			
	Grain moisture at harvest,%			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	2321	2781	2419	1453
120	3046	2998	2418	1499
180	2625	2623	2153	1053
S.Em.±		49.90		
L.S.D.(P=0.05)		103		
L.S.D.(P=0.01)		140		

Table 4.15 Head yield of the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 2.

Levels of nitrogen, kg/ha	Head yield, kg/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	3219 (70.2)	3048 (65.6)	2781 (62.8)	2389 (57.7)
90	3484 (69.2)	3352 (67.2)	2956 (62.9)	2605 (58.7)
120	3345 (68.9)	3299 (66.2)	3124 (62.8)	2735 (60.6)
S.Em.±	47.965 (0.775)			
L.S.D. (P=0.05)	99 (1.6)			
L.S.D. (P=0.01)	134 (2.1)			

Values under parenthesis represent the head yield recovery per cent.

Table 4.16 Head yield of the cultivar IR 22 as affected by interaction between submergence and grain moisture at harvest - Experiment 1.

Levels of submergence, cm	Head yield, kg/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
0 - 5	2753 (68.1)	2748 (66.9)	2205 (57.4)	1160 (32.2)
5 ± 2	2951 (69.2)	2894 (67.0)	2426 (60.2)	1382 (35.9)
10 ± 2	2789 (68.1)	2760 (66.8)	2359 (60.9)	1465 (40.5)
S.Em.±	49.90(1.26)			
L.S.D.(P=0.05)	103(2.6)			
L.S.D.(P=0.01)	140(3.5)			

The values under parenthesis represent the head yield recovery per cent.

submergence treatments. The head yield recovery per cent of the crop at lower harvest grain moisture contents of 19.5 - 16.5 and 16.5 - 13.5 per cent was appreciably high under continuous submergence of 5 $\pm$ 2 cm as compared to that of 0 - 5 cm. This trend in head yield recovery per cent was similar in Experiment 2 only when the crop was harvested at 16.5 - 13.5 per cent grain moisture (Table 4.17). However, under all the levels of submergence, significant increase in head yield recovery percentage was noted with the increase in grain moisture content at harvest up to 22.5 - 19.5 in Experiment 1 and up to 25.5 - 22.5 in Experiment 2.

It is apparent from Table 4.18 that there was significant increase in head yield at 120 kg N/ha and at all the three levels of phosphate, 30, 60 and 90 kg/ha when the crop was harvested above 19.5 per cent grain moisture. On the other hand, at each level of nitrogen, the beneficial effect of phosphate application in increasing the head yield recovery percentage was noted only in case of the crop harvested below 19.5 per cent grain moisture. But in general, under all the levels of nitrogen and phosphate, the head yield recovery percentage was decreased significantly with the decrease in grain moisture at harvest below 19.5 per cent(Table 4.18).

Table 4.17 Head yield recovery per cent of the cultivar IR 22 as affected by interaction between submergence and grain moisture at harvest - Experiment 2.

Levels of submergence, cm	Head yield,%			
	Grain moisture at harvest,%			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
0 - 5	69.3	66.8	62.6	57.1
5 ± 2	69.1	66.4	63.0	60.5
10 ± 2	70.0	65.9	62.9	59.4
S.Em.±		0.78		
L.S.D.(P=0.05)		1.60		
L.S.D.(P=0.01)		2.10		

Table 4.18 Head yield of the cultivar IR 22 as affected by interaction between nitrogen, phosphate and grain moisture at harvest - Experiment 1.

Levels of nitrogen, kg/ha	:	Levels of phosphate, kg/ha	Head yield, kg/ha — Grain moisture at harvest, % 25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	:	30	2896 (69.5)	2726 (65.7)	2367 (60.8)	1300 (36.5)
60	:	60	2889 (68.1)	2958 (68.4)	2567 (65.6)	1882 (51.3)
60	:	90	2680 (67.6)	2659 (68.4)	2323 (63.3)	1177 (34.3)
120	:	30	3054 (68.3)	2967 (65.8)	2330 (56.6)	1313 (33.4)
120	:	60	3073 (68.1)	3042 (66.7)	2469 (57.3)	1465 (36.3)
120	:	90	3013 (69.9)	2985 (67.8)	2456 (61.1)	1719 (44.2)
180	:	30	2649 (69.1)	2711 (67.1)	2094 (54.5)	1142 (32.3)
180	:	60	2737 (67.7)	2737 (66.7)	2231 (56.7)	1091 (30.5)
180	:	90	2488 (67.8)	2421 (64.7)	2134 (59.4)	928 (27.1)
S.Em.±				86.72 (2.18)		
L.S.D. (P=0.05)				179 (4.5)		
L.S.D. (P=0.01)				242 (6.1)		

The values under parenthesis represent the head yield recovery per cent.

<u>Broken rice</u> Under the four different grain moisture contents at harvest, the broken rice yield and its percentage followed almost an opposite trend to that of head yield and its recovery percentage (Table 4.11 and 4.12). It is also apparent from Table 4.19 that the broken rice yield and its percentage followed almost an opposite trend to that of head yield and its recovery percentage under all the interaction of nitrogen,phosphate and grain moisture content at harvest.

Under the three different water management practices, 0 - 3, 5 ± 2 and 10 ± 2 cm submergence, the broken yield and its percentage was significantly reduced under the latter two as compared to the former one, for the crop harvested at grain moisture content below 19.5 per cent. But, in case of the crop harvested at grain moisture content above 19.5 percent the three water management practices were found on par with each other for the broken rice yield and its percentage(Table 4.20).

<u>Husk</u> Under the four levels of grain moisture at harvest, the husk yield followed the trend similar to that of grain yield. However, some variation in husk per cent was noted. In both the experiments, no definite trend could be obtained in the husk percentage with the increase or decrease of grain moisture content because the variation in grain yield under these treatments was not found proportional with that of husk yield (Table 4.11 and 4.12).

Table 4.19 Broken rice yield of the cultivar IR 22 as affected by interaction between nitrogen, phosphate and grain moisture at harvest - Experiment 1.

Levels of nitrogen, kg/ha	:	Levels of phosphate, kg/ha	Broken rice, kg/ha			
			Grain moisture at harvest, %			
			25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	:	30	191 (6.2)	308 (10.1)	469 (16.4)	1268 (49.4)
60	:	60	211 (6.8)	201 (6.3)	319 (11.0)	758 (28.7)
60	:	90	204 (7.0)	224 (7.7)	390 (14.4)	1283 (52.0)
120	:	30	254 (7.6)	317 (9.6)	711 (23.3)	1509 (53.3)
120	:	60	230 (7.0)	295 (8.8)	708 (22.4)	1420 (49.2)
120	:	90	175 (5.4)	231 (7.1)	506 (17.0)	1071 (38.3)
180	:	30	185 (6.6)	296 (9.8)	710 (25.1)	1397 (55.0)
180	:	60	216 (7.3)	257 (8.6)	654 (20.9)	1426 (56.6)
180	:	90	202 (7.5)	293 (10.9)	469 (18.1)	1482 (62.0)
S.Em.±				78.00(2.96)		
L.S.D.(P=0.05)				161 (6.1)		
L.S.D.(P=0.01)				218 (8.2)		

The values under parenthesis represent broken rice per cent.

Table 4.20 Broken rice yield of the cultivar IR 22 as affected by interaction between submergence and grain moisture at harvest - Experiment 1.

Levels of submergence, cm	Broken rice, kg/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
0 - 5	211 (7.1)	276 (9.1)	618 (21.7)	1383 (54.6)
5 ± 2	195 (6.2)	268 (8.5)	536 (17.9)	1379 (50.1)
10 ± 2	216 (7.2)	263 (8.8)	491 (16.6)	1109 (43.4)
S.Em.±	45.06 (1.69)			
L.S.D. (P=0.05)	93 (3.5)			
L.S.D. (P=0.01)	126 (4.7)			

The values under parenthesis represent the broken rice per cent.

Bran The bran was found to increase with the decrease in moisture content of the grain at harvest. Significant increase was noted under 19.5 - 16.5 per cent and 16.5 - 13.5 per cent grain moisture as compared to that under 22.5 - 19.5 per cent and 25.5 - 22.5 per cent grain moisture at harvest. Only in Experiment 2, bran was found significantly higher under 22.5 - 19.5 per cent than 25.5 - 22.5 per cent grain moisture level. The increase or decrease in per cent polish under the different grain moisture contents at harvest, followed similar trend as that of bran. In general, there was increase in per cent polish with decrease in grain moisture content at harvest at constant pressure and time of polishing (Table 4.11 and 4.12).

Economic Evaluation

The quantitative significance of nitrogen and phosphate fertilizers and different water management practices in the economic evaluation of the crop, harvested at four different grain moisture contents, were known by calculating treatment wise gross return and net returns of rough rice(Paddy). These calculations were also made for polished rice with brokenbran and husk, in order to obtain its comparative evaluation with that of rough rice.

Gross return Significant increase in the estimate of gross return was noted with the increase in nitrogen level from 60 to 120 kg/ha in Experiment 1 and from 60 to 90 and 120 kg/ha in Experiment 2. Whereas, at 180 kg N/ha, in Experiment 1, the estimate was significantly lower as compared to that of both 60 and 120 kg N/ha (Table 4.21 and 4.22).

Regarding phosphate levels, in Experiment 1, gross return was found significantly higher at 60 kg P_2O_5/ha than 30 as well as 90 kg P_2O_5/ha. Significantly lower gross return was noted at 90 kg P_2O_5/ha as compared to that of even 30 kg P_2O_5/ha (Table 4.21) whereas, in Experiment 2, the gross return was significantly higher at 45 and 60 kg P_2O_5/ha over that of 30 kg P_2O_5/ha and the values under the former two levels were found at par with each other (Table 4.22).

Among the three water management practices, the gross return was significantly higher under 5 ± 2 cm continuous submergence as compared to the other two treatments with 0 - 5 cm and 10 ± 2 cm submergence. While no significant difference in gross return was noted between 0 - 5 and 10 ± 2 cm submergence levels in Experiment 1, significantly higher return was noted under the latter submergence level in Experiment 2(Table 4.21 and 4.22).

It is revealed from Table 4.23 and 4.24 that there was significant increase in gross return with the increase in grain moisture content at harvest from 16.5 - 13.5 to 19.5 - 16.5 and 22.5 - 19.5 per cent. In Experiment 2, although, significant decrease in gross return was noted for rough rice with further increase in harvest grain moisture content from 22.5 - 19.5 to

Table 4.21 Gross return and net return per hectare for rough rice and polished rice with by-products of the cultivar IR 22 as influenced by the levels of nitrogen, phosphate and submergence - Experiment 1.

Treatments	Gross return		Net return	
	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha
Levels of nitrogen, kg/ha				
60	3264	3940	944	1630
120	3510	4195	1059	1743
180	3192	3725	607	1141
	**	**	**	**
Levels of phosphate, kg/ha				
30	3350	3961	981	1591
60	3417	4090	965	1639
90	3199	3309	664	1284
	**	**	**	**
Levels of submergence, cm				
0 - 5	3254	3834	855	1437
5 ± 2	3435	4097	992	1662
10 ± 2	3277	3929	763	1415
	**	**	**	**
S.Em.±	23.70	40.46	24.11	38.82
L.S.D. (P=0.05)	58	99	59	95
L.S.D. (P=0.01)	88	150	89	144

** Significant at (P=0.01)

Table 4.22 Gross return and net return per hectare for rough rice and polished rice with by-products of the cultivar IR 22 as influenced by the levels of nitrogen, phosphate and submergence - Experiment 2.

Treatments	Gross return: Rough rice, Rs/ha	Gross return: Polished rice, broken, bran and husk, Rs/ha	Net return: Rough rice, Rs/ha	Net return: Polished rice, broken, bran and husk, Rs/ha
Levels of nitrogen, kg/ha				
60	3714	4600	1424	2310
90	3958	4940	1601	2584
120	4067	5041	1645	2617
	**	**	**	**
Levels of phosphate kg/ha				
30	3860	4817	1546	2502
45	3954	4899	1598	2542
60	3925	4865	1526	2467
	**	**	**	**
Levels of submergence, cm				
0 - 5	3832	4748	1565	2479
5 ± 2	4021	5005	1672	2656
10 ± 2	3886	4828	1436	2376
	**	**	**	**
S.Em.±	18.39	18.39	18.80	18.39
L.S.D. (P=0.05)	45	45	46	45
L.S.D. (P=0.01)	68	68	89	68

** Significant at (P=0.01)

Table 4.23 Gross return and net return per hectuare for rough rice and polished rice with by-products of the cultivar IR 22 as influenced by the grain moisture at harvest – Experiment 1.

Treatments	Gross return		Net return	
	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha
Grain moisture at harvest, %				
25.5 – 22.5	3434	4367	993	1915
22.5 – 19.5	3471	4363	1020	1912
19.5 – 16.5	3278	3943	827	1502
16.5 – 13.5	3178	3141	651	689
	**	**	**	**
S.Em.±	14.05	27.13	13.56	25.19
L.S.D.(P=0.05)	29	56	28	52
L.S.D.(P=0.01)	39	76	38	70

** Significant at (P=0.01)

Table 4.24 Gross return and net return per hectare for rough rice and polished rice with by-products of the cultivar IR 22 as influenced by the grain moisture at harvest - Experiment 2.

Treatments	Gross return		Net return	
	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha
Grain moisture at harvest, %				
25.5 - 22.5	4010	5133	1653	2776
22.5 - 19.5	4044	5056	1688	2699
19.5 - 16.5	3929	4833	1571	2476
16.5 - 13.5	3670	4420	1315	2064
	**	**	**	**
S.Em.±	16.93	33.43	17.93	33.43
L.S.D.(P=0.05)	34	69	37	69
L.S.D.(P=0.01)	46	94	50	94

** Significant at (P=0.01)

25.5 – 22.5 per cent, no decrease rather, significant increase in return was noted in case of polished rice with broken, bran and husk.

It is revealed from the interaction between harvest grain moisture and levels of nitrogen that in Experiment 1, with the increase in level of nitrogen from 60 to 120 kg/ha, the gross return for rough rice was increased significantly, irrespective of the grain moisture content at harvest. On the contrary, increasing the nitrogen level from 60 to 180 kg/ha, appreciable decrease was noted only when the crop was harvested at grain moisture content above 19.5 per cent(Table 4.25). Regarding Experiment 2, significant increase in gross return for both rough rice and polished rice with broken, bran and husk was noted with the increase in nitrogen level from 60 to 90 and 120 kg/ha under all the levels of grain moisture contents at harvest except under the moisture content of 25.5 – 22.5 per cent, where at 120 kg N/ha, significant decrease was noted as compared to 90 kg N/ha level (Table 4.26).

<u>Net return</u> With the increasing levels of nitrogen upto 120 kg/ha there was significant increase in net return for rough rice and polished rice with broken, bran and husk. In Experiment 1, while there was appreciable increase in net return with the increase in nitrogen level from 60 to 120 kg/ha, further increase to 180 kg/ha brought significant decrease (Table 4.21). Whereas, in Experiment 2, appreciable increase was noted at 90 as well as

Table 4.25 Gross return per hectare for rough rice for the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 1.

Levels of nitrogen, kg/ha	Gross return, ₦/ha			
	Grain moisture at harvest, %			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	3419	3404	3203	3028
120	3638	3682	3431	3290
180	3246	3328	3200	2993
S.Em.±		23.74		
L.S.D.(P=0.05)		49		
L.S.D.(P=0.01)		66		

Table 4.26 Gross return per hectare for rough rice and polished rice with broken, bran and husk for the cultivar IR 22 as affected by interaction between nitrogen and grain moisture at harvest - Experiment 2.

Levels of nitrogen, kg/ha	Gross return, Rs/ha			
	Grain moisture at harvest,%			
	25.5-22.5	22.5-19.5	19.5-16.5	16.5-13.5
60	3836 (4953)	3850 (4761)	3692 (4539)	3479 (4147)
90	4132 (5287)	4096 (5189)	3913 (4840)	3690 (4447)
120	4062 (5158)	4187 (5218)	4178 (5120)	3842 (4667)
S.Em.±	29.55 (58.14)			
L.S.D.(P=0.05)	61 (120)			
L.S.D.(P=0.01)	83 (163)			

The values under parenthesis are for polished rice with broken, bran and husk.

120 kg N/ha over that of 60 kg N/ha, and no significant difference was noted between the former two levels. In other words, significant increase in net return was noted only upto 90 kg N/ha level (Table 4.22). Further, at this level of nitrogen, the additional return in case of polished rice with broken, bran and husk over that of rough rice was found maximum (Fig.4.1).

In Experiment 1, there was decrease in net return with the increase in phosphate levels from 30 to 60 kg/ha and significant decrease was noted at 90 kg P_2O_5/ha level (Table 4.22). In Experiment 2, where the three levels of P_2O_5 were 30, 45 and 60 kg/ha, significant increase at 45 kg/ha level was noted over that of other two levels (Table 4.23). In case of polished rice with broken, bran and husk, the net return was though high, but the trend remained almost similar to that of rough rice under the three levels of phosphate in both the experiments. The only variation noted was that in Experiment 2, where there was no significant difference between 30 and 45 kg P_2O_5/ha levels. The additional return estimated in case of polished rice with broken, bran and husk over that of rough rice was maximum at 60 and 30 kg P_2O_5/ha levels in Experiments 1 and 2 respectively. While there was wide difference between 30 and 60 kg levels of phosphate in Experiment 1, the additional return earned between 30, 45 and 60 kg levels showed practically no difference in Experiment 2 (Fig.4.1).

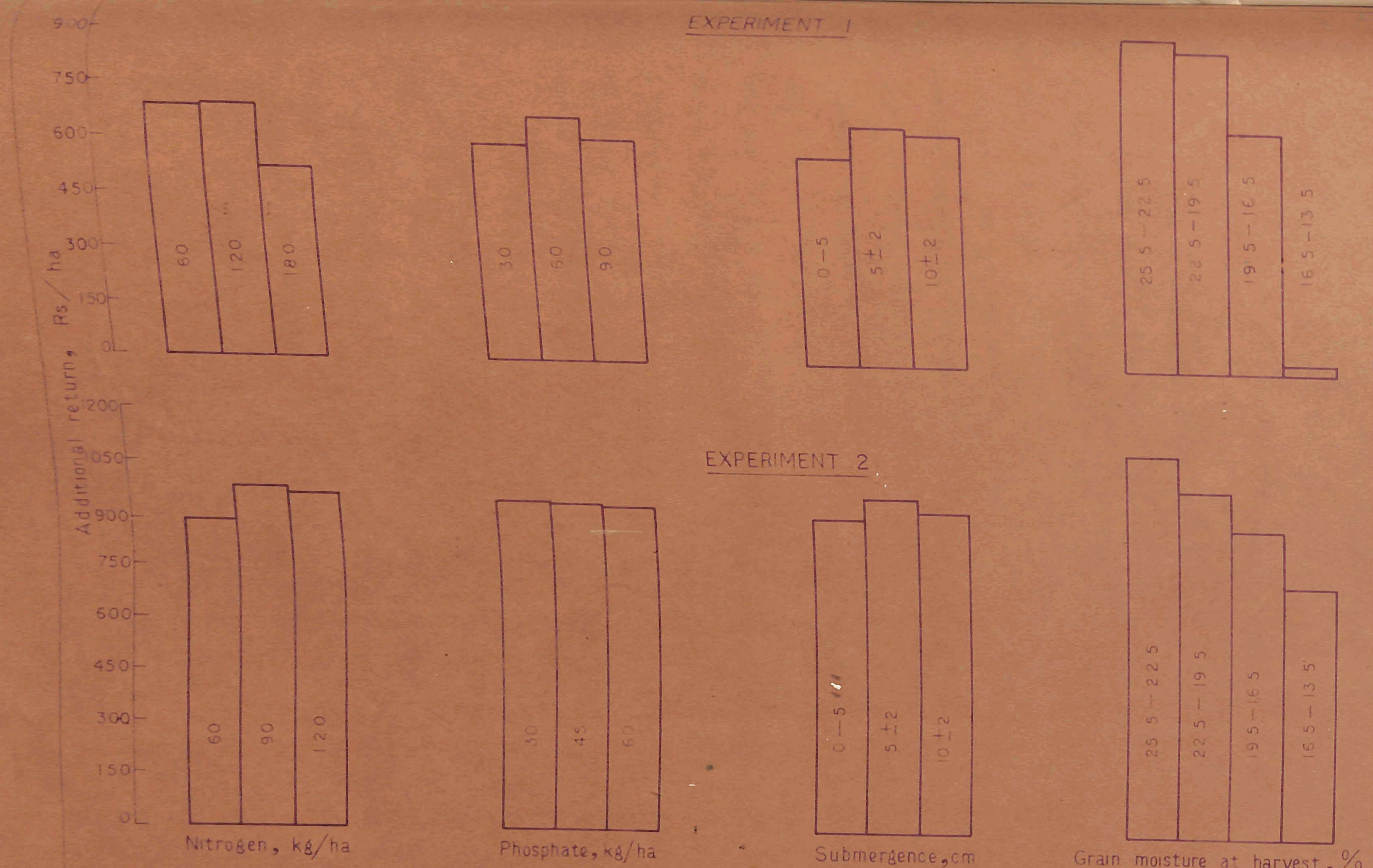


FIG. 4.1. ADDITIONAL RETURN PER HECTARE FOR POLISHED RICE WITH BROKEN BRAN AND HUSK AS COMPARED TO ROUGH RICE UNDER THE DIFFERENT LEVELS OF NITROGEN PHOSPHATE SUBMERGENCE AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT 1 AND 2).

Under the three water management practices, significantly higher net return for rough rice was obtained at 5 ± 2 cm continuous submergence than the other two treatments with 0 - 5 cm and 10 ± 2 cm submergence. Significant difference was also noted between the latter two treatments, where under 0 - 5 cm submergence level, the return was higher than 10 ± 2 cm submergence. Similar trend under the different levels of submergence was also noted for polished rice with broken bran and husk. However, in Experiment 1, no significant difference was noted between 0 - 5 cm and 10 ± 2 cm submergence levels(Table 4.21 and 4.22). It was further revealed that the additional return for polished rice with broken, bran and husk over that of rough rice was maximum under 5 ± 2 cm submergence followed by 10 ± 2 and 0 - 5 cm submergence levels (Fig.4.1).

The net return for rough rice was significantly increased with the increase in grain moisture at harvest upto 22.5 - 19.5 per cent. At higher grain moisture, ranging from 25.5 - 22.5 per cent, significant reduction was noted. In other words, maximum return was estimated when the crop was harvested at grain moisture content of 22.5 - 19.5 per cent. Further, the grain moisture content lower or higher than this level lowered the return. For polished rice with broken, bran and husk the trend in net return remained almost similar to that of rough rice under the different levels of grain moisture at harvest.

The only variation observed in Experiment 2 was between 22.5 - 19.5 and 25.5 - 22.5 per cent grain moisture contents, where significant increase in net return was higher under the latter over that of the former. The additional return in case of polished rice with broken, bran and husk over that of rough rice was found to increase with the increasing level of grain moisture at harvest and was maximum at 25.5 - 22.5 per cent grain moisture (Fig.4.1).

It is revealed from the interaction between nitrogen levels and grain moisture contents at harvest (Table 4.27) that there was significant increase in net return from rough rice with the decrease in harvest grain moisture from 25.5 - 22.5 to 22.5 - 19.5 per cent at nitrogen level of 120 kg/ha. Particularly in Experiment 2, while there was significant increase in net return at 90 kg N/ha over that of 120 kg/ha for the crop harvested at 25.5 - 22.5 per cent grain moisture, no significant difference was noted when harvesting was done at lower grain moisture content of 22.5 - 19.5 per cent. In both the Experiments, 1 and 2 the net return in case of polished rice with by-products followed almost similar trend to that of rough rice (Table 4.28). Except that in Experiment 2, where, with the increasing grain moisture content at harvest from 16.5 - 13.5 to 25.5 - 22.5 per cent, significant increase in net return was observed at 60 kg N/ha. But at 90 kg N/ha significant increase was noted only up to harvest grain

Table 4.27 Net return per hectare for rough rice for the cultivar IR 22 as affected by interaction between grain moisture content at harvest and nitrogen - Experiments 1 and 2.

