REPORT

OF

FERTILIZER USE EFFICIENCY

UNDER

MOISTURE STRESS CONDITIONS

PROJECT. CGP-ISM-R-IV

AT

BARANI AGRICULTURAL COLLEGE

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FERTILIZER USE EFFICIENCY UNDER MOISTURE STRESS CONDITIONS.

ABSTRACT.

The fertilizer use efficiency in Pakistan is quite low and highly variable under different soil and climate conditions. Fertilizers have been mostly subject of irrigated agriculture. In rainfed conditions it is common notion among farming community that fertilizer application is of little value and fertilizer use efficiency has not been investigated under such environments. In this context investigations pertaining to fertilizer use efficiency under differential irrigation/moisture levels were undertaken with wheat and maize as test crops. Experiments pertaining to wheat were conducted at Barani Agricultural College, Rawalpindi, subhumid region in field and greenhouse conditions with variables, fertilizer and moisture levels. The wheat sown in field was supplemented with one sprinkler irrigation to incidental rainfall received during growth season of the crop. The wheat planted under green house conditions was applied fertilizers dose identical to field experiment and irrigation at field capacity, half and quarter field capacity by conventional flood and sprinkler methods.

The green house experiment in maize was similar to wheat sown under green house conditions with regards to irrigation levels. and methods, however the fertilizer levels differ compared to wheat crop. The field experiment in maize was laid under semi-arid conditions of Talagang with similar fertilizer treatment as in case of maize of green house trial. One irrigation at critical stage by sprinkler method was also applied.

The germination in both the crops was not affected by fertilizer and irrigation treatments. However all other yield components like plant height, number of grains per spike and hundred grain weight of wheat crop were affected significantly by different fertilizer and irrigation levels. The growth/yield parameters depicted an increase with increase in fertilizer and moisture application. Same was true and valid for maize crop. The results in detail are discussed in text of the report.

PROJECT INTRODUCTION.

Water is most limiting factor in crop production all the world over. Of the total 20.5 million hectare cultivated area in Pakistan five million hectare re rainfed.. In rainfed cultivated area almost 50% of land has no inherent soil limitation except moisture deficit. Low productivity is common feature in rainfed areas and is mostly result of erratic, seasonal and inadequate precipitation. (National Agriculture Commission, 1988). Moisture not only affects soil characteristics and plant growth but also nutrient availability. Fertilizer is costly input and total cost incurred on fertilizers during 1988-89 was rupees 9.90 billions (NFDC, 1989). This evidently call for effective use of fertilizers. The way and means to increase fertilizer efficiency has been subject of many deliberations in the past (FAO, 1983, FFC, 1989; Saleem et al, 1986).

Fertilizer efficiency has been regarded as amount of increase in yield in harvested portion of crop per unit of fertilizer nutrient applied. Fertilizer efficiency is dependent on seedbed preparation, crop variety, quality seed sowing time, plant population & density, irrigation management, weed control, insect, pest attack and fertilizer management. Among the factors stated fertilizer, merit at the top, as fertilizer is vital to realize full genetic potential of crops. Nitrogen, phosphorus and potassium are most used plant nutrients that are supplemented through chemical fertilizers. The utilization efficiency of these fertilizers on farmers fields have been quite low. The reports of IRRI revealed that in Asia farmers only recover 1/3rd of urea nitrogen applied to rice crop. Phosphorus and potassium utilization efficiency is also effected variably in different soils.

Under irrigated conditions fertilizer use efficiency has been extensively investigated (Chaudhry and Qureshi, 1981; Sharif, 1985; Sandhu, 1985). However similar information is lacking under rainfed agriculture that constitute about 25 percent of total cultivated area in the country. Water is important factor that affect fertilizer efficiency significantly. Adequate soil moisture increase fertilizer utilization by crops. (Viets, 1962). The nutrient absorption specifically that of nitrogen, phosphorus and potassium in dry soil