Grain moisture at harvest, %	Net return, Rs/ha					
	Levels of nitrogen, kg/ha			Levels of nitrogen, kg/ha		
	60	120	180	60	90	120
	Experiment 1			Experiment 2		
25.5 - 22.5	1101	1187	661	1546	1775	1638
22.5 - 19.5	1085	1251	743	1560	1740	1763
19.5 - 16.5	885	980	616	1402	1556	1755
16.5 - 13.5	705	839	409	1189	1334	1424
S.Em.±	23.74				30.52	
L.S.D. (P=0.05)	49				63	
L.S.D. (P=0.01)	67				86	

Table 4.28 Net return per hectare for polished rice with broken, bran and husk for the cultivar IR 22 as affected by interaction between nitrogen and grain moisture content at harvest - Experiments 1 and 2.

Grain moisture at harvest, %	Net return, Rs/ha					
	Levels of nitrogen, kg/ha			Levels of nitrogen, kg/ha		
	60	120	180	60	90	120
	Experiment 1			Experiment 2		
25.5 - 22.5	2015	2205	1526	2663	2931	2735
22.5 - 19.5	1991	2172	1572	2471	2832	2795
19.5 - 16.5	1662	1664	1180	2249	2483	2697
16.5 - 13.5	852	931	285	1857	2090	2244
S.Em.±		43.6			58.62	
L.S.D. (P=0.05)		90			121	
L.S.D. (P=0.01)		123			163	

moisture level of 22.5 - 19.5. With further increase in nitrogen level to 120 kg/ha, an appreciable increase was noted even up to a low harvest grain moisture of 19.3 - 16.5 per cent. In other words, by increasing the nitrogen level the variety IR 22 could be harvested with some delay, at low grain moisture content, without any appreciable reduction in net return.

Resource Optimization :

In order to obtain maximum benefits from the different inputs of nitrogen and phosphate the crop is required to be harvested at a optimum time. Therefore, interection effect of nitrogen and phosphates with the grain moisture at harvest becomes very important for maximization of grain yield and head yield. In view of the above, production functions were fitted with the help of equations 3.1 and 3.2 and 3.4 given in page and using the data collected from Experiments 1 and 2. Among the different functions tested, the quadratic form gave the best fit (highest R^2) and was used for final interpretations.

The production equations obtained through production functions for the grain and head yield for Experiments 1 and 2, separately, are given

<u>Grain yield</u>

Experiment 1

$$Y = -1456 + \underset{(14.615)}{27.4669\,N} - \underset{(-22.442)}{0.1112\,N^2} + \underset{(4.924)}{375.2202\,M}$$

$$- \underset{(-4.076)}{7.8989\,M} - \underset{(-1.334)}{0.1097\,NM} \qquad \ldots (4.1)$$

$R^2 = .93$

Where:

Y = grain yield, kg/ha

N = elemental nitrogen, kg/ha

M = grain moisture at harvest, %

't' values are given under parentheses in the equation.

Grain yield is maximum when the elasticity of production = 0

or when $\frac{\partial Y}{\partial N}$ and $\frac{\partial Y}{\partial M} = 0$ ... (4-A$_1$)

$$\frac{\partial^2 Y}{\partial N^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial N . \partial M}\right)^2 > 0 \text{ and} \qquad \ldots (4\text{-}B_1)$$

$$\frac{\partial^2 Y}{\partial N^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \ldots (4\text{-}C_1)$$

$$\frac{\partial Y}{\partial N} = 27.4669 - 0.2224\ N - 0.1097\ M = 0 \qquad \ldots (4.1a)$$

$$\frac{\partial Y}{\partial M} = 375.2202 - 15.7978\ M - 0.1097\ N = 0 \qquad \ldots (4.1b)$$

By solving these two simultaneous equations

Y_{max} = when $N = 112$ and $M = 23.3$

The conditions (4-B$_1$) and (4-C$_1$) can easily be shown to be satisfied for the equation (4.1).

By substituting the optimum values of N and M to the above equation (4.1) a maximum yield of 4393 kg/ha was attained.

$$Y = -939 + \underset{(4.274)}{33.2015}\,P - \underset{(-6.857)}{0.2820}\,P^2 + \underset{(2.335)}{367.7116}\,M - \underset{(-1.972)}{7.8990}\,M^2 - \underset{(-.203)}{0.0693}\,PM \qquad \ldots (4.2)$$

$R^2 = .65$

Where:

Y = grain yield, kg/ha

P = phosphate, kg/ha

M = grain moisture at harvest, %

$$\frac{\partial Y}{\partial P} \text{ and } \frac{\partial Y}{\partial M} = 0 \qquad \ldots (4\text{-}A_2)$$

$$\frac{\partial^2 Y}{\partial P^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial P \cdot \partial M}\right)^2 > 0 \text{ and} \qquad \ldots (4\text{-}B_2)$$

$$\frac{\partial^2 Y}{\partial P^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \ldots (4\text{-}C_2)$$

$$\frac{\partial Y}{\partial P} = 33.2015 - 0.5640\,P - 0.0693\,M = 0 \qquad \ldots (4.2a)$$

$$\frac{\partial Y}{\partial M} = 367.7116 - 15.6980\,M - 0.0693\,P = 0 \qquad \ldots (4.2b)$$

By solving these two simultaneous equations

Y_{max} = when P = 56 and M = 23.0

The conditions (4-B_2) and (4-C_2) can easily be shown to be satisfied for the equation (4.2).

By substituting the optimum values of P and N to the above equation (4.2) a maximum yield of 4225 kg/ha was attained.

Experiment 2

$$Y = -1572 + \underset{(9.671)}{29.7161}\,N - \underset{(-10.378)}{0.1208}\,N^2 + \underset{(5.444)}{443.5471}\,M - \underset{(-4.741)}{9.8012}\,M^2 - \underset{(-0.880)}{0.1211}\,NM \qquad \ldots (4.3)$$

$$R^2 = .94$$

Grain yield is maximum when

$$\frac{\partial Y}{\partial N} \text{ and } \frac{\partial Y}{\partial M} = 0 \qquad \ldots (4\text{-}A_3)$$

$$\frac{\partial^2 Y}{\partial N^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial N . \partial M}\right)^2 > 0 \text{ and} \qquad \ldots (4\text{-}B_3)$$

$$\frac{\partial^2 Y}{\partial N^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \qquad \ldots (4\text{-}C_3)$$

$$\frac{\partial Y}{\partial N} = 29.7161 - 0.2416N - 0.1211M = 0 \qquad \ldots (4.3a)$$

$$\frac{\partial Y}{\partial M} = 443.5471 - 19.6024\,M - 0.1211\,N = 0 \qquad \ldots (4.3b)$$

By solving these two simultaneous equations

Y_{max} = When N = 112 and M = 21.9

The conditions (4-B_3) and (4-C_3) can easily be shown to be satisfied for the equation (4.3).

By substituting the optimum values of N and M to the above equation (4.3) a maximum yield of 4957 kg/ha was attained.

$$Y = -794 + \underset{(2.702)}{35.9796}\,P - \underset{(-4.262)}{0.4214}\,P^2 + \underset{(-2.840)}{422.9382}\,M - \underset{(-2.225)}{9.7672}\,M^2 + \underset{(0.462)}{0.2752}\,PM \quad \ldots (4.4)$$

$R^2 = .66$

Grain yield is maximum when

$$\frac{\partial Y}{\partial P} \text{ and } \frac{\partial Y}{\partial M} = 0 \quad \ldots (4\text{-}A_4)$$

$$\frac{\partial^2 Y}{\partial P^2} \cdot \frac{\partial^2 Y}{\partial M^2} - \left(\frac{\partial^2 Y}{\partial P . \partial M}\right)^2 > 0 \text{ and} \quad \ldots (4\text{-}B_4)$$

$$\frac{\partial^2 Y}{\partial P^2} \text{ and } \frac{\partial^2 Y}{\partial M^2} < 0 \quad \ldots (4\text{-}C_4)$$

$$\frac{\partial Y}{\partial P} = 35.9776 - 0.8428\,P + 0.2752\,M = 0 \quad \ldots (4.4a)$$

$$\frac{\partial Y}{\partial M} = 422.9382 - 19.5344\,M + 2752\,P = 0 \quad \ldots (4.4b)$$

By solving these two simultaneous equations

Y_{max} = When P = 50 and M = 22.4

The conditions ($4-B_4$) and ($4-C_4$) can easily be shown to be satisfied for the equation (4.4).

By substituting the optimum values of P and M to the above equation (4.4) a maximum yield of 4833 kg/ha was attained.

<u>Head yield</u>

Experiment 1

$$H = -10083 + \underset{(5.235)}{9.0437}\,N - \underset{(-15.154)}{0.0690}\,N^2 + \underset{(15.878)}{1112.1920}\,M$$

$$- \underset{(-14.146)}{25.1996}\,M^2 + \underset{(3.657)}{0.2764}\,NM \qquad \ldots (4.5)$$

$R^2 = .96$

Where :

H = Head yield, kg/ha

Head yield is maximum when

$$\frac{\partial H}{\partial N} \text{ and } \frac{\partial H}{\partial M} = 0 \qquad \ldots (4-A_5)$$

$$\frac{\partial^2 H}{\partial N^2} \cdot \frac{\partial^2 H}{\partial M^2} - \left(\frac{\partial H}{\partial N.\partial M}\right)^2 > 0 \text{ and} \qquad \ldots (4-B_5)$$

$$\frac{\partial^2 H}{\partial N^2} \text{ and } \frac{\partial^2 H}{\partial M^2} < 0 \qquad \ldots (4-C_5)$$

$$\frac{\partial H}{\partial N} = 9.0437 - 0.1380\,N + 0.2764\,M = 0 \qquad \ldots (4.5a)$$

$$\frac{\partial H}{\partial M} = 1112.1920 - 50.3992\,M + 0.2764\,N = \qquad \ldots (4.5b)$$

By solving these two simultaneous equations

H_{max} = When N 111 and M = 22.7

The conditions 4-B_5 and (4-C_5) can easily be shown to be satisfied for the equation (4.5).

By substituting the optimum values of N and M to the above equation (4.5) a maximum head yield of 3029 kg/ha was attained.

$$H = -10321 + \underset{(2.315)}{12.4574}\,P - \underset{(-4.492)}{0.1274}\,P^2 + \underset{(10.399)}{1134.3437}\,M$$

$$- \underset{(-9.084)}{25.1996}\,M^2 + \underset{(.466)}{0.1097}\,PM \qquad \ldots (4.6)$$

R^2 = .89

Head yield is maximum when

$$\frac{\partial H}{\partial P} \text{ and } \frac{\partial H}{\partial M} = 0 \qquad \ldots (4\text{-}A_6)$$

$$\frac{\partial^2 H}{\partial P^2} \cdot \frac{\partial^2 H}{\partial M^2} - \left(\frac{\partial^2 H}{\partial P \partial M}\right)^2 > 0 \text{ and} \qquad \ldots (4\text{-}B_6)$$

$$\frac{\partial^2 H}{\partial P^2} \text{ and } \frac{\partial^2 H}{\partial M^2} < 0 \qquad \ldots (4\text{-}C_6)$$

$$\frac{\partial H}{\partial P} = 12.4574 - 0.2548\,P + 0.109\,M = 0 \qquad \ldots (4.6a)$$

$$\frac{\partial H}{\partial M} = 1134.3437 - 50.3992\,M + 0.1097\,P = 0 \qquad \ldots (4.6b)$$

By solving these two simultaneous equations

H_{max} = When P = 59 and M = 22.6

The conditions (4-B_6) and (4-C_6) can easily be shown to be satisfied for the equation (4.6).

By substituting the optimum values of P and N to the above equation (4.6) a maximum head yield of 3382 kg/ha was attained.

Experiment 2

$$H = -2151 + \underset{(8.437)}{21.1275}\, N - \underset{(-8.395)}{0.0797}\, N^2 + \underset{(5.103)}{338.8341}\, M$$

$$- \underset{(-3.667)}{6.1788}\, M^2 - \underset{(-1.251)}{0.1404}\, NM \qquad \ldots (4.7)$$

$$R^2 = .93$$

Head yield is maximum when

$$\frac{\partial H}{\partial N} \text{ and } \frac{\partial H}{\partial M} = 0 \qquad \ldots (4\text{-}A_7)$$

$$\frac{\partial^2 H}{\partial N^2} \cdot \frac{\partial^2 H}{\partial M^2} - \left(\frac{\partial H}{\partial N \cdot \partial M}\right)^2 > 0 \text{ and} \qquad \ldots (4\text{-}B_7)$$

$$\frac{\partial^2 H}{\partial N^2} \text{ and } \frac{\partial^2 H}{\partial N^2} < 0 \qquad \ldots (4\text{-}C_7)$$

$$\frac{\partial H}{\partial N} = 21.1275 - 0.1594N - 0.1404\, M = 0 \qquad \ldots (4.7a)$$

$$\frac{\partial H}{\partial M} = 338.8341 - 12.3576\, M - 0.1404\, N = 0 \qquad \ldots (4.7b)$$

By solving these two simultaneous equations

H_{max} = When N = 109 and M = 26.1

The conditions $(4\text{-}B_7)$ and $(4\text{-}C_7)$ can easily be shown to be satisfied for the equation (4.7).

By substituting the optimum values of N and M to the above equation (4.7) a maximum head yield of 3440 kg/ha was attained.

$$H = -1625 + \underset{(2.993)}{28.3751}\,P - \underset{(-4.547)}{0.3201}\,P^2 + \underset{(2.631)}{324.7634}\,M - \underset{(-1.974)}{6.1684}\,M^2 + \underset{(.199)}{0.0846}\,PM \quad \ldots (4.8)$$

$$R^2 = .76$$

Head yield is maximum when

$$\frac{\partial H}{\partial P} \text{ and } \frac{\partial H}{\partial M} = 0 \quad \ldots (4\text{-}A_8)$$

$$\frac{\partial^2 H}{\partial P^2} \cdot \frac{\partial^2 H}{\partial M^2} - \left(\frac{\partial H}{\partial P \cdot \partial M}\right)^2 > 0 \text{ and} \quad \ldots (4\text{-}B_8)$$

$$\frac{\partial^2 H}{\partial P^2} \text{ and } \frac{\partial^2 H}{\partial M^2} < 0 \quad \ldots (4\text{-}C_8)$$

$$\frac{\partial H}{\partial P} = 28.3751\,P - 0.6402\,P + 0.0846\,M = 0 \quad \ldots (4.8a)$$

$$\frac{\partial H}{\partial M} = 324.7634 - 12.3368\,M + 0.0846\,P = 0 \quad \ldots (4.8b)$$

By solving these two simultaneous equations

H_{max} = When P = 48 and M = 26.6

The conditions $(4-B_3)$ and $(4-C_3)$ can easily be shown to be satisfied for the equation (4.8).

By substituting the optimum values of P and M to the above equation (4.8) a maximum head yield of 3382 kg/ha was attained.

The production surfaces obtained by these equations (4.1) to (4.8) are depicted through Figs. 4.2 to 4.9.

The production equations obtained through production functions for grain and head yield by taking into account all the four factors - nitrogen, phosphate, water and grain moisture at harvest, are given as follows.

<u>Grain Yield</u>

Experiment 1

$$\begin{aligned} Y = & - 4517 + \underset{(11.576)}{22.9261}\,N - \underset{(-30.756)}{0.1052}\,N^2 + \underset{(4.635)}{18.3360}\,P \\ & - \underset{(-13.194)}{0.1805}\,P^2 + \underset{(3.959)}{45.5503}\,S - \underset{(-4.475)}{0.1725}\,S^2 \\ & + \underset{(6.183)}{345.9155} - \underset{(-6.169)}{7.7330}\,M^2 + \underset{(2.549)}{0.0149}\,NP \\ & + \underset{(1.368)}{0.0154}\,NS - \underset{(-1.988)}{0.1076}\,NM - \underset{(-0.130)}{0.0029}\,PS \\ & - \underset{(-0.218)}{0.0236}\,PM + \underset{(0.917)}{0.1664}\,SM \qquad \ldots (4.9) \end{aligned}$$

Where :

Y = grain yield, kg/ha

N = nitrogen, kg/ha

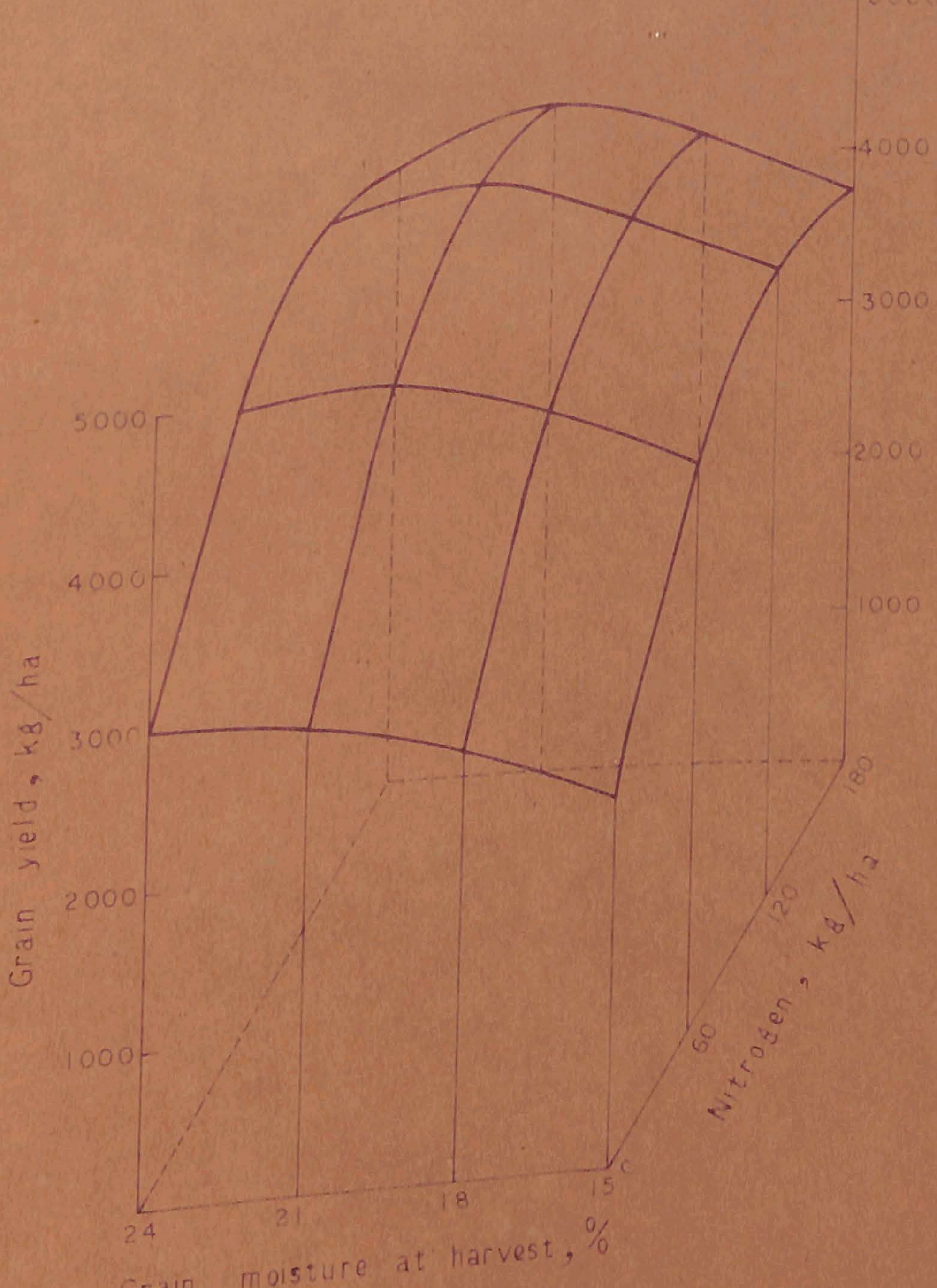


FIG. 4.2. PRODUCTION SURFACE FOR GRAIN YIELD AS A FUNCTION OF NITROGEN AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT 1).

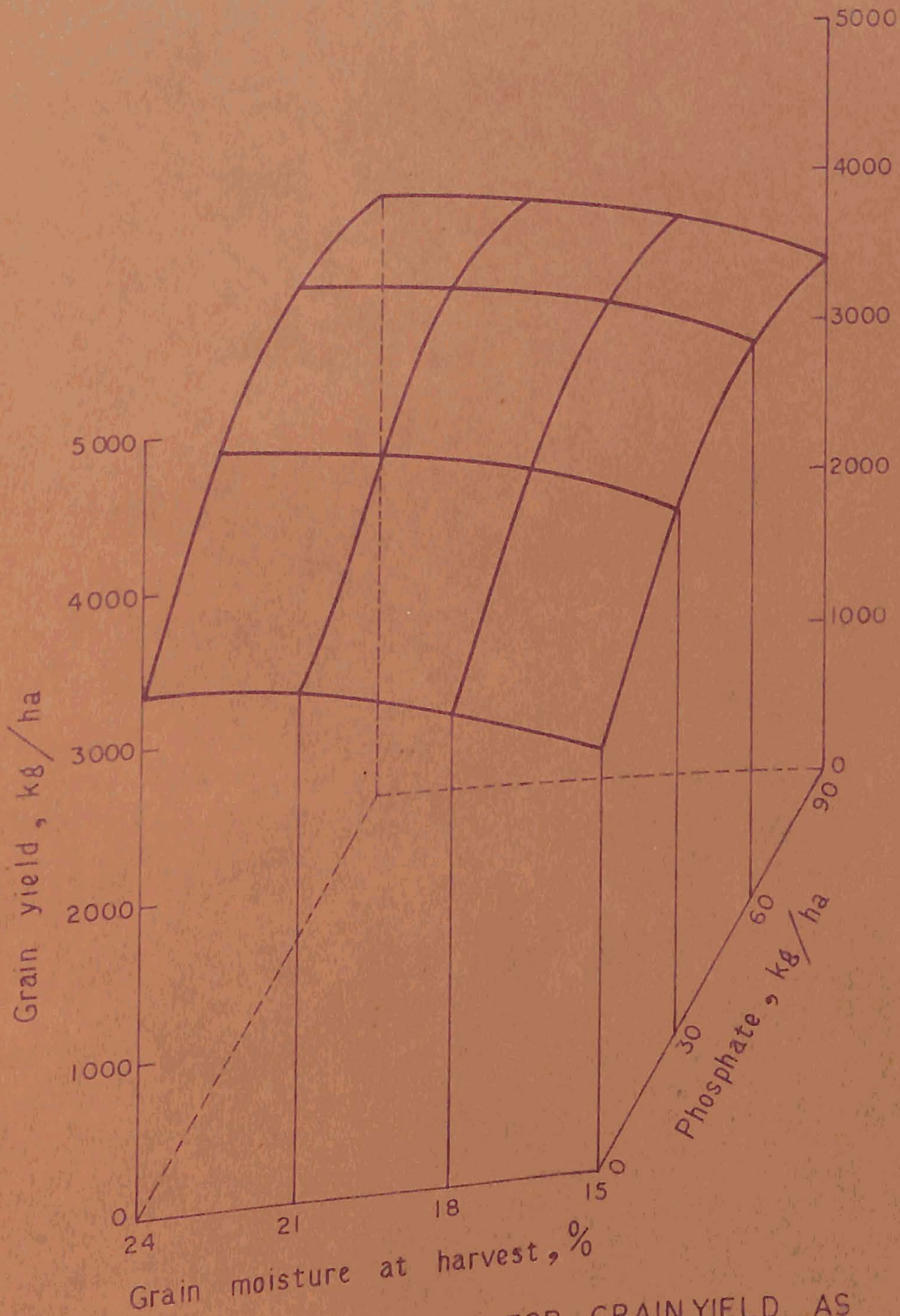


FIG.4.3.PRODUCTION SURFACE FOR GRAIN YIELD AS A FUNCTION OF PHOSPHATE AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT I).

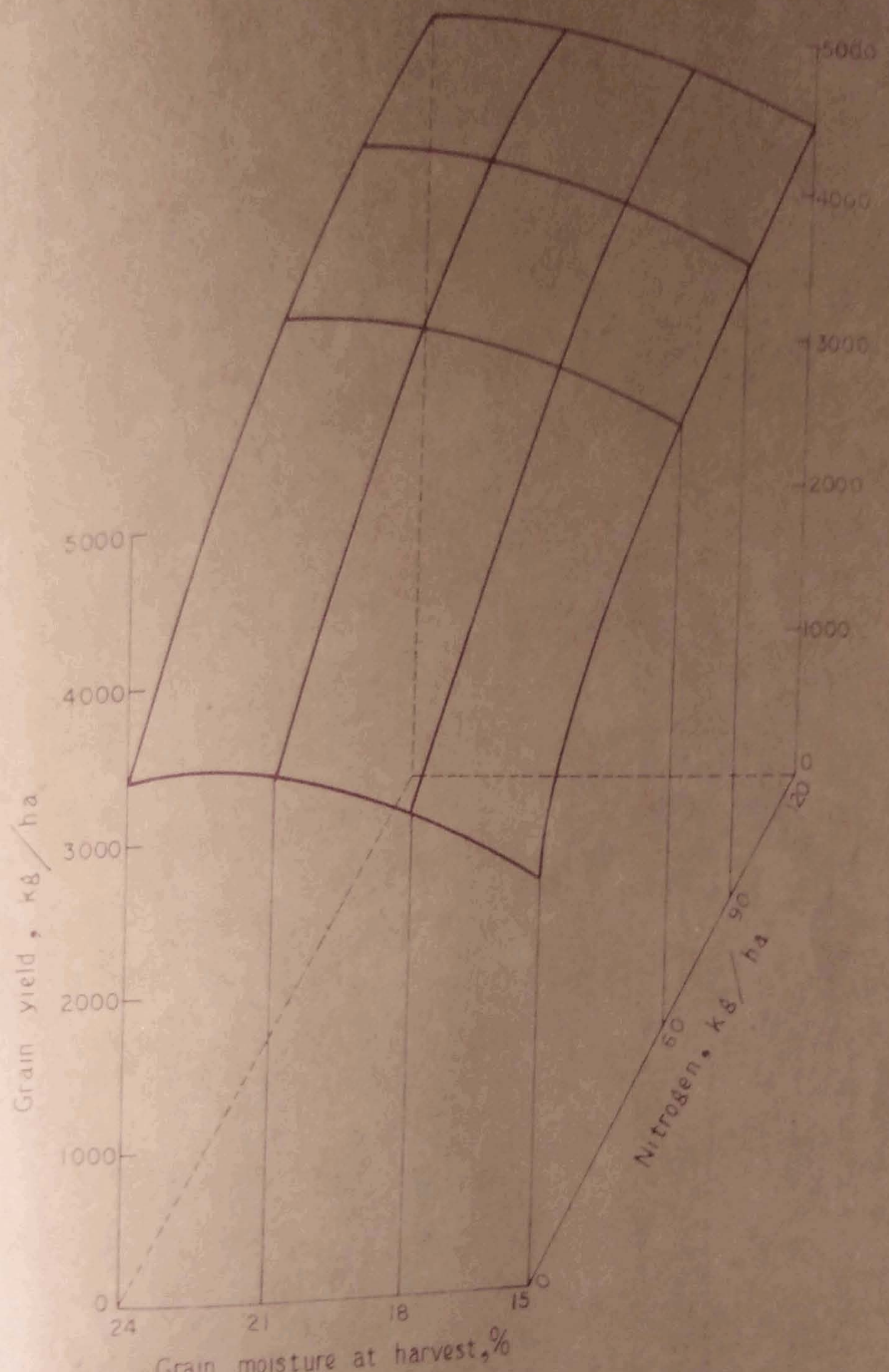


FIG.4.4. PRODUCTION SURFACE FOR GRAIN YIELD AS A FUNCTION OF NITROGEN AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR22 (EXPERIMENT 2).

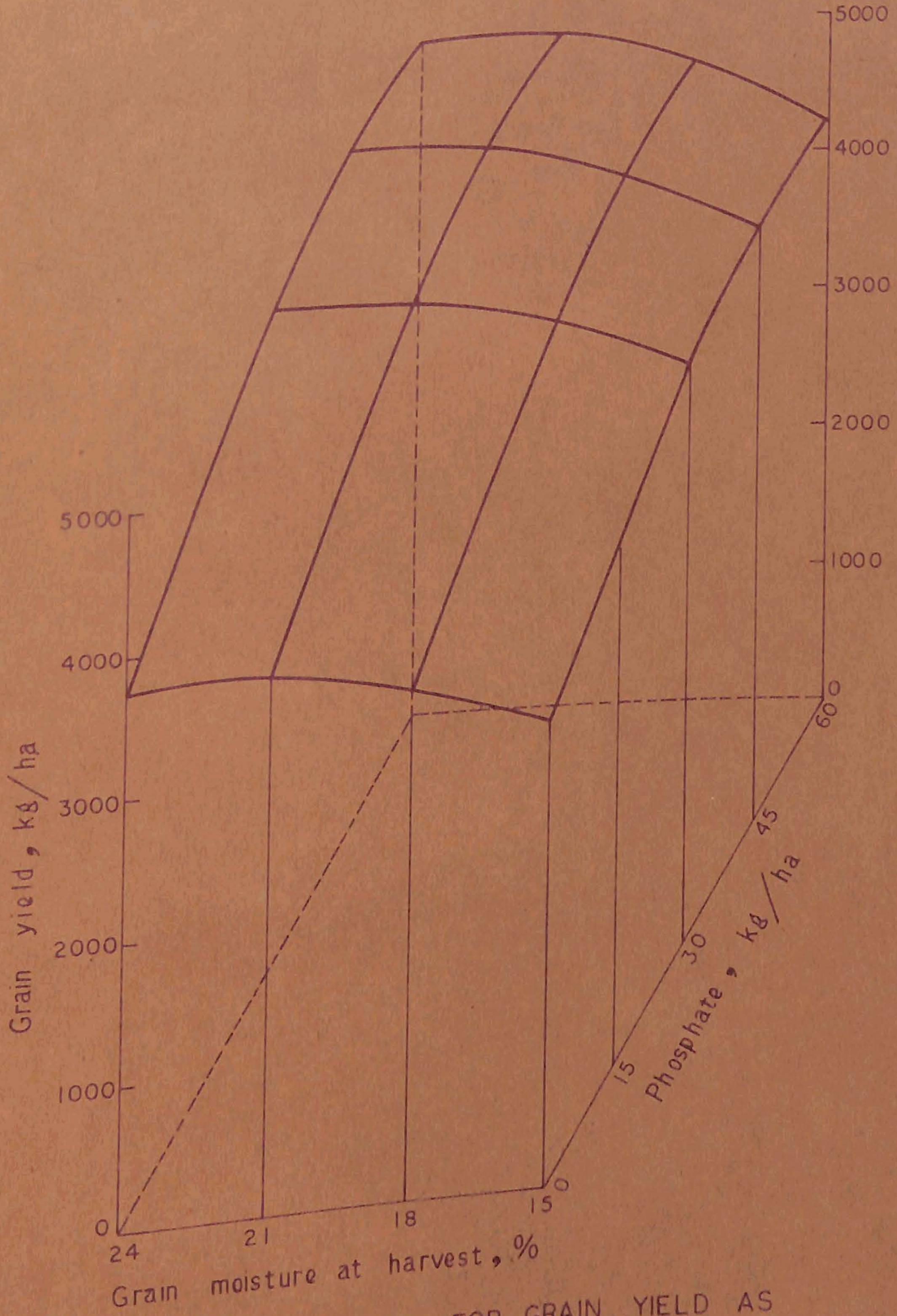


FIG. 4.5. PRODUCTION SURFACE FOR GRAIN YIELD AS A FUNCTION OF PHOSPHATE AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT 2).

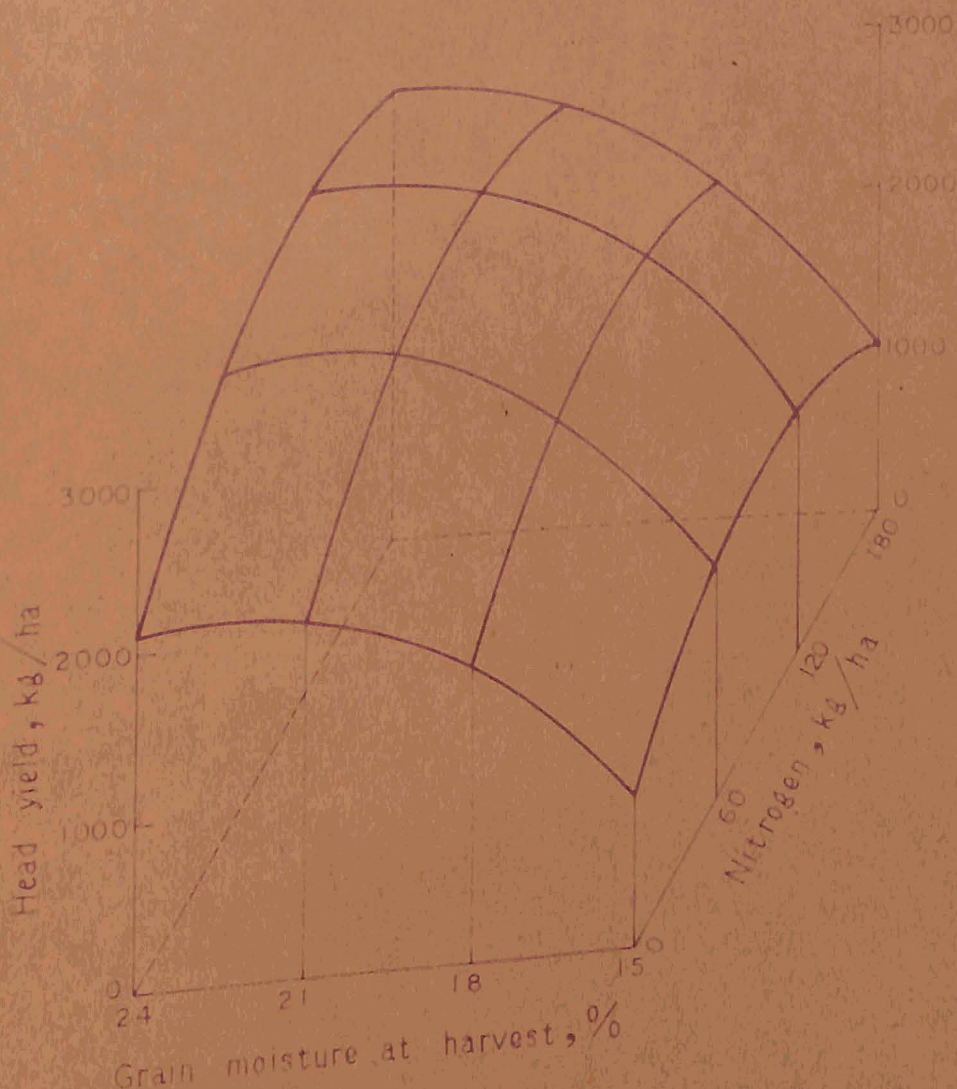


FIG. 4.6. PRODUCTION SURFACE FOR HEAD YIELD AS A FUNCTION OF NITROGEN AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT I).

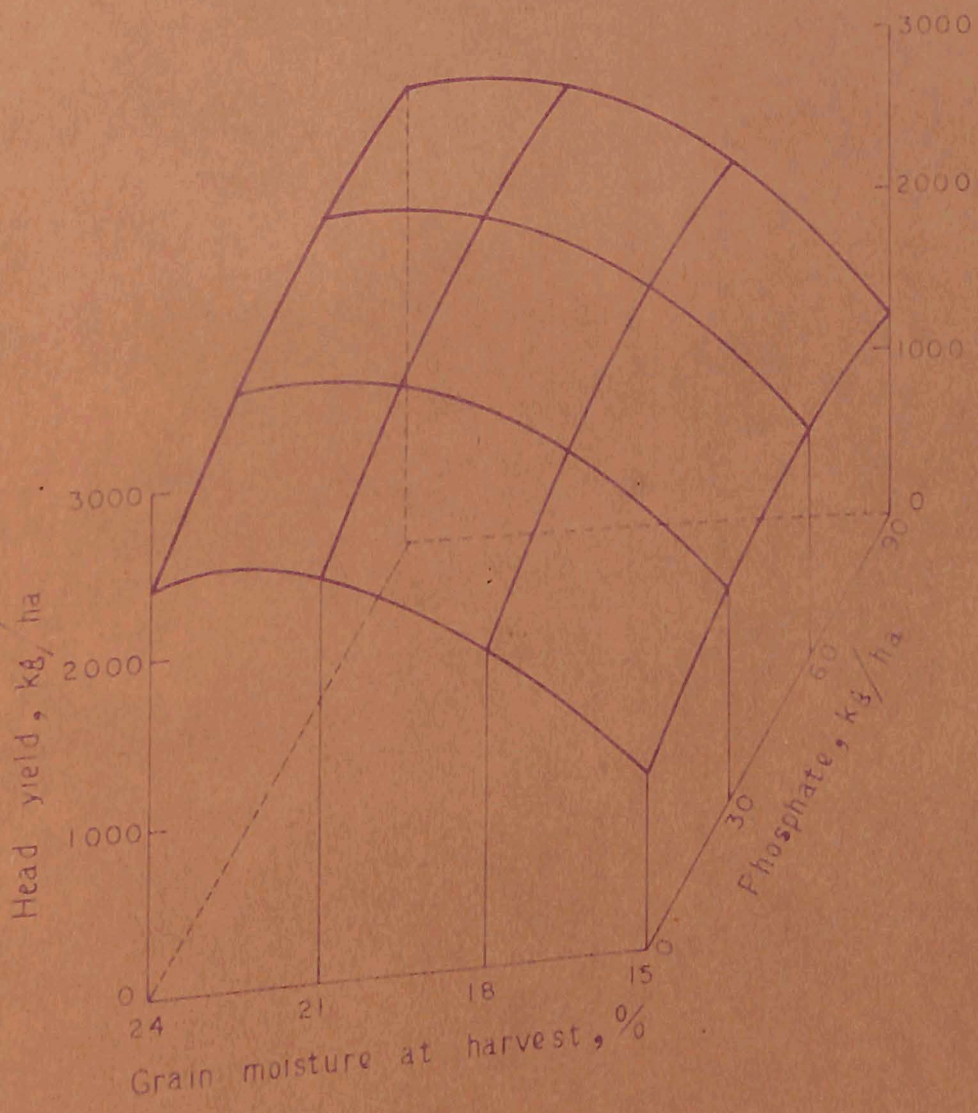


FIG.4.7. PRODUCTION SURFACE FOR HEAD YIELD AS A FUNCTION OF PHOSPHATE AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT I).

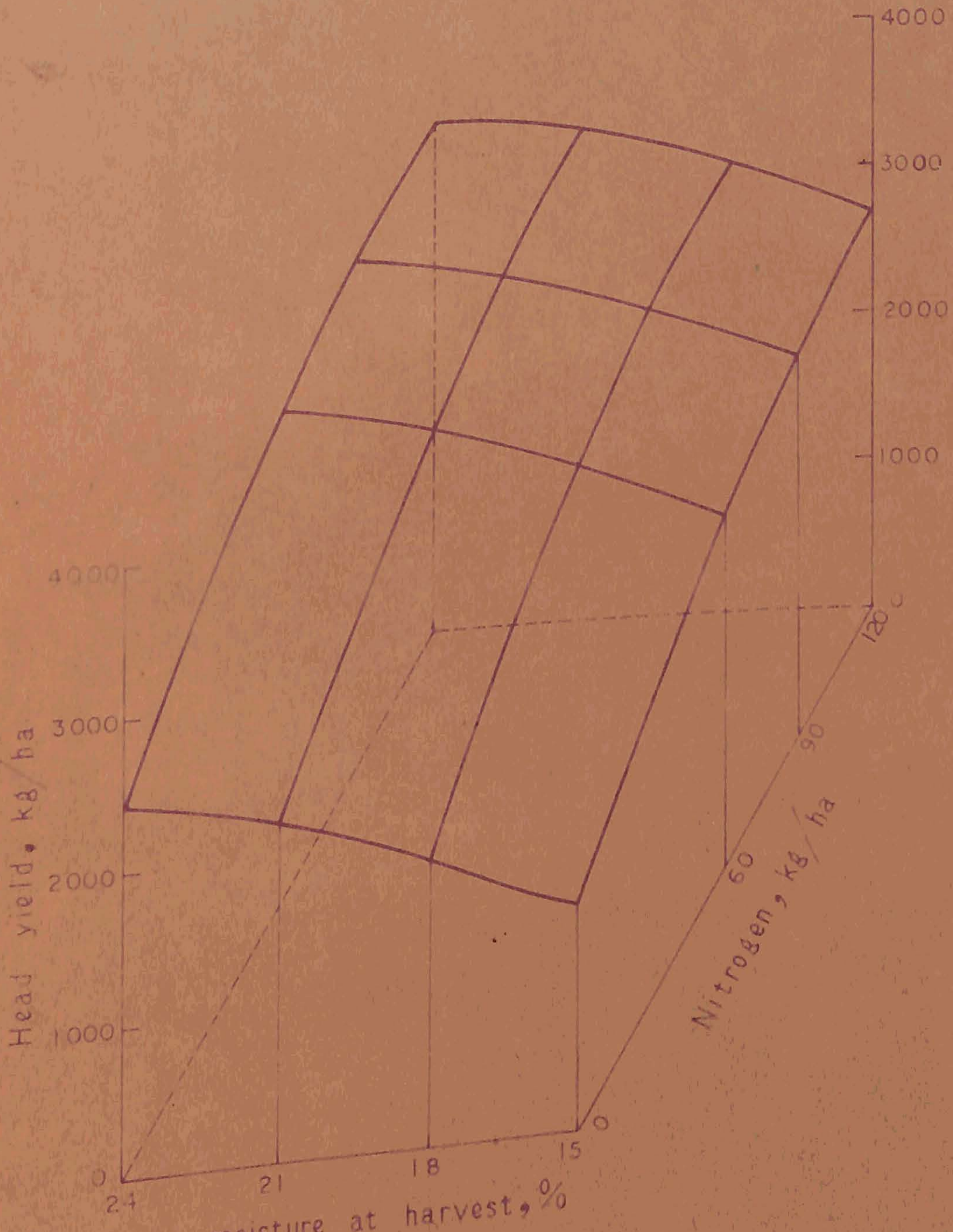


FIG.4.8. PRODUCTION SURFACE FOR HEAD YIELD AS A FUNCTION OF NITROGEN AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT 2).

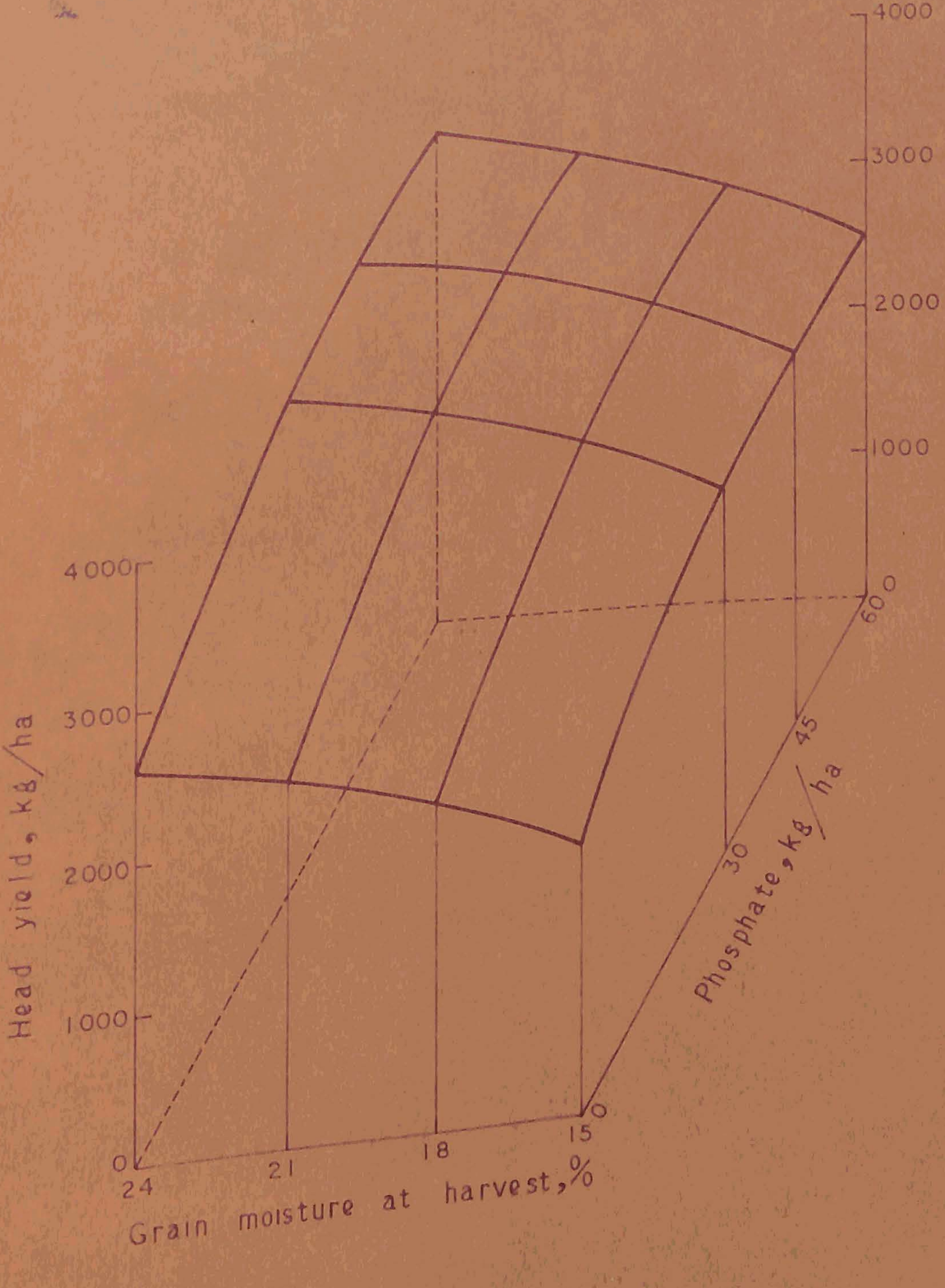


FIG.4.9. PRODUCTION SURFACE FOR HEAD YIELD AS A FUNCTION OF PHOSPHATE AND GRAIN MOISTURE AT HARVEST FOR THE CULTIVAR IR 22 (EXPERIMENT 2).

P = phosphate, kg/ha

S = water requirement, cm

M = grain moisture content at harvest, %

b = regression coefficient

a = constant

R^2 = .97.

Grain yield is maximum when the elasticity of production = 0

or when $\frac{\partial Y}{\partial N} = 22.9261 - 0.2104\ N + 0.0149\ P + 0.01545\ S - 0.1076\ M = 0$ ... (4.9a)

$$\frac{\partial Y}{\partial P} = 18.3380 - 0.3610 + 0.0149\ N - 0.0029\ S - 0.0236\ M = 0 \quad \text{... (4.9b)}$$

$$\frac{\partial Y}{\partial S} = 45.5503 - 0.3450\ S + 0.0154\ N - 0.0029\ P + 0.1664\ M = 0 \quad \text{... (4.9c)}$$

$$\frac{\partial Y}{\partial M} = 345.9155 - 15.4660\ M - 0.1076\ N - 0.0236\ P + 0.1664\ S = 0 \quad \text{... (4.9d)}$$

By solving these four simultaneous equations

Y_{max} = when N = 112, P = 53, S = 148 and M = 23.1

The conditions for Y_{max} as described in equations 3.4b, 3.4c, 3.4d and 3.4e are satisfied for the equation 4.9.

By substituting the optimum values of N, P, S and M to the above equation (4.9) a maximum grain yield of 4606 kg/ha was attained.

Experiment 2

$$
\begin{aligned}
Y = & -1862 + \underset{(7.194)}{22.9814\, N} - \underset{(-12.28)}{0.0947\, N^2} + \underset{(0.688)}{4.4221\, P} \\
& - \underset{(-5.902)}{0.1843\, P^2} + \underset{(3.040)}{12.6961\, S} - \underset{(-4.021)}{0.0764\, S^2} \\
& + \underset{(7.267)}{403.7710\, M} - \underset{(-7.296)}{9.4630\, M^2} - \underset{(-0.683)}{0.0097\, NP} \\
& + \underset{(1.337)}{0.0264\, NS} - \underset{(-1.869)}{0.1674\, NM} + \underset{(1.776)}{0.0698\, PS} \\
& + \underset{(1.965)}{0.3605\, PM} + \underset{(0.773)}{0.1273\, SM} \qquad \ldots (4.10)
\end{aligned}
$$

$$R^2 = 0.97$$

Grain yield is maximum when the elasticity of production = 0

or when

$$\frac{\partial Y}{\partial N} = 22.9814 - 0.1894\, N - 0.0097\, P + 0.0264\, S - 0.1674\, M = 0 \qquad \ldots (4.10a)$$

$$\frac{\partial Y}{\partial P} = 4.4221 - 0.3686\, P - 0.0097\, N + 0.0698\, S + 0.3605\, M = 0 \qquad \ldots (4.10b)$$

$$\frac{\partial Y}{\partial S} = 12.6961 - 0.1528\, S + 0.0264\, N + 0.0698\, P + 0.1273\, M = 0 \qquad \ldots (4.10c)$$

$$\frac{\partial Y}{\partial M} = 403.7710 - 18.9260\, M - 0.1674\, N + 0.3605\, P + 0.1273\, S = 0 \qquad \ldots (4.10d)$$

By solving these four simultaneous equations

Y_{max} = When N = 119, P = 59, S = 149 and M = 22.4.

The conditions for Y_{max} as described in equations 3.4b, 3.4c, 3.4d and 3.4e are satisfied for the equation 4.10.

By substituting the optimum values of N, P, S and M to the above equation (4.10) a maximum grain yield of 5112 kg/ha was attained

Head yield

Experiment 1

$$
\begin{aligned}
H = & -14083 + \underset{(3.532)}{9.1202\,N} - \underset{(-14.618)}{0.0651\,N^2} + \underset{(1.803)}{9.2857\,P} \\
& - \underset{(-4.087)}{0.0728\,P^2} + \underset{(2.701)}{40.4468\,S} - \underset{(1.775)}{0.0890\,S^2} + \underset{(16.392)}{1192.5234\,M} \\
& - \underset{(-15.443)}{25.1940\,M^2} - \underset{(-0.137)}{0.0010\,NP} - \underset{(-0.578)}{0.0076\,NS} + \underset{(3.978)}{0.2802\,NM} \\
& - \underset{(-0.379)}{0.0111\,PS} + \underset{(0.044)}{0.0061\,PM} - \underset{(-2.419)}{0.5712\,SM} \qquad \ldots (4.11)
\end{aligned}
$$

$R^2 = 0.96$

Head yield is maximum when the elasticity of production = 0

or when $\frac{\partial H}{\partial N} = 9.1202 - 0.1302\,N - 0.0010\,P - 0.0076\,S + 0.2802\,M = 0 \qquad \ldots (4.11a)$

$$\frac{\partial H}{\partial P} = 9.2857 - 0.1456\,P - 0.0010\,N - 0.0111\,S + 0.0061\,M = 0 \qquad \ldots (4.11b)$$

$$\frac{\partial H}{\partial S} = 40.4468 - 0.1780\,S - 0.0076\,N - 0.0111\,P - 0.5712\,M = 0 \qquad \ldots (4.11c)$$

$$\frac{\partial H}{\partial M} = 1192.5234 - 50.3880\,M + 0.2802\,N + 0.0061\,P - 0.5712\,S = 0 \qquad \ldots (4.11d)$$

By solving these four simultaneous equations

H_{max} = When N = 110, P = 53, S = 147 and M = 22.6

The conditions for H_{max} as described in equations 3.4b, 3.4c, 3.4d and 3.4e are satisfied for the equation 4.11.

By substituting the optimum values of N, P, S and M to the above equation (4.11) a maximum head yield of 3117 kg/ha was attained.

Experiment 2

$$
\begin{aligned}
H = & - 2375 + \underset{(4.231)}{13.4354}\, N - \underset{(-8.066)}{0.0618}\, N^2 + \underset{(1.843)}{11.7844}\, P \\
& - \underset{(-5.038)}{0.1564}\, P^2 + \underset{(1.465)}{6.080}\, S - \underset{(-1.902)}{0.0359}\, S^2 + \underset{(5.905)}{326.2136}\, M \\
& - \underset{(-4.692)}{6.050}\, M^2 - \underset{(-0.383)}{0.0054}\, NP + \underset{(2.047)}{0.0401}\, NS \\
& - \underset{(-1.824)}{0.1624}\, NM + \underset{(0.095)}{0.0037}\, PS + \underset{(0.894)}{0.1631}\, PM \\
& + \underset{(10.143)}{0.0234}\, SM \qquad \ldots (4.12)
\end{aligned}
$$

$R^2 = 0.96$

Head yield is maximum when the elasticity of production = 0

or when $\frac{\partial H}{\partial N} = 13.4354 - 0.1236\, N - 0.0054\, P + 0.0401\, S - 0.1624\, M = 0$ ... (4.12a)

$\frac{\partial H}{\partial P} = 11.7844 - 0.3128\, P - 0.0054\, N + 0.0037\, S + 0.1631 M = 0$ ... (4.12b)

$$\frac{\partial H}{\partial S} = 6.0800 - 0.0718\ S + 0.0401\ N - 0.0037\ P + 0.0234\ M = 0 \quad \ldots (4.$$

$$\frac{\partial H}{\partial M} = 326.2136 - 12.1000\ M - 0.1624\ N + 0.1631\ P + 0.0234\ S = 0 \quad \ldots (4.1$$

By solving these four simultaneous equations

H_{max} = When N = 124, P = 51, S = 159, M = 26.2

The conditions for H_{max} as described in equations, 3.4b, 3.4c, 3.4d and 3.4e are satisfied for the equation 4.12.

By substituting the optimum values of N, P, S and M to the above equation (4.12) a maximum head yield of 3562 kg/ha was attained.

Effect of Nitrogen and Phosphate on Rice Varieties - Sona, Jayanti, Pankaj and IR 22 :

Performance of the four rice varieties for yield and milling quality was studied by growing them under different levels of nitrogen and phosphate during 'aman' (June to November) 1972 and 1973. During 1972 (Experiment 3) the levels of nitrogen were 0,60,120 and 180 kg/ha and the phosphate levels were 0.30,60 and 90 kg/ha. Whereas during 1973 (Experiment 4) the levels of nitrogen were 0, 60, 90 and 120 kg/ha and levels of phosphate were 0, 30, 45 and 60 kg/ha. In both the experiments, 5 ± 2 cm continuous submergence was maintained during the entire growing period of the crop and all the varieties were harvested between 19.5 and 16.5 per cent grain moisture content.

<u>Grain yield and yield attributes</u> Among the different varieties tried, Pankaj gave maximum grain yield followed by IR 22, Sona and Jayanti in order. The yield difference between the varieties were found signficant except between Sona and Jayanti in Experiment 3 and Sona and IR 22 in Experiment 4 where they were found on par with each other. The significant variation in yield between the varieties was found almost associated with significant variation in number of productive tillers per hill, number of grains per panicle and thousand grain weight. However, in case of variety IR 22, only the number

of grains per panicle did not follow the trend (Table 4.29 and 4.30).

The grain yield under different treatments of nitrogen has revealed that in Experiment 3 there was significant increase with the increase in the level of nitrogen from 0 to 60, and 120 kg/ha whereas, significant decrease was noted when the level was raised from 120 to 180 kg/ha. In Experiment 4 significant increase in yield was noted with the increase in the level of nitrogen upto 90 kg/ha and thereafter at 120 kg N/ha the increase was not significant. Significant increase in grain yield was found associated with the significant increase in number of productive tillers per hill and number of grains per panicle (Table 4.29 and 4.30).

It is revealed from the interaction between varieties and levels of nitrogen for grain yield that irrespective of the levels of nitrogen in Experiment 3, variety Pankaj was found superior than all other varieties. The superiority of variety IR 22 over Sona was noted by the significantly higher grain yield when the nitrogen levels were 60 kg/ha and above. The yield performance of varieties Sona and Jayanti were found almost similar under the levels of nitrogen above 60 kg/ha. The grain yield performance of all the varieties under the different levels of nitrogen were found almost associated with the number of productive tillers per hill (Table 4.31).

Table 4.29 Grain yield and yield attributes as influenced by different varieties and levels of nitrogen and phosphate - Experiment 3.

Treatment	Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/panicle	1000 grain weight, g
Varieties				
Bona	3952	9.2	108.5	18.51
Jayanti	3822	9.6	105.1	18.58
Pankaj	4891	10.3	113.8	24.76
IR 22	4255	9.9	92.5	22.82
	**	**	**	**
Levels of nitrogen, kg/ha				
0	3454	9.1	86.6	21.18
60	4319	9.6	112.6	21.20
120	4790	10.8	119.5	21.19
180	4347	10.5	101.0	21.20
	**	**	**	NS
Levels of phosphate, kg/ha				
0	3693	9.2	93.8	21.17
30	4203	9.8	109.9	21.20
60	4565	10.1	109.5	21.21
90	4449	9.9	106.5	21.19
	**	**	**	NS
S.Em.±	66.30	0.06	1.51	0.02
L.S.D. (P=0.05)	136	0.13	3.14	0.05
L.S.D. (P=0.01)	185	0.18	4.25	0.06

** Significant at (P=0.01); NS = Not significant.

Table 4.30 Grain yield and yield attributes as influenced by different varieties and levels of nitrogen and phosphate – Experiment 4.

Treatment	Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/panicle	1000 grain weight, g
Varieties				
Sona	4611	10.1	113.1	18.69
Jayanti	4326	9.9	110.0	18.68
Pankaj	5192	10.7	120.1	24.71
IR 22	4616	10.2	104.4	22.82
	**	**	**	**
Levels of nitrogen, kg/ha				
0	3767	8.6	98.4	21.20
60	4766	10.0	112.9	21.23
90	5094	11.3	116.6	21.23
120	5118	11.0	119.7	21.24
	**	**	**	NS
Levels of phosphate, kg/ha				
0	4135	9.8	97.9	21.23
30	4673	10.1	114.6	21.22
45	4921	10.6	116.7	21.21
60	5016	10.4	118.4	21.24
	**	**	**	NS
S.Em.±	49.97	0.06	0.83	0.07
L.S.D. (P=0.05)	103	0.10	1.72	0.14
L.S.D. (P=0.01)	139	0.20	2.32	0.19

** Significant at (P=0.01); NS = Not significant.

Table 4.31 Grain yield and number of productive tillers per hill as affected by interaction between varieties and nitrogen - Experiment 3.

Varieties	Grain yield, kg/ha				Productive tillers/hill			
	Levels of nitrogen, kg/ha				Levels of nitrogen, kg/ha			
	0	60	120	180	0	60	120	180
Sona	3351	3995	4480	3980	7.4	8.9	10.5	10.1
Jayanti	3069	4017	4437	3768	8.4	9.7	10.5	10.0
Pankaj	4082	4962	5523	4956	8.8	10.1	11.2	11.2
IR 24	3314	4303	4920	4682	8.0	9.8	11.1	10.8
S.Em.±		132.64				0.13		
L.S.D.(P=0.05)		274				0.3		
L.S.D.(P=0.01)		370				0.4		

The yield performance under different levels of phosphate revealed that there was significant increase with the increase in the levels from 0 to 30 and 60 kg/ha in Experiment 3 and 0 to 30 and 45 kg/ha in Experiment 4. In both the Experiments 3 and 4, further increase in phosphate levels, from 60 to 90 and 45 to 60 kg/ha respectively, did not bring any appreciable increase in yield. The significant increase in yield was found almost associated with the significant increase in the number of productive tillers per hill and number of grains per panicle (Table 4.29 and 4.30).

Milling yield   The total mill yield per hectare was maximum in case of variety Pankaj followed by IR 22, Sona and Jayanti. There was significant difference between them except among Sona and Jayanti in Experiment 3 and IR 22 and Pankaj in Experiment 4 where they were found on par with each other. However, regarding total mill yield percentage, it was found maximum in case of IR 22 followed by Sona, Jayanti and Pankaj. While there was significant difference between all the varieties for total mill yield percentage in Experiment 3, significant difference was noted only between IR 22 and other three varieties in Experiment 4 (Table 4.32 and 4.33).

It is apparent from the Table 4.32 and 4.33 that there was significant increase in total mill yield per hectare with the increase in nitrogen and phosphate levels upto 120 and 60 kg/ha in Experiment 3 and 90 and 45 kg/ha in Experiment 4

Table 4.32 Total mill yield and head yield as influenced by different varieties and levels of nitrogen and phosphate - Experiment 3.

Treatment	Total mill yield		Head yield	
	kg/ha	%	kg/ha	%
Varieties				
Sona	2392	73.2	2119	53.6
Jayanti	2789	73.0	2068	54.1
Pankaj	3558	72.8	2693	55.4
IR 32	3118	73.3	2593	60.9
	**	**	**	**
Levels of nitrogen, kg/ha				
0	2512	72.8	1921	55.6
60	3156	73.1	2403	55.7
120	3507	73.2	2688	56.2
180	3182	73.2	2461	56.5
	**	**	**	**
Levels of phosphate, kg/ha				
0	2706	73.2	2123	57.5
30	3067	73.0	2377	56.5
60	3332	73.0	2465	55.3
90	3252	73.1	2498	54.7
	**	**	**	**
S.Em.±	39.95	0.06	32.60	0.20
L.S.D. (P=0.05)	82	0.12	67	0.42
L.S.D. (P=0.01)	112	0.16	91	0.56

** Significant at (P=0.01)

Table 4.33 Total mill yield and head yield as influenced by different varieties and levels of nitrogen and phosphate - Experiment 4.

Treatment	Total mill yield		Head yield	
	kg/ha	%	kg/ha	%
Varieties				
Sona	3345	72.5	2595	56.2
Jayanti	3136	72.5	2469	57.0
Pankaj	3768	72.5	3027	58.4
IR 22	3386	74.4	2896	62.9
	**	**	**	**
Levels of nitrogen, kg/ha				
0	2727	72.4	2185	58.0
60	3463	72.7	2772	58.3
90	3714	72.9	2990	58.8
120	3731	72.9	3040	59.4
	**	**	**	**
Levels of phosphate kg/ha				
0	3005	72.6	2509	60.6
30	3411	73.0	2757	58.8
45	3577	72.7	2853	57.9
60	3642	72.6	2868	57.1
	**	**	**	**
S.Em.±	34.48	0.08	28.80	0.21
L.S.D. (P=0.05)	71	0.16	59	0.44
L.S.D. (P=0.01)	96	0.23	81	0.60

** Significant at (P=0.01)

respectively. Regarding total mill yield per cent, although there was increasing trend with the increasing level of nitrogen upto 120 kg/ha in Experiment 3 and 90 kg/ha in Experiment 4, no definite trend could be obtained with the increasing level of phosphate in any of the two experiments. It was further noted from the interaction between nitrogen and phosphate levels (Table 4.34) that there was significant increase in total mill yield with the increase in phosphate level from 30 to 45 kg/ha at nitrogen levels of 0 and 60 kg/ha. But at higher levels of nitrogen 90 and 120 kg/ha significant increase was noted only upto 30 kg P_2O_5/ha. In case of total mill yield percentage, significant increase was noted at 30 kg P_2O_5/ha level than that of other levels only when the crop was fertilized with nitrogen at 60 kg/ha and above.

The performance of the four different varieties for total mill yield varied with the varying levels of nitrogen. There was significant decrease when the level of nitrogen was raised from 120 to 180 kg/ha except for the variety Pankaj where the total mill yield did not decrease appreciably even at 180 kg N/ha. The total mill yield of Pankaj under all the levels of nitrogen was found superior to that of other varieties. Similar was the case for IR 22 when compared with variety Sona and Jayanti. Only at 0 level of nitrogen, variety IR 22 was found on par with Sona (Table 4.35).

Table 4.34 Total mill yield as affected by interaction between nitrogen and phosphate - Experiment 4.

Levels of nitrogen, kg/ha	Total mill yield, kg/ha			
	Levels of phosphate, kg/ha			
	0	30	45	60
0	2204 (72.3)	2654 (72.3)	2966 (72.7)	3080 (72.4)
50	2966 (72.4)	3380 (73.2)	3567 (72.7)	3660 (72.6)
90	3342 (72.7)	3766 (73.3)	3856 (72.7)	3880 (72.7)
120	3492 (72.8)	3863 (73.3)	3927 (72.8)	3937 (72.7)
S.Em.±	68.96	(0.16)		
L.S.D. (P=0.05)	142	(0.33)		
L.S.D. (P=0.01)	193	(0.45)		

The values under parenthesis represent the total mill yield per cent.

Table 4.35 Total mill yield as affected by interaction between varieties and nitrogen - Experiment 3.

Varieties	Total mill yield, kg/ha			
	Levels of nitrogen, kg/ha			
	0	60	120	180
Sona	2439	2929	3283	2917
Jayanti	2232	2931	3240	2753
Pankaj	2958	3609	3840	3724
IR 22	2420	3154	3665	3434
S.Em.±		79.89		
L.S.D. (P=0.05)		165		
L.S.D. (P=0.01)		223		

The varietal performance for total mill yield percentage under the varying levels of phosphate (Table 4.36) revealed that variety IR 22 was significantly better than all other varieties. However, discrepancy was noted with Sona in Experiment 3 where at 30 kg/ha level of phosphate, it performed better than IR 22. In Experiment 4, variety Pankaj performed significantly better than Sona and Jayanti, only when the phosphate level was raised to 60 kg/ha but was not found superior than IR 22. Although the variation in total mill yield per cent is statistically significant among the varieties, levels of nitrogen and phosphate, but for all practical purposes, it can not be accounted to adjudge the superiority of any variety, level of nitrogen or phosphate as the magnitude of variation is too little.

Head yield The head yield was maximum in case of variety Pankaj followed by IR22,Sona and Jayanti. There was significant difference between them except among Sona and Jayanti in Experiment 3 where they were found on par with each other. On the other hand, the head yield recovery percentage was found maximum in case of IR 22 followed by Pankaj, Jayanti and Sona and the difference between them was found significant (Table 4.32 and 4.33).

Significant increase in head yield and its recovery percentage was noted with the increase in nitrogen levels

Table 4.36 Total mill yield per cent as affected by interaction between varieties and phosphate - Experiments 3 and 4.

Varieties	Total mill yield,%							
	Levels of phosphate,kg/ha				Levels of phosphate,kg/ha			
	0	30	60	90	0	30	45	60
	Experiment 3				Experiment 4			
Sona	73.2	73.3	73.1	73.1	72.6	72.7	72.4	72.3
Jayanti	73.0	72.8	72.9	73.1	72.3	72.8	72.7	72.3
Pankaj	73.1	72.6	73.0	73.0	72.1	72.9	72.6	72.6
IR 22	73.4	73.1	73.2	73.4	73.2	73.8	73.2	73.1
S.Em.±	0.12				0.16			
L.S.D.(P=0.05)	0.24				0.33			
L.S.D.(P=0.01)	0.32				0.45			

upto 150 kg/ha in both the Experiments 3 and 4. But with the further increase in nitrogen level to 180 kg/ha in Experiment 3, significant decrease was noted. Contrary to the beneficial effect of nitrogen, particularly increasing head yield recovery percentage, the phosphate application did not benefit the crop rather significant decrease was noted with the increase in its level. However, significant increase in head yield was noted, as a result of increase in grain yield of the crop, with the increase in phosphate level upto 60 kg/ha in Experiment 3 and 45 kg/ha in Experiment 4 (Table 4.32 and 4.33).

It is apparent from the Table 4.37 that, irrespective of the phosphate levels, 0, 30, 45 and 60 kg/ha, significant increase in head yield was noted with the increase in nitrogen level from 0 to 60 and 90 kg/ha. Further increase in nitrogen level to 120 kg/ha brought significant increase in head yield only at 30 kg P_2O_5/ha.

The performance of four different varieties for head yield and its recovery percentage varied with the varying levels of nitrogen. The head yield per hectare of variety Pankaj under all the levels of nitrogen was found significantly higher than all other varieties except IR 22 where in Experiment 3, significantly higher head yield was noted when the nitrogen level was raised to 180 kg/ha. Further in Experiment 2, variety Pankaj was found at par with IR 22 at

Table 4.37 Head yield as affected by interaction between nitrogen and phosphate - Experiment 4.

Nitrogen, kg/ha	Head yield, kg/ha			
	Levels of phosphate, kg/ha			
	0	30	45	60
0	1831	2147	2313	2415
60	2451	2707	2838	2883
90	2820	3020	3078	3058
120	2936	3156	3180	3116
S.Em.±		57.60		
L.S.D. (P=0.05)		119		
L.S.D. (P=0.01)		161		

120 kg N/ha (Table 4.38). It is apparent from the table that the head yield recovery percentage of variety IR 22 was significantly higher than all other varieties under all the levels of nitrogen. While there was decrease in head yield recovery percentage with the increasing level of nitrogen in case of variety Pankaj an opposite trend was noted in case of varieties IR 22, Sona and Jayanti. The extent of decrease in case of Pankaj and increase in case of IR 22, did not show any appreciable variation beyond 60 kg N/ha level. Whereas, in case of variety Sona and Jayanti the recovery percentage were significantly higher even at 120 kg N/ha level over that of 60 kg N/ha.

The interaction between varieties and phosphate levels revealed that the head yield recovery per cent was maximum in IR 22 followed by Pankaj, Jayanti and Sona under all the levels of phosphate. The recovery percentage was decreased considerably in all the varieties except IR 22 when the levels of phosphate was raised from 30 to 60 kg/ha. In Experiment 4 by increasing the level of phosphate from 30 to 45 kg/ha, significant decrease in recovery percentage was noted only for varieties Sona and Jayanti. Regarding Pankaj, the recovery percentage was significantly decrease even at 30 kg P_2O_5/ha in both the experiments. In case of IR 22, while there was significant decrease even at 30 kg P_2O_5/ha in Experiment 4, in Experiment 3 significant decrease was noted only when the level of phosphate was raised from 60 to 90 kg/ha(Table 4.39).

Table 4.38 Head yield as affected by interaction between varieties and nitrogen - Experiments 3 and 4

Varieties	Head yield,kg/ha							
	Levels of nitrogen,kg/ha				Levels of nitrogen,kg/ha			
	0	60	120	180	0	60	90	120
	Experiment 3				Experiment 4			
Sona	1781 (53.3)	2118 (53.0)	2413 (53.9)	2162 (54.4)	2092	2545	2797	2945
Jayanti	1634 (53.3)	2152 (53.7)	2418 (54.5)	2070 (55.1)	1941	2399	2727	2809
Pankaj	2278 (56.0)	2723 (55.1)	3042 (55.3)	2729 (55.3)	2492	2999	3290	3328
IR 22	1989 (60.0)	2620 (60.9)	2879 (61.0)	2884 (61.6)	2180	2935	3161	3307
S.Em.±		65.20	(0.41)			57.60		
L.S.D.(P=0.05)		135	(0.84)			119		
L.S.D.(P=0.01)		182	(1.14)			161		

The values under parenthesis represent the head yield recovery per cent.

Table 4.39 Head yield recovery per cent as affected by interaction between varieties and phosphate - Experiments 3 and 4.

Varieties	Head yield,%							
	Levels of phosphate,kg/ha				Levels of phosphate,kg/ha			
	0	30	60	90	0	30	45	60
	Experiment 3				Experiment 4			
Sona	54.3	54.6	53.1	52.6	57.3	57.3	55.7	54.8
Jayanti	55.8	55.2	53.0	52.6	57.8	58.0	56.7	55.7
Pankaj	58.6	55.3	54.2	53.5	61.7	58.4	57.2	56.4
IR 22	61.5	61.0	61.0	60.2	65.6	62.1	62.0	61.8
S.Em.±	0.41				0.43			
L.S.D.(P=0.05)	0.84				0.88			
L.S.D.(P=0.01)	1.14				1.13			

Economic Evaluation :

Comparative efficiency of different varieties under the different levels of nitrogen and phosphate was finally evaluated on the basis of their economic returns. The evaluation was made by calculating treatmentwise gross return and net return of rough rice and polished rice with broken, bran and husk separately. This was done in order to find out the extent of additional return which can be expected on milling.

<u>Gross return</u> It is apparent from the estimates on gross return for rough rice and polished rice with broken, bran and husk for different varieties that the variety Pankaj gave maximum gross return followed by IR 22, Sona and Jayanti and the difference between them was found significant. However, in Experiment 4, no appreciable difference was noted between varieties IR 22 and Sona for rough rice only (Table 4.40 and 4.41).

There was significant increase in gross return for rough rice and polished rice with broken, bran and husk, by the increase in the level of nitrogen from 0 to 60 and 120 kg/ha in Experiment 3 and from 0 to 60 and 90 kg N/ha in Experiment 4. Increase in nitrogen level over 120 kg/ha in Experiment 3 brought considerable reduction in gross return while in Experiment 4 increase over 90 kg N/ha did not show any appreciable increase (Table 4.40 and 4.41). Under all the levels of nitrogen variety Pankaj had significantly higher gross returns for rough rice and polished rice with broken, bran and husk as compared to

Table 4.40 Gross return and net return per hectare for rough rice and polished rice with by-products of the cultivars Sona, Jayanti, Pankaj and IR 22 as influenced by the levels of nitrogen and phosphate - Experiment 3.

Treatments	Gross return		Net return	
	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha
Varieties				
Sona	3281	3861	945	1526
Jayanti	3174	3704	839	1369
Pankaj	4001	4751	1716	2415
IR 22	3582	4318	1196	1983
	**	**	**	**
Levels of nitrogen, kg/ha				
0	2866	3414	730	1278
60	3586	4228	1317	1959
120	3976	4705	1574	2304
180	3610	4287	1075	1752
	**	**	**	**
Levels of phosphate, kg/ha				
0	3066	3667	866	1455
30	3488	4176	1194	1882
60	3694	4348	1315	1972
90	3790	4443	1321	1984
	**	**	**	**
S.Em.±	46.51	72.19	46.51	72.19
L.S.D. (P=0.05)	96	149	96	149
L.S.D. (P=0.01)	130	202	130	202

** Significant at (P=0.01).

Table 4.41 Gross return and net return per hectare for rough rice and polished rice with by-products of the cultivars Sona, Jayanti, Pankaj and IR 22 as influenced by the levels of nitrogen and phosphate - Experiment 4.

Treatments	Gross return		Net return	
	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha
Varieties				
Sona	3827	4515	1561	2248
Jayanti	3592	4261	1325	1995
Pankaj	4310	5143	2043	2876
IR 22	3866	4744	1598	2475
	**	**	**	**
Levels of nitrogen, kg/ha				
0	3128	3724	1011	1606
60	3906	4635	1655	2385
90	4229	5079	1912	2761
120	4332	5225	1949	2842
	**	**	**	**
Levels of phosphate, kg/ha				
0	3434	4169	1260	1995
30	3880	4675	1623	2419
45	4085	4878	1787	2578
60	4196	4941	1857	2602
	**	**	**	**
S.Em.±	42.37	47.48	42.37	47.48
L.S.D. ($P=0.05$)	87	98	87	98
L.S.D. ($P=0.01$)	118	133	118	133

** Significant at ($P=0.01$).

other three varieties, IR 22, Sona and Jayanti. However, at 120 kg N/ha level, no significant difference was found between the varieties Pankaj and IR 22 (Table 4.42).

Under the different levels of phosphate significant increase in gross return for rough rice and polished rice with broken, bran and husk was noted with the increasing level of phosphate from 0 to 30 and 60 kg/ha in Experiment 3 and 0 to 30 and 45 kg/ha in Experiment 4. While the estimated gross return for polished rice with broken, bran and husk did not show any appreciable increase with the increase in phosphate level from 45 to 60 kg/ha, significant increase was noted for rough rice under the latter level in Experiment 4 (Table 4.40 and 4.41).

Net return It is apparent from Tables 4.40 and 4.41 that the net return was maximum in case of variety Pankaj followed by IR 22, Sona and Jayanti in order. The difference between them was highly significant except in Experiment 4 where no significant difference was noted between varieties IR 22 and Sona. The net return estimated in case of polished rice with broken, bran and husk for different varieties showed similar trend as that of rough rice. However, on milling the additional return per hectare over that of rough rice was found maximum for variety IR 22 followed by Pankaj, Sona and Jayanti in order (Fig.4.10).

In Experiment 3, the net return showed an increasing trend with the increase in level of nitrogen from 0 to 60,

Table 4.42 Gross return per hectare for rough rice and polished rice with broken, bran and husk for the cultivars Sona, Jayanti, Pankaj and IR 22 as affected by interaction between varieties and nitrogen - Experiment 3.

Varieties	Gross return, Rs/ha							
	Levels of nitrogen, kg/ha				Levels of nitrogen, kg/ha			
	0	60	120	180	0	60	120	180
	Rough rice				Polished rice with broken, bran and husk			
Sona	2778	3317	3716	3307	3384	3851	4337	3872
Jayanti	2547	3336	3684	3131	2952	3878	3872	3676
Pankaj	3388	4118	4404	4093	3979	4815	5379	4828
IR 22	2750	3571	4098	3907	3339	4365	4795	4772
S.Em.±	92.71				94.72			
L.S.D.(P=0.05)	191				194			
L.S.D.(P=0.01)	259				265			

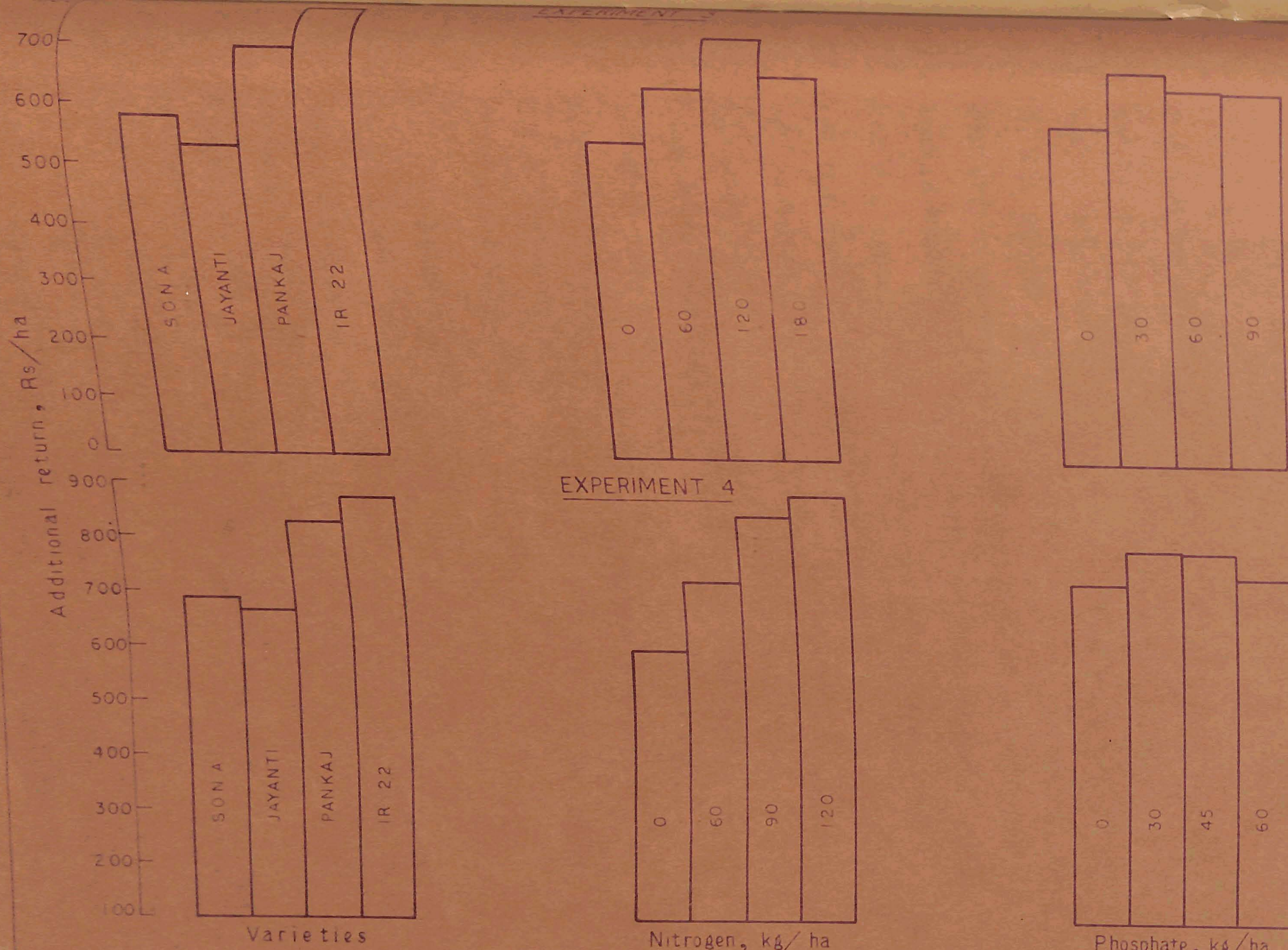


FIG.4.10.ADDITIONAL RETURN PER HECTARE FOR POLISHED RICE WITH BROKEN,BRAN AND HUSK AS COMPARED TO ROUGH RICE UNDER THE DIFFERENT LEVELS OF NITROGEN AND PHOSPHATE FOR THE CULTIVARS SONA, JAYANTI, PANKAJ AND IR 22 (EXPERIMENT 3 AND 4).

and 120 kg/ha, thereafter, at 180 kg/ha level, significant decrease was noted. But the increase in net return from 0 to 120 kg N/ha was at a diminishing rate. In Experiment 4, where 0, 60, 90 and 120 kg/ha nitrogen levels were tried, the difference in net return between 0 to 60 and 60 to 90 kg/ha levels were highly significant. But between 90 to 120 kg N/ ha, the difference was not significant. Significant increase in net return with the increasing level of nitrogen from 0 to 120 kg/ha in Experiment 3 and 0 to 90 kg/ha in Experiment 4, was also noted in case of polished rice with broken, bran and husk (Table 4.40 and 4.41). An additional return in case of polished rice with broken, bran and husk over that of rough rice was maximum under 120 kg N/ha and a decreasing trend was noted either with the increase or decrease in the level of nitrogen (Fig.4.10).

Under all the levels of nitrogen, variety Pankaj had significantly high net returns for rough rice and polished rice with broken, bran and husk as compared to other three varieties - IR 22, Sona and Jayanti. However, at 180 kg N/ha level, variety Pankaj was found on par with IR 22 in the net return from polished rice with broken, bran and husk (Table 4.43 and 4.44).

Regarding the different levels of phosphate the net return increased significantly with the increase in the levels from 0 to 30 and 60 kg/ha in Experiment 3 and 0 to 30, and

Table 4.43 Net return per hectare for rough rice for the cultivars Sona, Jayanti, Pankaj and IR 22 as affected by interaction between varieties and nitrogen - Experiments 3 and 4.

Varieties	Net return, ₹/ha							
	Levels of nitrogen, kg/ha				Levels of nitrogen, kg/ha			
	0	60	120	180	0	60	90	120
	Experiment 3				Experiment 4			
Sona	642	1048	1314	772	1024	1537	1782	1895
Jayanti	411	1067	1282	596	752	1272	1627	1649
Pankaj	1252	1849	1957	1587	1474	2024	2345	2330
IR 22	615	1302	1516	1352	792	1788	1892	1921
S.Em.±	92.71				84.74			
L.S.D.(P=0.05)	191				175			
L.S.D.(P=0.01)	259				237			

Table 4.44 Net return per hectare for polished rice with broken, bran and husk for the cultivers Sona, Jayanti, Pankaj and IR 22 as affected by interaction between varieties and nitrogen - Experiments 3 and 4.

Varieties	Net return, Rs/ha							
	Levels of nitrogen, kg/ha				Levels of nitrogen, kg/ha			
	0	60	120	180	0	60	90	120
	Experiment 3				Experiment 4			
Sona	1249	1582	1935	1337	1557	2203	2534	2696
Jayanti	817	1609	1908	1141	1260	1913	2376	2425
Pankaj	1844	2546	2978	2293	2142	2847	3258	3257
IR 22	1204	2096	2395	2237	1462	2574	2875	2988
S.Em.±	144.14				94.72			
L.S.D.(P=0.05)	298				194			
L.S.D.(P=0.01)	403				265			

45 kg/ha in Experiment 4. No appreciable increase was noted by increasing the level of phosphate to 90 and 60 kg/ha in Experiment 3 and 4 respectively. In other words, the rate of increase in net returns showed a diminishing trend with the increase in the levels of phosphate. Regarding polished rice with broken, bran and husk, the trend of net return under the different levels of phosphate remained similar to that of rough rice (Table 4.40 and 4.41). The additional return for polished rice with broken,bran and husk over that of rough rice was maximum at 30 kg P_2O_5/ha in Experiment 3 and that under 30 and 45 kg P_2O_5/ha levels in Experiment 4(Fig.4.10).

It is revealed from the interaction between nitrogen and phosphate levels for net returns from rice and polished rice with broken,bran and husk that, under all the levels of phosphate there was significant increase in net return only up to 90 kg N/ha. Further, at 60 kg N/ha, significant increase in net return was noted with the increasing level of phosphate from 0 to 60 kg/ha for rough rice and that from 0 - 45 kg/ha for polished rice with broken, bran and husk (Table 4.45).

CHAPTER V

Table 4.45 Net return per hectare for rough rice and polished rice with broken, bran and husk as affected by interaction between nitrogen and phosphate - Experiment 4.

Levels of nitrogen, kg/ha	Net return, Rs/ha							
	Levels of phosphate, kg/ha				Levels of phosphate, kg/ha			
	0	30	45	60	0	30	45	60
	Rough rice				Polished rice with broken, bran and husk			
0	510	941	1239	1352	1037	1537	1861	1989
60	1242	1593	1792	1993	1942	2372	2577	2645
90	1592	1956	2054	2043	2431	2830	2905	2877
120	1694	2002	2061	2038	2567	2936	2967	2895
S.Em.±	84.74				94.72			
L.S.D.(P=0.05)	175				194			
L.S.D.(P=0.01)	237				265			

DISCUSSION

Four field experiments were conducted in a cultivators field to study the performance of rice under varying fertility levels and water management practices. The experiments were conducted for successive 'aman' (June to November) seasons of 1972 and 1973 for finding out the optimum level of each input for the high yielding IR 22 variety of rice grown under clay loam soil of West Bengal. Further, attempts were made to find out the optimum grain moisture for harvesting in order to obtain maximum field yield of paddy with a quality to give the maximum milling yield. The results obtained from the four experiments are discussed in this chapter.

Positive response of the crop for grain yield in the first year was obtained only up to 120 kg/ha of nitrogen and 60 kg/ha of phosphate, and the yield decreased when the crop was supplied with 180 kg N/ha and 90 kg P_2O_5/ha. In the second year, therefore, the levels of nitrogen and phosphate were modified and the maximum levels of nitrogen and phosphate were limited to 120 and 60 kg/ha respectively. The findings of the second year of experimentation suggested further reduction in the level of fertilization as the variety IR 22 could respond significantly only up to 90 kg N/ha and 45 kg P_2O_5/ha. The yield of crop under 90 and 120 kg N/ha and that under 45 and 60 kg P_2O_5/ha was found at par with each other.

The grain yield is primarily influenced by the number of bearing tillers, number of grains per panicle and thousand grain weight as evident from the significant positive correlations (Fig. 5.1 and 5.2). It was noted in Experiment 1 that with the increase in the level of nitrogen from 60 to 120 kg/ha, there was significant increase in productive tillers and number of grains per panicle but, at 180 kg N/ha significant decrease was noted. Whereas, in Experiment 2, no significant increase was noted by increasing the level of nitrogen to 120 kg/ha (Table 4.2). During major part of the total growing period, the crop received less than its optimum requirement of 7 hours of daily sunshine (Moomaw and Vergara, 1964) which at times was as low as 2 hours a day (Fig.3.4). These cloudy days coincided with the active tillering-anthesis phase of crop growth. Any limitation in light decreased the effective tiller number with the increase in nitrogen level during rainy season because, high level of nitrogen caused vigorous growth at early vegetative phase and mutual shading (Tanaka et al., 1964). Further, under high levels of nitrogen, increase in the number of unproductive tillers also decreased the efficiency of productive tillers by sharing of the synthesised food and ultimately decreased the number of grains per panicle. The productive tiller number and grains per panicle being two of the major yield attributes, any decrease in their number affected the yield adversely.

Nitrogen and phosphate are absorbed vigourously at the early stage of crop growth. Therefore, any limitation in the availability of light at this stage would hinder the full utilisation of these elements. The crop in the present experiment did not show response beyond 90 kg N/ha and 45 kg P_2O_5/ha. The probable cause for the same may be the lack of light energy as explained above. It is further noted that when the level of phosphate was increased to 60 or 90 kg/ha the crop was not benefited, rather a decrease in yield was noted. This may be attributed to the deficiency of zinc under high pH of 8.1 of the experimental soil (Table 3.2). With the increase in phosphate the precipitation of zinc as zinc phosphate has frequently been given as the explanation for the phosphate induced zinc deficiency (Tisdale and Nelson, 1968). Reduction of zinc availability at pH above 7.0 in the soil has also been reported by Chatterjee and Das (1964). Further, beneficial effect of zinc application in this soil has already been established (Singh V.P. 1975). From these it is amply evident that in the present experiments, application of higher levels of phosphate caused zinc deficiency and affected the crop adversely. In the influence of nitrogen and phosphate levels on crop yield and yield attributes, some variation was noted between the two years. This was mainly due to the variation in the levels of nitrogen and phosphate and the climatic conditions of the two years as apparent from the Figs. 3.1 to 3.5.

The crop yield under continuous shallow submergence of 5 ± 2 cm was significantly higher than under 0 - 5 cm and 10 ± 2 cm submergence levels. Decrease in crop yield under 0 - 5 cm submergence was mainly attributed to the less number of grains per panicle, while under deeper depth of 10 ± 2 cm of submergence, it was due to the combined effect of less grain number per panicle and less number of productive tillers (Table 4.1 and 4.2). The intermittant saturation and submergence treatment (0 - 5 cm) encouraged tillering at early growth stage, caused mutual shading and finally high mortality of tillers. The unproductive tillers decreased the efficiency of productive tillers for the synthesis of food by causing mutual shading and sharing the food which otherwise would have helped in increasing the number of grains per panicle. In the present investigation, significant positive correlations have been found for the number grains per panicle and productive tillers with that of grain yield (Fig.5.1 and 5.2).

The crop was harvested at four different grain moisture contents attained by prolonging the period of harvesting with reference to the date of flowering as given in Table 5.1

Table 5.1 Grain moisture content at harvest and corresponding period of harvesting after flowering

Grain moisture at harvest	Days after flowering	
	Experiment 1	Experiment 2
25.5 - 22.5	26	26
22.5 - 19.5	30	30
19.5 - 16.5	37	35
16.5 - 13.5	44	41

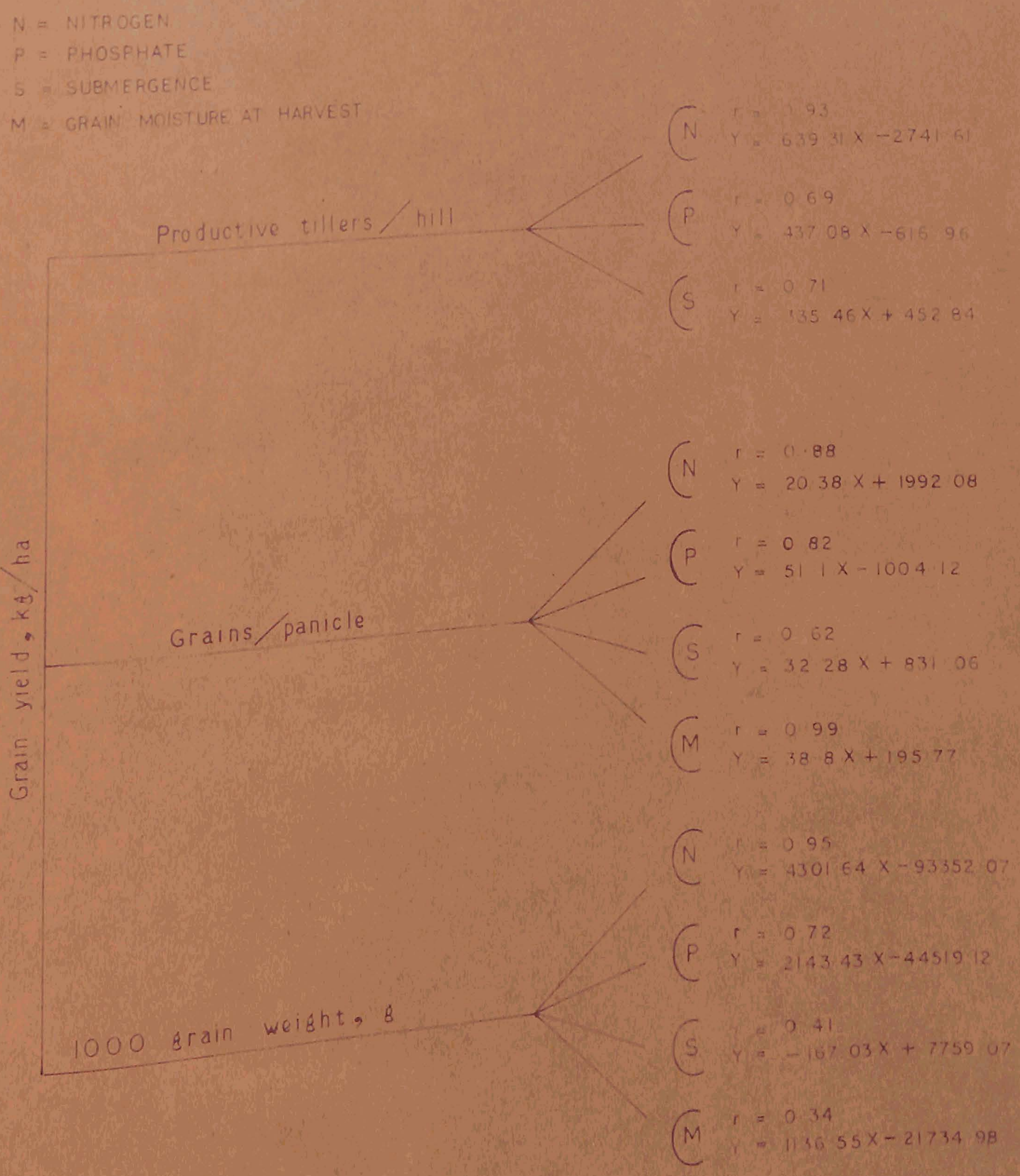


FIG.5.1. CORRELATION AND REGRESSION OF GRAIN YIELD WITH YIELD ATTRIBUTES OF THE CULTIVAR IR 22 (EXPERIMENT I).

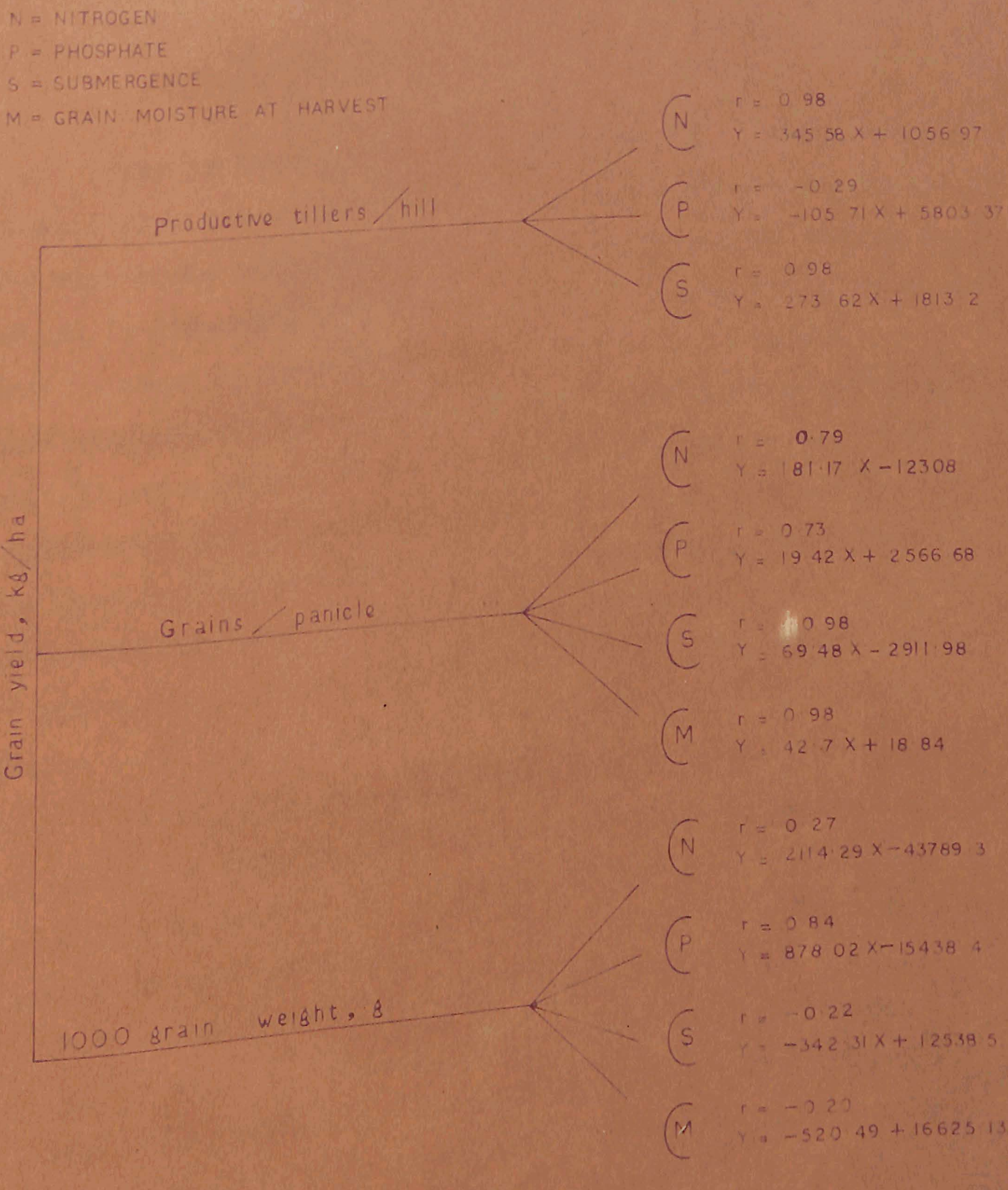


FIG.5.2. CORRELATION AND REGRESSION OF GRAIN YIELD WITH YIELD ATTRIBUTES OF THE CULTIVAR IR 22 (EXPERIMENT 2).

The yield of rice is greatly influenced by the moisture content of the grain at harvest. There are evidences that when the rice grain matures physiologically, its moisture content is around 25 per cent. Rice can be harvested at slightly lower than this moisture content to get higher field and mill yield. Harvesting at moisture content higher than 16 per cent or lower than 25 per cent has few distinct advantages like reduction of shattering loss, vacation of the field 10 to 15 days earlier for the benefit of subsequent cropping and minimising checks/cracks in the grains. With the above understanding, the experimental crop was harvested at four grain moisture ranges, namely, 25.5 - 22.5, 22.5 - 19.5, 19.5 - 16.5, and 16.5 - 13.5 per cent.

It is observed that by harvesting the crop at 22.5 - 19.5 per cent grain moisture, the grain yield increased significantly over that of the crop harvested at lower and higher levels. Decrease in yield due to high grain moisture content of 25.5 - 22.5 per cent at harvest was attributed to the harvesting of some physiologically immature grains of the late forming tillers resulting in reduction of thousand grain weight (Table 4.7 & 4.8). On the other hand, harvesting at low grain moisture content of 16.5 - 13.5 per cent, the reduction in yield was mainly due to the shattering loss, and decrease in number of grains per panicle (Table 4.7 & 4.8).

Variable influence of nitrogen levels on grain yield was noted when the crop was harvested at different grain moisture. It was observed that for the crop, supplied with 60 and 90 kg N/ha and harvested at 25.5 - 22.5 per cent grain moisture content, the grain yield was similar to that of the crop harvested at 22.5 - 19.5 per cent moisture level. But, when the crop was allowed to dry further in the field there was decrease in grain yield. However, the decrease was arrested with the increase in nitrogen level to 120 kg/ha. Further, at this level of nitrogen, the grain yield increased when the crop was harvested at 22.5 - 19.5 or 19.5 - 16.5 per cent grain moisture instead of at 16.5 - 13.5 per cent grain moisture. Decrease in yield at low grain moisture at harvest was due to the increase in shattering loss which resulted in less number of grains per panicle, as evident from Tables 4.7 and 4.8. On the other hand, by increasing the nitrogen level, the shattering loss was arrested even at low grain moisture and hence the yield did not decrease. At a higher level of nitrogen, the formation of abscission layer is delayed, which might have ~~been~~ shown a favourable influence in reducing the shattering loss. However, in absence of direct evidence, no definite conclusion can be drawn.

For better assessment of the produce and its milling quality under the different levels of nitrogen, phosphate and water management practices, the rice was milled after sun drying to around 12 per cent moisture content. The total mill yield and head yield of rice were found to be related to the grain yield of paddy under the different treatments of nitrogen, phosphate, water management practices and grain moisture at harvest, as was confirmed from the significant positive correlation between them (Fig.5.3 and 5.4). Hence, the influence of any input on grain yield was also noted for mill yield and head yield. The influence of the inputs, namely, nitrogen, phosphate and submergence on grain yield has already been explained earlier and their influence on mill yield and head yield is obvious.

As the value of the milled produce depends mainly on the head yield, more emphasis has been given on the influences of different treatments on the head yield recovery. The head yield of rice had shown some improvement when the crop was harvested 26 days after flowering at grain moisture content of 25.5 - 22.5 per cent, compared to that at 22.5 - 19.5 per cent. This is attributed to the appreciable decrease in broken rice (Table 4.12 and 4.13) as compared to the crop harvested at lower grain moisture of 19.5 - 16.5 and 16.5 - 13.5 per cent and correspondingly at 35 and 44 days after flowering. The rice kernel is sensitive to unequal moisture distribution which is a common phenomenon when the harvesting is delayed. By delay in harvesting, the moisture is removed from the grain during the day while during night time, due to deposition of dews, some amount of moisture is absorbed. Such alternate drying and wetting cycles cause mechanical stresses in the grains, which

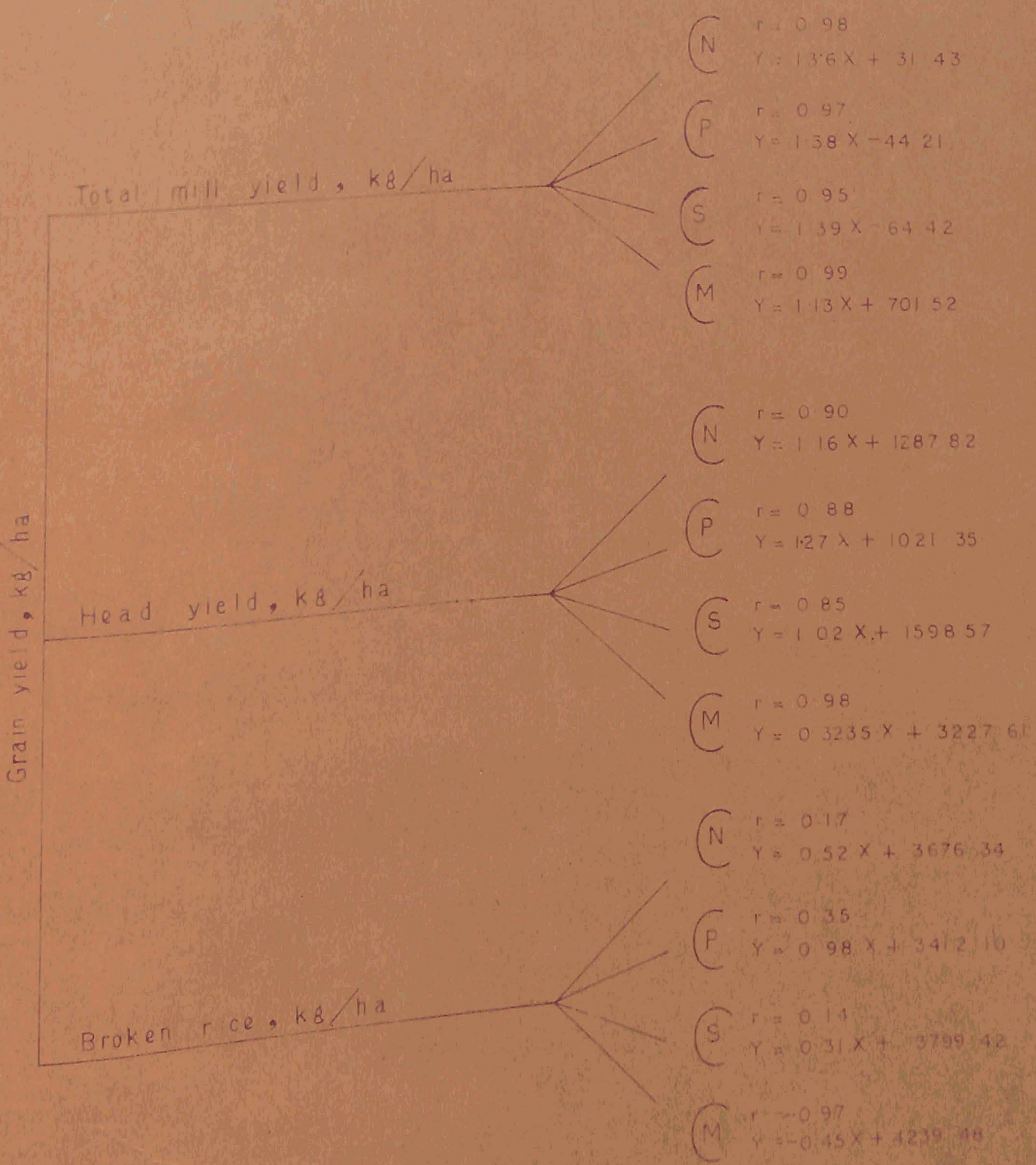
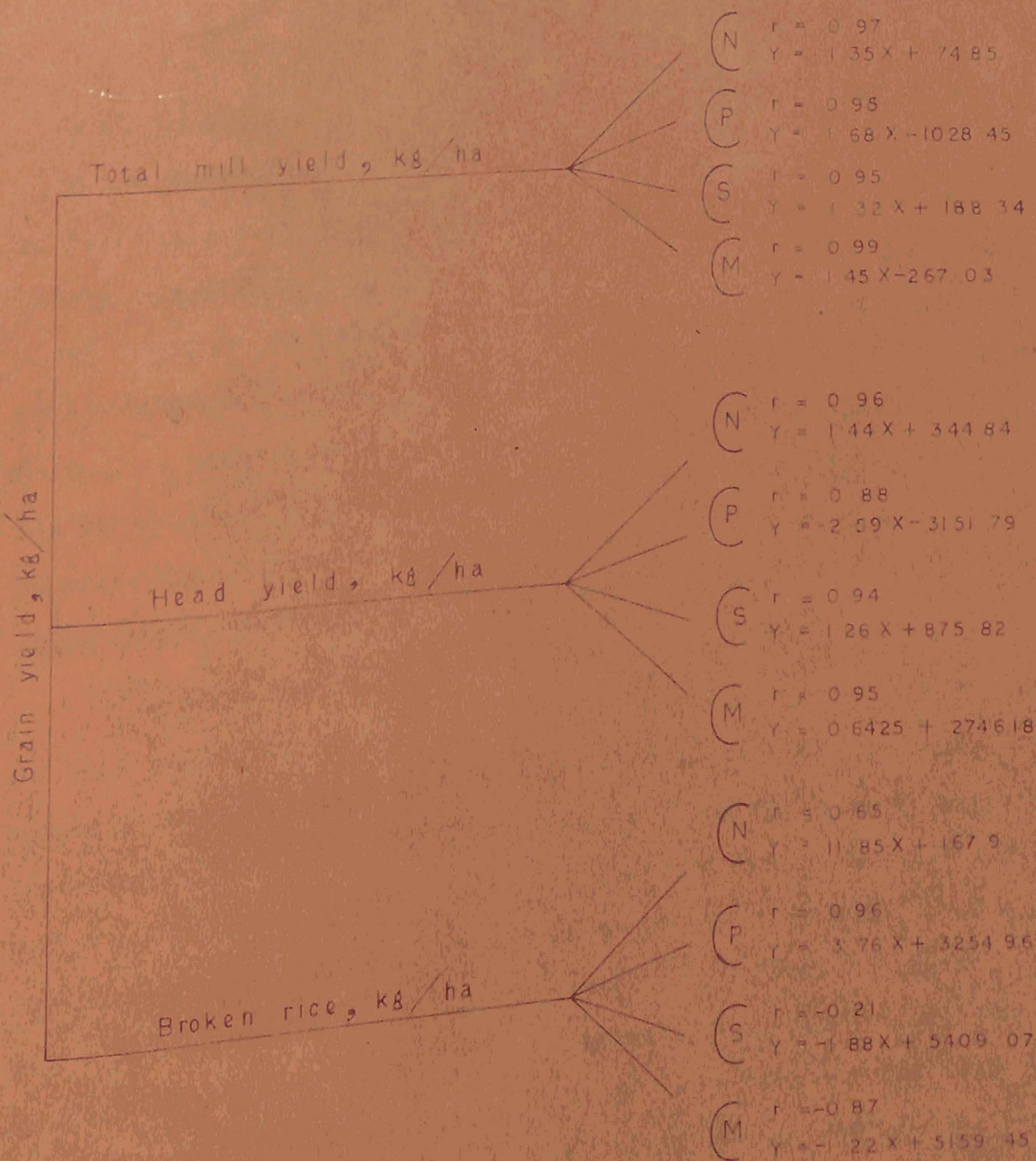


FIG. 5.3. CORRELATION AND REGRESSION OF GRAIN YIELD WITH MILLING YIELD OF THE CULTIVAR IR 22 (EXPERIMENT I).



IG.5.4. CORRELATION AND REGRESSION OF GRAIN YIELD WITH MILLING YIELD OF THE CULTIVAR IR 22 (EXPERIMENT 2).

results in checking. Development of checks/cracks increases when the harvesting is delayed after physiological maturity of the grain (Stahel,1935 and Henderson,1954). This, ultimately increases the broken percentages and reduces the head yield recovery on milling. The reason for higher head yield at grain moisture above 19.5 per cent is attributed to the decrease in broken percentage (Table 4.12 and 4.13) and the reduction due to shattering loss in the field because of early harvest of the crop. The above observations support the findings of Nangju and De Datta (1970) and Seetanun and De Datta (1975).

A variable influence of nitrogen and phosphate levels on head yield was noted when the crop was harvested at different grain moisture contents. It was noted that with the increase in nitrogen from 60 to 120 and from 60 to 90 kg/ha in Experiments 1 and 2 respectively, there was significant increase in head yield when the crop was harvested at grain moisture above 19.5 per cent. By increasing the nitrogen levels from 90 to 120 kg/ha, considerable improvement in head yield recovery was noted even when the crop was harvested late,at grain moisture below 19.5 per cent. With the increasing level of nitrogen, the protein content of the grain increases,which ultimately helps in decreasing the broken percentage,thereby increasing the head yield. This may hold good even in case of the crop harvested late at low grain moisture. In other words, in case of the crop fertilized with higher levels of nitrogen, some delay in harvesting may not result in decreasing the head yield recovery. Increase in head rice with the increase in nitrogen levl was probably due to greater resistance to breakage of the grain, resulting from a possible higher protein content which adds to its resistance to breakage (Del Rosario *et al.* 1968). Cagampang *et al.* (1966) as well as Nangju and De Datta (1970) have indicated that high protein rices are more resistant to abrasive milling, yield less bran and polish, and tend to have higher head yield. However, in absence of data on protein analysis of the grain, enough justification to the findings could not be given.

Beneficial effect of phosphate, in combination with nitrogen, was noted in improving milling quality of rice when the crop was harvested at grain moisture between 22.5 - 19.5 per cent. On the contrary, high levels of phosphate (90 kg P_2O_5/ha) in combination with high levels of nitrogen (180 kg N/ha) brought adverse effect by increasing breakage and thereby decreasing the head yield recovery when harvested at grain moisture below 19.5 per cent (Table 4.27). This clearly indicates that, for attaining high head yield and its recovery percentage, judicious application of nitrogen and phosphate and harvesting of the crop at the right grain moisture become very essential. Keeping these points in view, assessment of the various inputs for maximizing grain yield and head yield was made with the help of production functions. The response surfaces (Fig. 4.2 to 4.9) show that, increase in the levels of nitrogen and phosphate brought about increase in grain and head yields at a diminishing rate. The optimum levels at which maximum grain yield and head yield were obtained are summarised below, in Table 5.2.

Table 5.2 Optimum levels of various inputs for maximising grain and head rice yields of cultivar IR 22

	Experiment 1	Experiment 2
Maximum grain yield :	4606 kg/ha	5112 kg/ha
Optimum N	= 112 kg/ha	N = 119 kg/ha
" P	= 53 kg/ha	P = 59 kg/ha
" S	= 148 cm	S = 149 cm
" M	= 23.1%	M = 22.4%
Maximum head yield :	3117 kg/ha	3562 kg/ha
Optimum N	= 110 kg/ha	N = 124 kg/ha
" P	= 53 kg/ha	P = 51 kg/ha
" S	= 147 cm	S = 48159 cm
" M	= 22.6 %	M = 26.2%

N, P, S and M denote nitrogen, phosphate, total water requirement and harvest grain moisture respectively.

The Table 5.2 indicates that , for cultivation of IR 22 variety of rice in the agroclimatic condition of West Bengal during the rainy season, maximum grain yields can be obtained by supplying the crop with 112 - 119 kg N/ha and 53 - 59 kg P_2O_5/ha, 148 - 149 cm of water and harvesting the crop at 22.4 - 23.1 per cent grain moisture content. Whereas, maximum head yield can be obtained from the produce of a crop supplied with 110 - 124 kg N/ha, 51 - 53 kg P_2O_5/ha, 147 - 159 cm of water and by harvesting the crop at 22.6 - 26.2 % grain moisture. The estimated optimum values of grain moisture content at harvest for maximising grain and head rice yields, coincide with the harvesting time at about 26 days after flowering as apparent from Table 5.2. These conclusions could be drawn from the production functions showing very high R^2 values and a good fit.

The beneficial effect of continuous shallow submergence of 5 ± 2 cm in increasing the head yield may be justified on the basis of the grain yield performance of the crop as discussed earlier. However, superiority of the shallow continuous submergence over intermittent submergence (0 - 5 cm) for head yield recovery percentage could also be noted only in case of the crop harvested at grain moisture contents below 19.5 per cent. Better availability of nutrients to the crop, particularly nitrogen, under continuous submergence might have brought about this effect. Grain analysis values for nitrogen and protein content would have helped support the above findings. This study, however, has not been made in this experiment. Assessment of submergence treatments for grain and head rice yields was made with the help of production functions on the basis of the total water requirement under each treatments. However, the production function for grain moisture at harvest under different levels of submergence gave a low R^2 value and has shown a poor fit.

Being hygroscopic in nature, rice tends to absorb and lose moisture, whenever there is imbalance of temperature and humidity between grain and its environment. It was noted that breakages of rice increased, and thereby the head yield decreased, in the crop harvested during 1972 as compared to that of 1973. This may be due to more frequent changes in the relative humidity and temperature prevailing during 1972 as compared to 1973 (Fig.3.7 and 3.5). Tenhave (1963) and Govindaswamy and Ghose (1969) have also reported similar effects of temperature and relative humidity fluctuations on the milling quality in general and of broken percentage in particular.

To identify a suitable type from a set of promising high yielding rice varieties under a specific management of production and processing, Sona, Jayanti, Pankaj and IR 22 were grown for two successive 'aman' seasons (June-November) of 1972 and 1973. The varietal characteristics of these types are given in brief in Chapter 3 page 33 . While the grain quality of these varieties is influenced largely by their genetic constitution, their yield and milling performance will vary according to fertility and other management practices. To assess their suitability for the agro-climatic condition of this region and to obtain high grain yield and milling outturn, the relative performance of all the four varieties was studied under different levels of nitrogen and phosphate fertilization. Harvesting of the varieties was done at a grain moisture content in the range of 19.5 - 16.5 per cent. During 1972 'aman', (Experiment 3) the levels of nitrogen were 0, 60, 120 and 180 kg/ha, and the levels of phosphate were 0, 30, 60 and 90 kg/ha, whereas during 1973 'aman' (Experiment 4), the levels of nitrogen were 0, 60, 90 and 120 kg/ha and the phosphate levels were 0, 30, 45 and 60 kg/ha. The modifications in the levels of the two fertilizers in Experiment 4 were made on the basis of the findings of Experiment 3.

Among the four varieties, Pankaj yielded maximum, followed by IR 22, Sona and Jayanti in that order. All the varieties responded significantly to the fertilisers up to 90 kg N/ha and 45 kg P_2O_5/ha. Further increase in nitrogen and phosphate did not benefit the crop, rather there was decrease when the levels were raised to 180 kg N/ha and 90 kg P_2O_5/ha. Grain yield has a positive correlation with the three major yield attributes, namely, number of productive tillers per hill, number of grains per panicle, and thousand grain weight, for all the varieties and levels of fertilizers (Fig. 5.5 and 5.6).

The milling quality of the four varieties was assessed by determining the total milling yield and head yield per hectare and their recovery percentage. The total mill yield and head yield were found positively correlated with the grain yield for all the varieties, levels of nitrogen and phosphate (Fig.5.7). Irrespective of the varieties, the milling quality was improved with the increasing levels of nitrogen. But no definite trend was noticed with levels of phosphate(Table 4.34 and 4.35). However, under all the levels of nitrogen and phosphate, IR 22 was found superior to the other varieties in head yield recovery percentage (Table 4.37, 4.39 and 4.40). While there was increase in the head rice recovery percentage with the increasing level of nitrogen in case of IR 22, Sona and Jayanti, an opposite trend was noted in case of Pankaj. This adds to the superior quality of IR 22 over Pankaj.

The market value of rice with the admixture of broken rice in less when compared to the rice sold as head rice alone. In the modern process of milling, head rice, broken, bran and husk are separated. The head rice thus separated fetch a higher price. In the present study, all the milling operations were performed under a similar condition to that of a modern rice mill. Hence, the assessments could be made taking into account the values of the polished rice, broken, bran and husk. The additional return estimated when the rice is processed

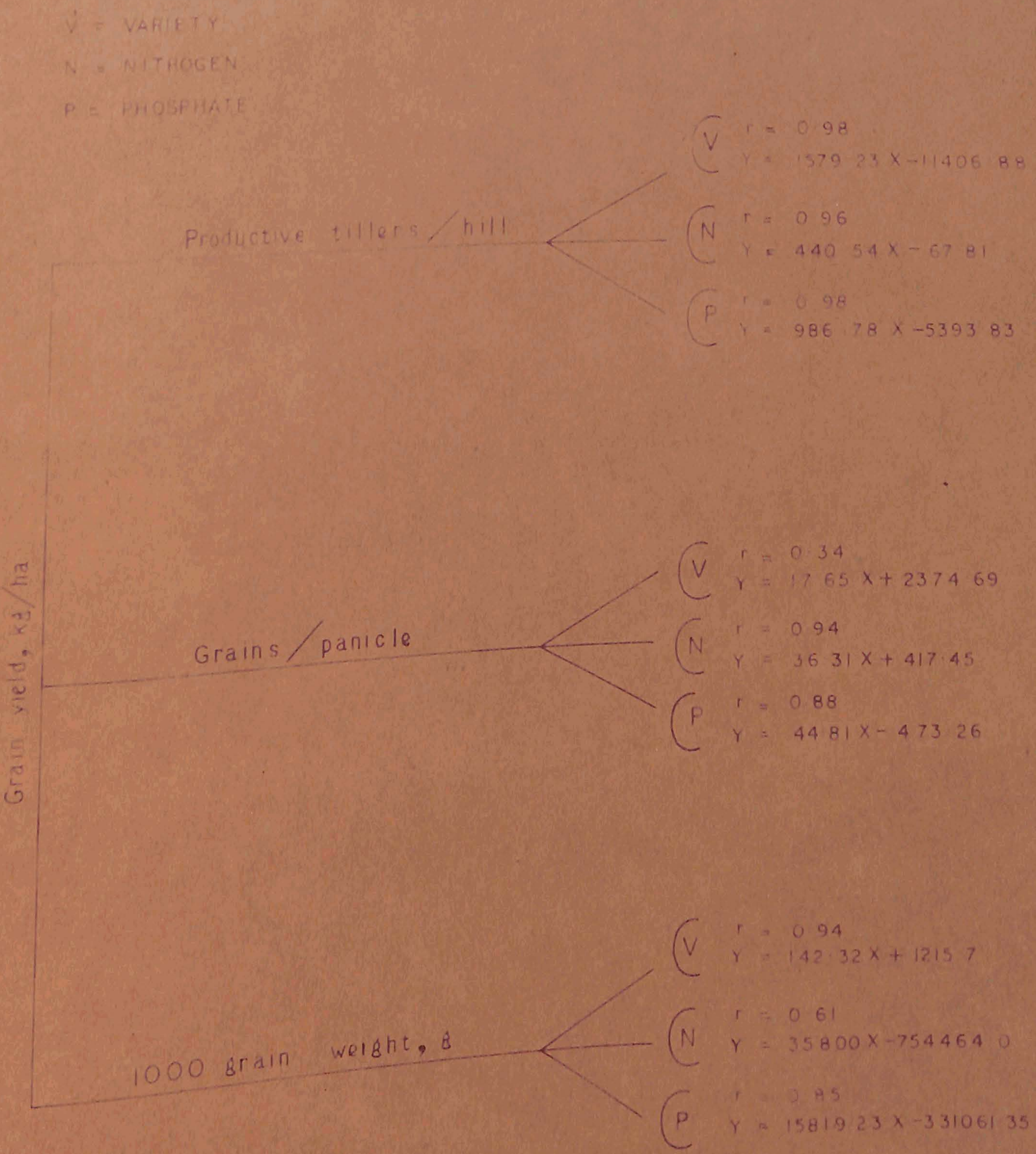


FIG. 5.5. CORRELATION AND REGRESSION OF GRAIN YIELD WITH YIELD ATTRIBUTES OF THE CULTIVARS SONA, JAYANTI, PANKAJ AND IR 22 (EXPERIMENT 3).

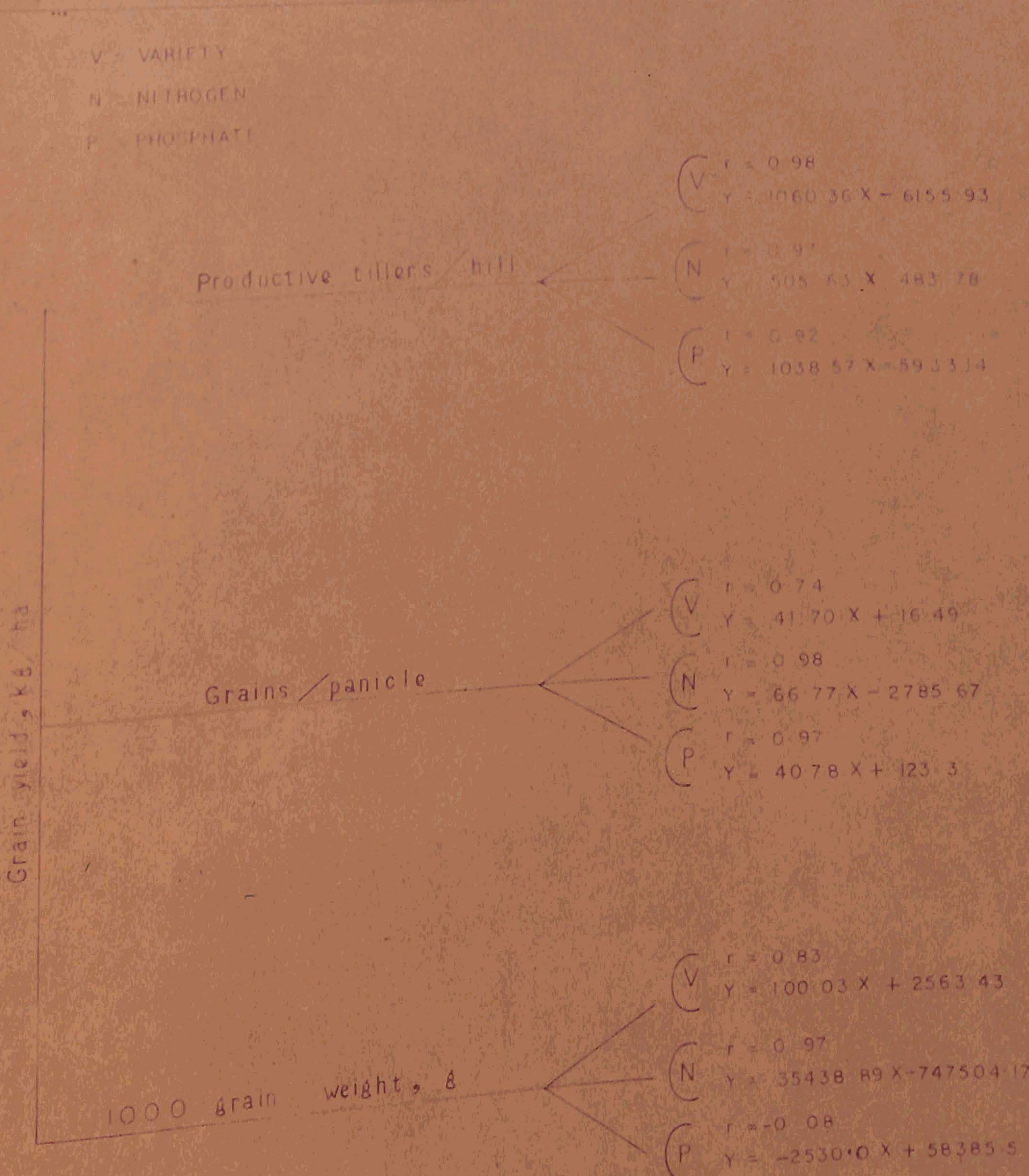


FIG. 5.6. CORRELATION AND REGRESSION OF GRAIN YIELD WITH YIELD ATTRIBUTES OF THE CULTIVARS SONA, JAYANTI, PANKAJ AND IR 22 (EXPERIMENT 4).

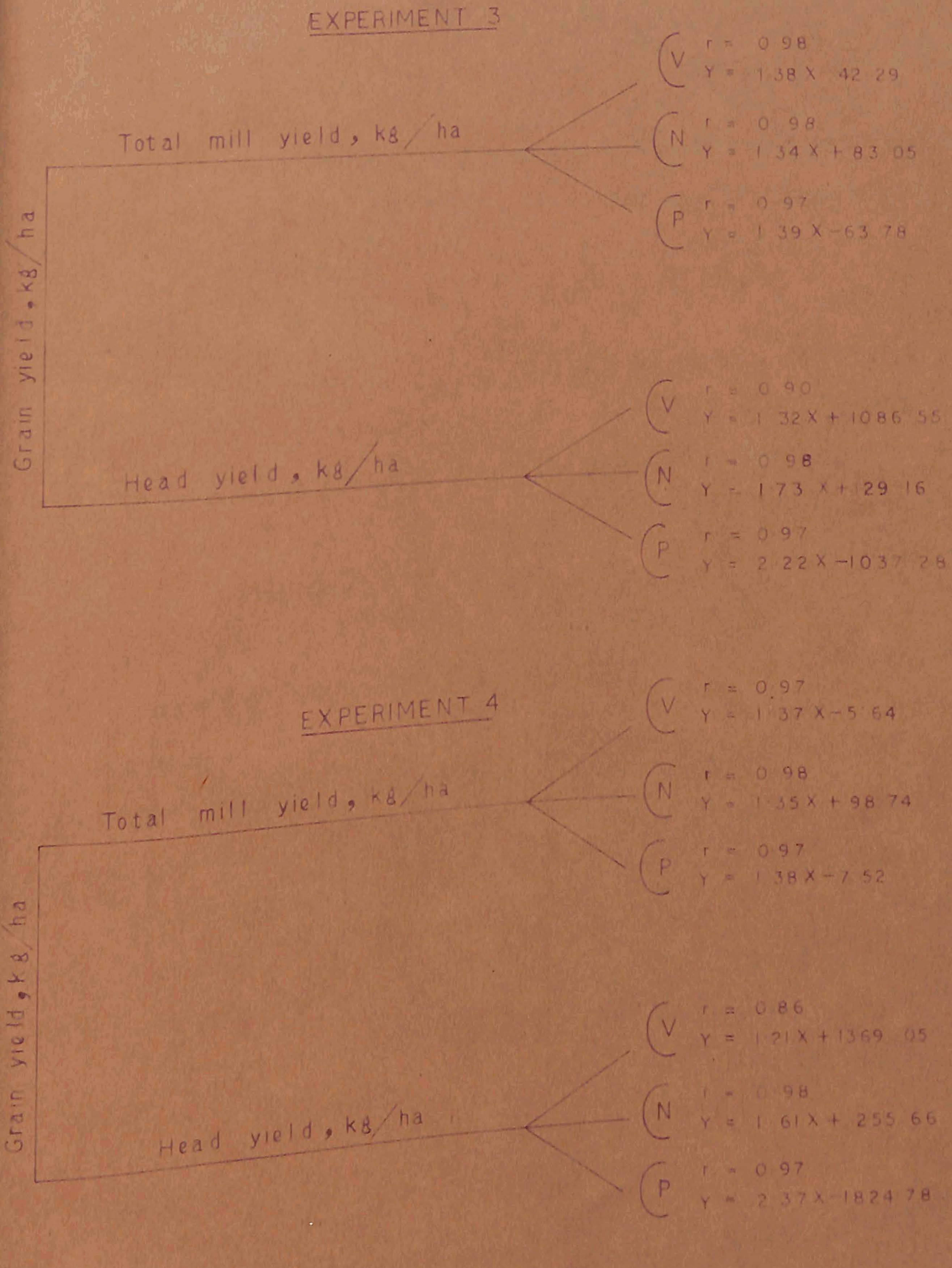


FIG. 5.7. CORRELATION AND REGRESSION OF GRAIN YIELD WITH MILLING YIELD (EXPERIMENT 3 AND 4).

are presented through Fig.4.1 and 4.10. This reveals the fact that if rough rice is sold after milling, it gives a higher net return even including the cost of processing, storage and handling charges (Appendix III).

The gross and net returns per hectare from rough rice and polished rice are dependent upon the yield of paddy as evident from the significant positive correlations between them (Fig.5.8, 5.9, 5.10 and 5.11). As the influence of the nitrogen, phosphate, submergence and grain moisture content at harvest on grain yield of rice has already been noted, their influence on gross and net returns needs no further elaboration. Further, the gross and net returns per hectare for rough rice as well as for polished rice plus brokens bran and husk was maximum for Pankaj followed by IR 22, Sona and Jayanti. However, when milled, the value of the processed products would bring higher additional income for IR 22 over the other varieties as apparent from Fig.4.10, and this may be attributed to its better milling and grain quality as already discussed.

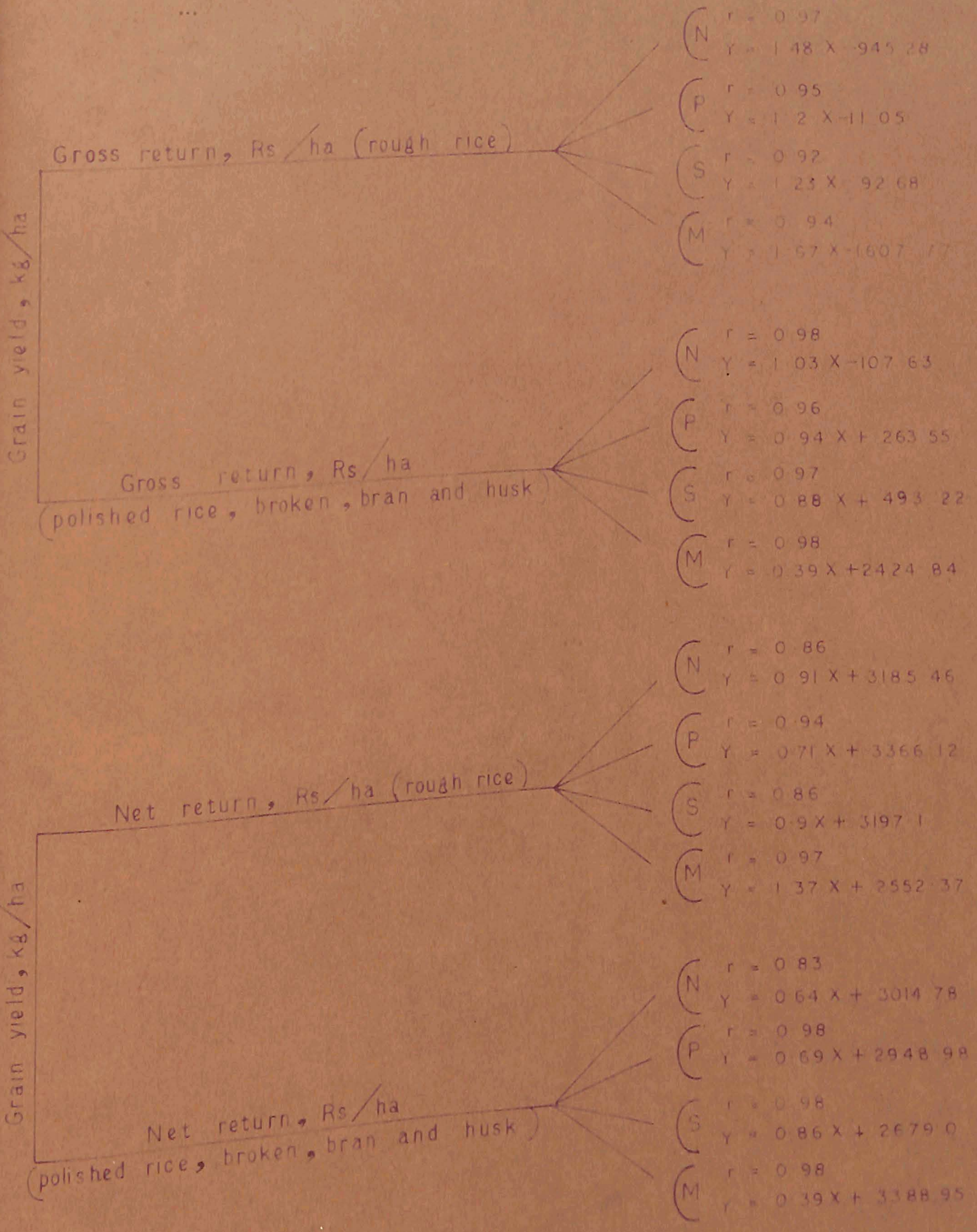


FIG. 5.8. CORRELATION AND REGRESSION OF GRAIN YIELD WITH GROSS AND NET RETURNS FOR ROUGH RICE AND POLISHED RICE INCLUDING ITS BY-PRODUCTS (EXPERIMENT I).

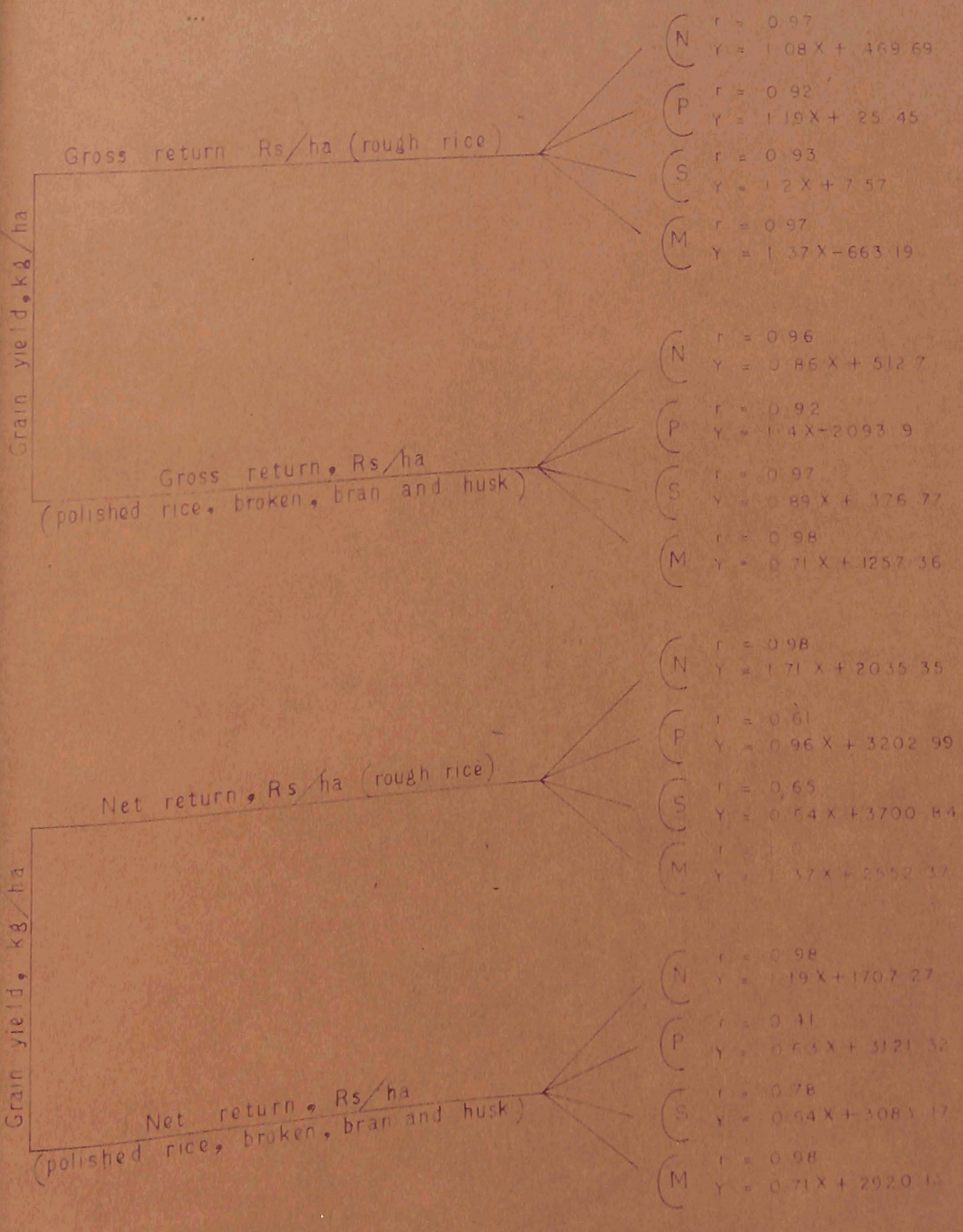


FIG. 5.9. CORRELATION AND REGRESSION OF GRAIN YIELD WITH GROSS AND NET RETURNS OF ROUGH RICE AND POLISHED RICE INCLUDING ITS BY-PRODUCTS (EXPERIMENT 2).

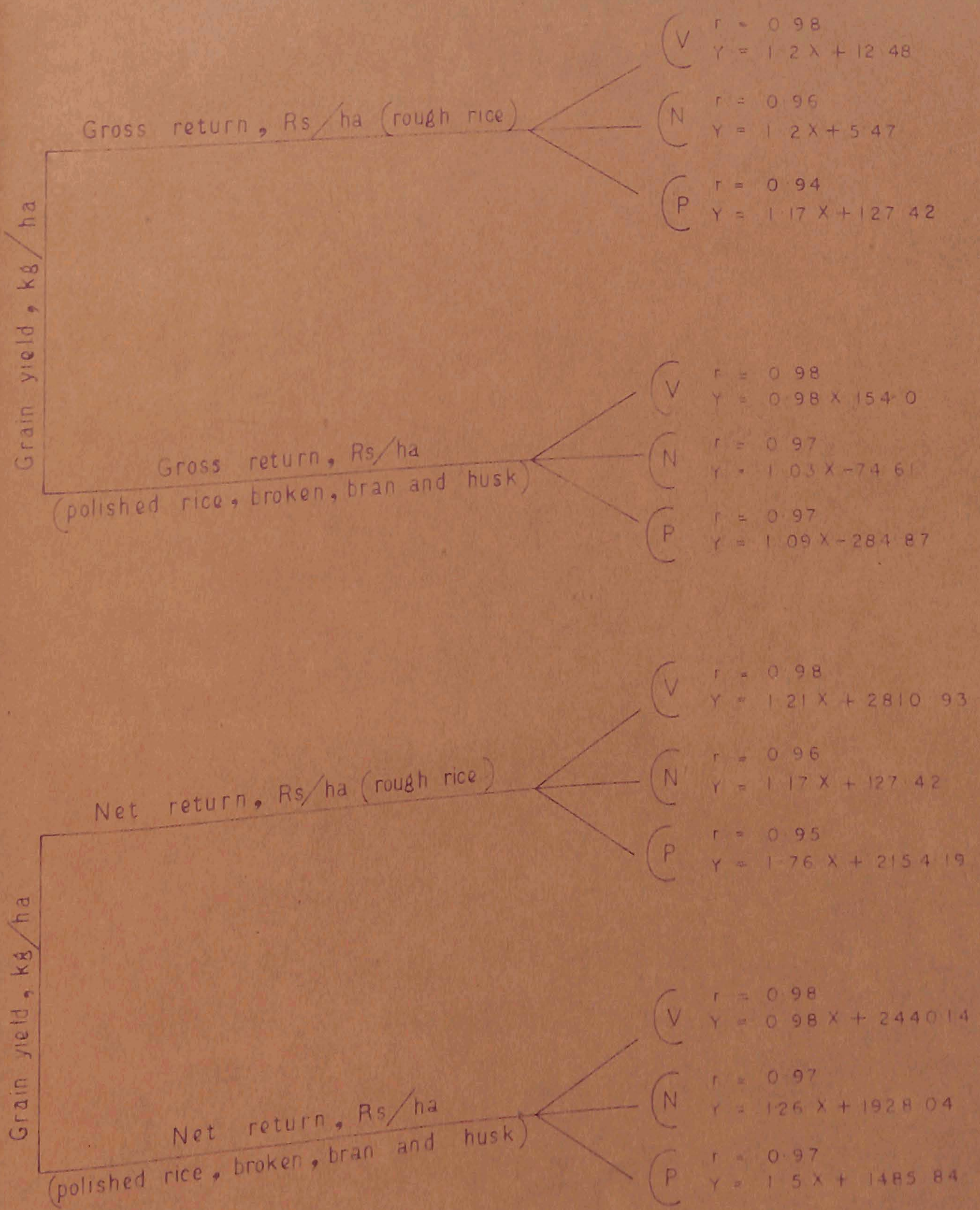


FIG.5.10. CORRELATION AND REGRESSION OF GRAIN YIELD WITH GROSS AND NET RETURNS OF ROUGH RICE AND POLISHED RICE INCLUDING ITS BY-PRODUCTS (EXPERIMENT 3).

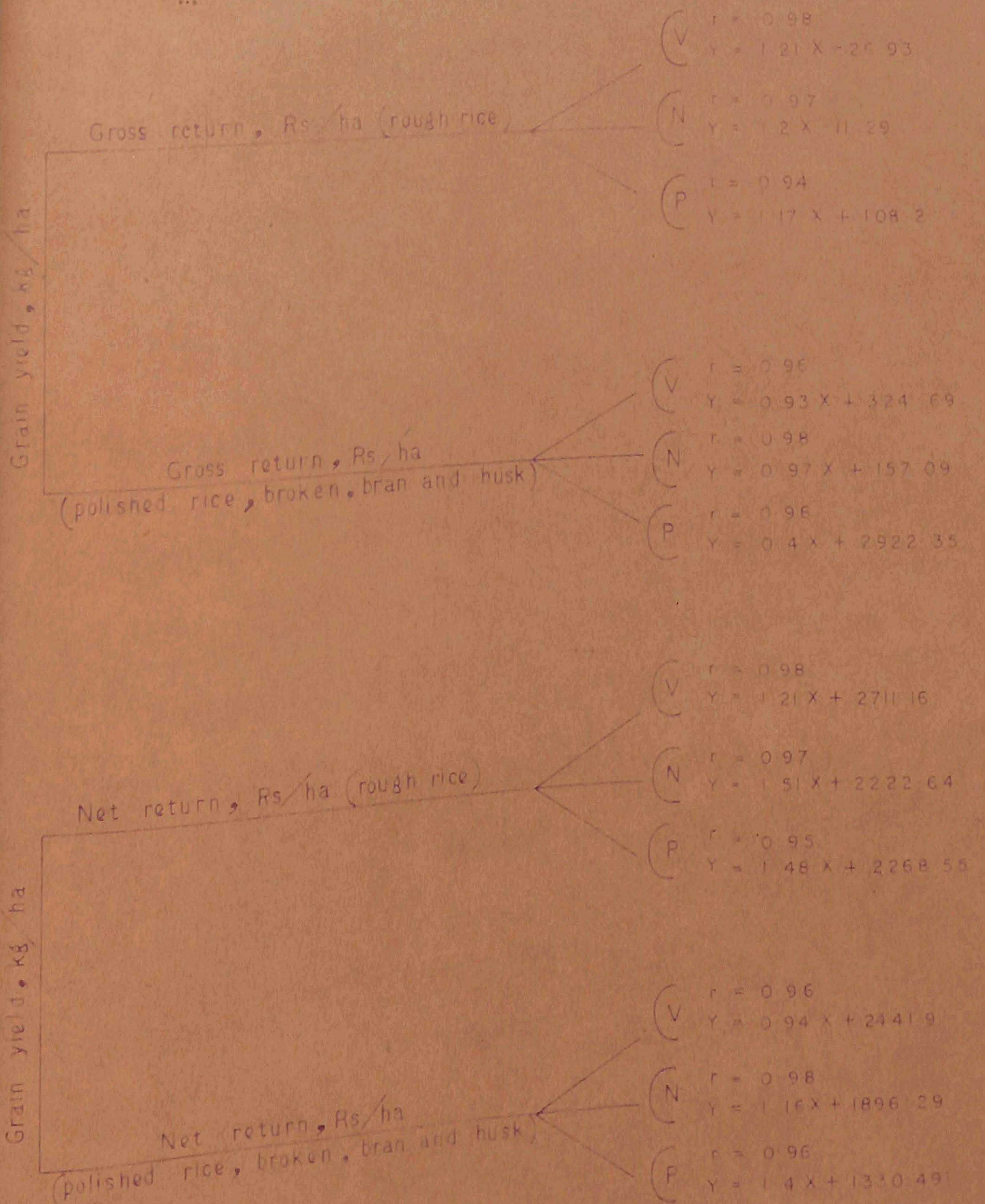


FIG. 5.11. CORRELATION AND REGRESSION OF GRAIN YIELD WITH GROSS AND NET RETURNS OF ROUGH RICE AND POLISHED RICE INCLUDING ITS BY-PRODUCTS (EXPERIMENT 4).

CHAPTER VI

SUMMARY

An investigation was planned during the main growing season, i.e., 'aman' (June to November) to find out the optimum levels of the major inputs for rice cultivation such as nitrogen, phosphate, and water, associated with the management practices like optimum time of harvest, in order to maximize production and to obtain quality paddy which, when processed, should give a high quality rice and thereby high economic returns. Keeping the above points in view, four field experiments were conducted during two consecutive 'aman' seasons of 1972 and 1973 in a cultivators' field at Abhoy Ashram, Balarampur which is located about 3 km south-east of the Institute. The farm soil was silty-clay-loam, having a pH of 8.1.

The experiments were conducted with the high-yielding rice variety IR 22 to study its performance under three levels each of nitrogen, phosphate and submergence and laid out in 3 x 3 x 3 confounded design. Nine additional plots to accommodate '0' levels of nitrogen and phosphate were included for fitting production functions. In the first year of experimentation, the nitrogen and phosphate levels were 60, 120 and 180 kg/ha and 30, 60 and 90 kg/ha respectively. In the second year, the levels were 60, 90 and 120 kg N/ha and 30, 45 and 60 kg P_2O_5/ha. The modification in the levels of nitrogen and phosphate, in the second year, were made on the basis of the

findings of the first year of experimentation. In both the years, the levels of submergence were kept constant, i.e., 0 - 5 cm, 5 ± 2 cm, and 10 ± 2 cm. For finding out the optimum grain moisture at harvest, suitable for higher milling yield, the crop was harvested at 25.5 - 22.5, 22.5 - 19.5, 19.5 - 16.5 and 16.5 - 13.5 per cent grain moisture. The optimum levels of each input for maximizing grain yield and head yield were found out by fitting production functions.

To identify a suitable variety under a specific management of production and processing, four high yielding rice varieties - Sona, Jayanti, Pankaj and IR 22 were grown in 'aman' season of 1972 and 1973 with similar levels of nitrogen and phosphate as mentioned in Experiments 1 and 2; an additional treatment, with nitrogen and phosphate at '0' level was also included. These experiments were laid out in 4 x 4 x 4 confounded design. The crop was grown under continuous submergence of 5 ± 2 cm and was harvested at grain moisture content ranging between 19.5 and 16.5 per cent.

Treatmentwise experimental details and the salient findings are given in the following pages.

Positive response with reference to grain yield, total mill yield and head yield of variety IR 22 was noted up to 90 kg N/ha and 45 kg P_2O_5/ha. Further increase in nitrogen and phosphate levels to 120 kg/ha and 60 kg/ha respectively did not benefit the crop, rather, at 180 kg N/ha and 90 kg P_2O_5/ha, adverse effect was noted.

Among the inputs studied, nitrogen had a greater influence on yield and milling quality of rice than phosphate and water. The influence of grain moisture at harvest, however, was found to be still greater. The extent of increase in grain yield, mill yield and head yield due to nitrogen application was respectively 4798, 3498 and 3099 kg/ha and that due to timely harvesting was 4871 kg/ha, 3533 kg/ha and 3549 kg/ha for the variety IR 22. The head yield recovery on milling had shown about 5 per cent variation ranging from 55.3 to 60.04 per cent due to varying levels of nitrogen, whereas, about 32 per cent variation, ranging from 36.21 to 68.45 per cent, was noted due to the varying grain moisture content at harvest. The influence of nitrogen application was found to be associated with the grain moisture at harvest. The crop, when fertilized with nitrogen levels of 90 kg/ha gave maximum grain yield and head yield amounting to 5035 and 3484 kg/ha respectively and the corresponding head yield recovery percentages to the extent of 69 per cent when harvesting was done between 25.5 and 22.5 per cent level of grain moisture. Any delay in harvesting below 16.5 per cent grain moisture content caused considerable reduction in grain yield and head yield and its recovery percentage to the extent of 604 kg/ha, 879 kg/ha and 10.5 per cent respectively. In other words, the broken yield and its percentage was minimized by harvesting the crop above 19.5 per cent grain moisture or between 26 and 30 days after flowering. However, by increasing the level of nitrogen from 90 to 120 kg/ha and 120 to 180 kg/ha, the head yield and its recovery per cent was less affected even when the crop was harvested with some delay, i.e., between 19.5 and 16.5 per cent grain moisture or between 35 and 37 days after flowering.

The influence of phosphate on grain yield and milling quality, particularly head yield recovery percentage, was more pronounced when considered in combination with grain moisture at harvest.

A suitable water management practice, of growing the crop with shallow submergence of 5 ± 2 cm was found beneficial in increasing the yield as well as the milling and head yields. The influence of submergence on the head yield recovery percentage was, however, not to the same extent as that of nitrogen and grain moisture at harvest.

On fitting the function, for variety IR 22, it could be ascertained that maximum grain yield to the extent of 5112 kg/ha can be attained with the optimum levels of 119 kg N/ha, 59 kg P_2O_5/ha, 149 cm of water and 22.4 per cent grain moisture at harvest which corresponded to harvesting the crop about 30 days after flowering. On the other hand, maximum head yield to the extent of 3562 kg/ha can be attained with the optimum levels of 124 kg N/ha, 51 kg P_2O_5/ha, 159 cm of water and around 26 per cent grain moisture at harvest which corresponded to harvesting the crop about 26 days after flowering.

The grain yield and consequently, the gross and net returns were maximum under the same levels of nitrogen, phosphate, submergence and grain moisture at harvest. However, from an assessment of rough rice and polished rice along with broken, bran and husk, it was ascertained that the increase in net return to the extent of 984 Rs/ha was possible only by processing the rough rice.

The positive response in grain yield of all the varieties was found only up to 90 kg N/ha and 45 kg P_2O_5/ha. In varietal comparison, grain yield, mill yield, head yield and net return were found to be maximum in case of the variety Pankaj, amounting to 5192 kg/ha, 3768 kg/ha, 3027 kg/ha and 1716 Rs/ha respectively. The variety Pankaj was followed by IR 22, Sona and Jayanti in order. However, in milling quality, particularly head yield recovery percent, IR 22 was found superior to all the other varieties. Further, the variety IR 22, with long and slender grains, proved superior in quality to Pankaj, with long and bold grain. The former, eventually, has higher market value that brought higher return. These characteristics in IR 22 narrowed the difference in profit, when compared to Pankaj, though the latter has significantly higher grain yield. The additional net return over milled rice was estimated at 877 Rs/ha in case of IR 22 and 833 Rs/ha in case of Pankaj.

The agro-climatic conditions of this region of West Bengal, where rice is the only crop during 'aman', provide better prospects for cultivation of variety IR 22 as well as Pankaj. In quality criteria as well as in growing period, IR 22 may prove superior to Pankaj. Their cultivation for higher yield and quality rice is possible only through suitable levels of fertility and water inputs as well as management input which includes the timeliness of operations, particularly harvesting, because it has a greater impact on the final outturn of the produce as quality rice.

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APPENDICES

APPENDIX I-A (Experiment 1)

Analysis of variance of the data given in Tables 4.1,4.3,4.6,4.7,4.9,4.11 , 4.14,4.16, 4.18,4.19,4.20,4.21,4.23,4.25,4.27 and 4.28

Source of variance	d.f.	Mean sum of squares					
		Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/panicle	1000 grain weight, g	Total mill yield	
						kg/ha	%
Block	2	14450	0.670	73.600	0.350	3070	0.805
N	2	2228200**	4.920**	4128.450**	0.314	1109566**	1.305
P	2	651050**	0.404	165.900*	0.075	333625**	0.195
S	2	527900**	0.576	192.050*	0.120	270000**	0.235
N x P	4	17500	0.328	303.375*	0.505	15742	1.742
N x S	4	30800	0.141	49.350	0.124	6680	1.562
P x S	4	19875	0.146	28.375	0.080	14117	1.407
Error (a)	6	16800	0.140	31.716	0.113	7943	1.810
M	3	1436233**	-	955.800**	0.142	112004**	29.116**
N x M	6	32083**	-	29.550**	0.085	1546	0.963
P x M	6	7783	-	4.916	0.021	4606	0.761
S x M	6	5133	-	6.333	0.065	7238	0.503
N x P x M	12	5575	-	5.766	0.131	4190	0.775
N x S x M	12	6750	-	4.075	0.054	4889	0.826
P x S x M	12	5425	-	3.083	0.087	7313	0.814
Error (b)	24	4729	-	5.112	0.392	6459	0.607

* Significant at P = 0.05, ** Significant at P = 0.01

contd../

APPENDIX I-A (Contd.)

Source of variance	d.f.	Mean sum of squares					
		Head yield		Broken rice		Bran	
		kg/ha	%	kg/ha	%	kg/ha	% +
Block	2	135080	77.050	10003	14.356	139	0.141
N	2	1331690**	202.810**	237520 **	327.171**	3632**	0.114
P	2	313135*	40.285	85534*	97.592	1701**	0.349
S	2	357175**	79.755*	100298*	156.621*	813*	0.219
N x P	4	148102*	75.800*	88951*	126.276*	386	0.464
N x S	4	24490	25.730	24029	31.714	185	0.170
P x S	4	53475	26.290	30062	38.991	134	0.315
Error (a)	6	30571	15.068**	16414	26.413	121	0.158
M	3	13159070**	5990.420**	6669798**	10448.860**	2038**	9.370**
N x M	6	46753**	61.576**	64690**	116.440**	458	0.589*
P x M	6	25918	24.775*	25833*	40.292*	62	0.108
S x M	6	46616**	36.063**	53284**	65.321**	284	0.272
N x P x M	12	42000**	31.025**	37008**	59.866**	404	0.368
N x S x M	12	7854	3.879	3638	5.248	155	0.177
P x S x M	12	18002	10.991	14462	21.480	109	0.208
Error (b)	24	11304	7.136	9187	13.043	223	0.211

* Significant at P = 0.05, ** Significant at P = 0.01 + Polish per cent

contd../

APPENDIX I-A(Contd.)

Source of variance	d.f.	Mean sum of squares					
		Husk		Gross return		Net return	
		kg/ha	%	Rough rice, ₨/ha	Polished rice, broken, bran, and husk, ₨/ha	Rough rice, ₨/ha	Polished rice, broken, bran and husk, ₨/ha
Block	2	3099	0.538	9500	80050	8962	67140
N	2	97038**	1.922	1006300**	1967200**	1985682**	3691460**
P	2	30535*	0.823	448050**	714400**	1145100**	1338790**
S	2	24566**	0.270	352000**	635200**	480572**	670945**
N x P	4	4117	1.304	14225	105850	14395	97397
N x S	4	8063	2.075	20650	23625	19886	16532
P x S	4	2980	1.352	11650	48525	11720	52955
Error (a)	6	4736	1.470	10131	29600	10461	27126
M	3	48260**	13.768**	759733**	8991566**	765419**	899026**
N x M	6	8059**	1.864*	16916**	25883	17217**	28546*
P x M	6	1501	0.544	4533	14400	4101	17921
S x M	6	1392	0.948	2550	23533	2702	23058
N x P x M	12	1378	0.838	2916	21324	2958	28307**
N x S x M	12	1012	0.647	3700	10475	3575	11520
P x S x M	12	1470	0.942	2983	14483	2844	15781
Error (b)	24	785	0.557	2620	10016	2572	6646

* Significant at P = 0.05, ** Significant at P = 0.01

APPENDIX I-B (Experiment 2)

Analysis of variance of the data given in Tables 4.2,4.4,4.5,4.8,4.10,4.12,4.13,4.15, 4.17,4.22,4.24,4.26,4.27 and 4.28

Source of variance	d.f.	Mean sum of squares					
		Grain yield, kg/ha	Number of productive tillers/ hill	Number of grains/ panicle	1000 grain weight, g	Total mill yield	
						kg/ha	%
Block	2	1800	0.108	70.851	0.438	500	0.015
N	2	1458750**	3.017	60.453	0.026	799500**	1.655
P	2	119450**	0.207	167.600*	0.127	41050**	1.125
S	2	485800**	1.508	100.052	0.206	278950**	0.360
N x P	4	21950	0.341	10.375	0.075	24825*	1.675
N x S	4	6000	0.314	9.525	0.053	2875	0.990
P x S	4	5500	0.145	109.204*	0.147	2325	1.702
Error (a)	6	9400	0.406	23.250	0.088	5150	0.855
M	3	1445166**	-	793.366*	0.222**	668933**	9.396**
N x M	6	91000**	-	40.002	0.029	48183**	2.141
P x M	6	16033	-	10.166	0.023	8116	0.965
S x M	6	4850	-	5.101	0.039	11616	1.853
N x P x M	12	8633	-	8.158	0.026	7566	0.910
N x S x M	12	9191	-	7.902	0.044	8783	1.901
P x S x M	12	6491	-	6.283	0.058	6016	0.757
Error (b)	24	7550	-	4.291	0.032	6833	0.891

* Significant at P = 0.05, ** Significant at P = 0.01

contd../

APPENDIX I-B(Contd.)

Source of variance	d.f.	Mean sum of squares					
		Head yield		Broken rice		Bran	
		kg/ha	%	kg/ha	%	kg/ha	% +
Block	2	32275	13.800	29021	29.178	597	0.282
N	2	705830**	3.035	4182	6.225	3961**	0.134
P	2	14150	6.190	8425	3.213	504	0.210
S	2	305750**	6.370	6381	11.185	318	0.420
N x P	4	20312	1.762	2009	1.905	120	0.069
N x S	4	7322	3.910	4553	5.053	77	0.080
P x S	4	13162	9.022	8515	7.139	230	0.138
Error (a)	6	9781	7.915	11969	9.895	243	0.145
M	3	3193543**	547.360**	987165**	1057.245**	3012**	4.991**
N x M	6	67751**	8.958*	5968	10.650*	130	0.036
P x M	6	18611	4.710	8035	8.073*	337	0.254*
S x M	6	23806	8.128*	3191	7.294	171	0.113
N x P x M	12	12748	3.774	4573	4.098	151	0.077
N x S x M	12	14536	4.749	4415	3.877	180	0.123
P x S x M	12	9456	1.857	1918	2.165	199	0.154
Error (b)	24	10492	2.355	3285	3.006	266	0.094

* Significant at P = 0.05, ** Significant at P = 0.01 + Polish per cent

APPENDIX I-B (Contd.)

Source of variance	d.f.	Mean sum of squares					
		Husk		Gross return		Net return	
		kg/ha	Rs	Rough rice, Rs/ha	Polished rice, broken, bran, and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran, and husk, Rs/ha
Block	2	1750	0.144	1400	8650	1160	8470
N	2	76060**	1.628	1174650**	1923300**	491970**	1051010**
P	2	16960*	0.894	82600**	61400**	48765*	51010*
S	2	33870**	0.917	33975**	6183000**	505715**	721955**
N x P	4	3597	2.258	16150	50075*	17217	25650
N x S	4	6397	0.855	4450	8650	4292	8807
P x S	4	5205	1.018	3050	7050	3297	7037
Error (a)	6	2241	0.562	6150	6066	6231	6065
M	3	185770**	12.843**	770966**	2761633**	764030**	2763243**
N x M	6	9985*	2.253*	48466**	98616**	48783**	98890**
P x M	6	6363	0.629	8500	14400	8991	14538
S x M	6	4941	1.853	2600	27150	2765	27325
N x P x M	12	4084	1.199	4633	19316	4717	19281
N x S x M	12	6134	1.578	4891	17550	5122	17450
P x S x M	12	4310	0.621	3408	9516	3451	9435
Error (b)	24	3233	0.850	3987	15208	4227	15374

* Significant at P = 0.05   ** Significant at P = 0.01

APPENDIX II-A (Experiment 3)

Analysis of variance of the data given in Tables 4.29, 4.31, 4.32, 4.35, 4.36, 4.38, 4.39 4.40, 4.42, 4.43 and 4.44

Source of variance	d.f.	Mean sum of squares					
		Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/panicle	1000 grain weight, g	Total mill yield	
						kg/ha	%
Block	3	24138	0.015	18.332	0.0003	56151	0.067
V	3	3559679**	3.650**	1352.334**	153.0497**	186386**	0.507**
N	3	4998171**	22.608**	3329.667**	0.0013	2776793**	0.783**
P	3	2395863**	2.452**	916.332**	0.0067	1269950**	0.149**
VN	9	101729*	0.361**	34.805	0.0006	54051**	0.041
VP	9	34861	0.014	30.442	0.0005	18923	0.074
NP	9	39364	0.051	20.111	0.0005	22242	0.023
Error	24	35192	0.033	18.460	0.0045	12766	0.027

* Significant at P = 0.05, ** Significant at P = 0.01

APPENDIX II-A (Contd.)

Source of variance	d.f.	Mean sum of squares					
		Head yield		Gross return		Net return	
		kg/ha	%	Rough rice, Rs/ha	Polished rice, broken, bran, and husk, Rs/ha	Rough rice, Rs/ha	Polished rice, broken, bran and husk, Rs/ha
Block	3	15265	0.732	32174	81785	32174	81785
V	3	1642769**	178.063**	2445750**	3577240**	2445750**	3577241**
N	3	1665789**	3.566**	3450717**	4666205**	2062300**	2939388**
P	3	439750**	25.596**	1691746**	1911050**	830739**	996698**
VN	9	63658**	0.966	69248**	138623**	69248**	138624**
VP	9	14129	3.390**	23932	48824	23932	48824
NP	9	13479	0.462	27111	30111	27146	30118
Error	24	8503	0.330	17190	41552	17190	41552

* Significant at P = 0.05 ** Significant at P = 0.01

APPENDIX II-B (Experiment 4)

Analysis of variance of the data given in Tables 4.30,4.33,4.34,4.36,4.37,4.38,4.39 4.41,4.43,4.44 and 4.45

Source of variance	d.f.	Mean sum of squares					
		Grain yield, kg/ha	Number of productive tillers/hill	Number of grains/panicle	1000 grain weight, g	Total mill yield	
						kg/ha	%
Block	3	2780	0.028	2.291	0.007	5112	0.037
V	3	2114186	1.637**	674.041**	146.495**	1109915**	2.608**
N	3	6895763**	23.662**	1405.375**	0.005	3810779**	0.829**
P	3	2492794**	1.910**	1432.708**	0.003	1324897**	0.816**
VN	9	39053	0.019	6.472	0.001	22050	0.031
VP	9	16083	0.008	3.194	0.003	9352	0.146*
NP	9	46016	0.029	4.194	0.004	32649**	0.149*
Error	24	19979	0.025	5.562	0.009	9510	0.052

* Significant at P = 0.05. ** Significant at P = 0.01

APPENDIX II-B (Contd.)

Source of variance	d.f.	Mean sum of squares					
		Head yield		Gross return		Net return	
		kg/ha	%	Rough rice, ₨/ha	Polished rice, broken, bran, and husk, ₨/ha	Rough rice, ₨/ha	Polished rice, broken, bran and husk, ₨/ha
Block	3	3706	0.355	10134	8524	10027	8154
V	3	1073196**	138.858**	1440823**	2244681**	1438901**	2243648**
N	3	2719545**	6.149**	4751280**	7322362**	3014428**	5099076**
P	3	439032**	35.213**	1807382**	1957483**	1137343**	1264747**
VN	9	19758*	0.641	39921	44688**	39987	44518*
VP	9	7942	3.542**	3047	13667	14250	13648
NP	9	25897**	0.790	37251	63717**	48434**	63835**
Error	24	6635	0.365	18445	17868	14363	17343

* Significant at P = 0.05, ** Significant at P = 0.01

APPENDIX III

Cost of inputs and market value of the produce (prevailed during 1973)

Input		Cost, Rs/ha
Land preparation	-	398.00
Seed	-	119.40
Nursery	-	55.72
Farm yard manure	-	258.80
Labour	-	541.28
Plant protection	-	175.00
Water	-	4.00**
Temporary dead stock	-	20.00
Land tax	-	20.00
Fertilizer		
Urea	-	98.20*
Superphosphate	-	36.50*
Muriate of potash	-	54.00*
Processing charges	-	1.20*
Handling and storage charges	-	0.80*
Interest charges @ 8% for 6 months	-	

** Cost per ha-cm

* Cost in Rs/q

(Appendix III contd.)

Market value		Rs/q
Rough rice(paddy)		
Sona, Jayanti and IR 22	-	73
Pankaj	-	70
Head rice		
Sona, Jayanti and IR 22	-	130
Pankaj	-	125
Broken rice	-	65
Bran	-	100
Husk	-	1
Straw	-	10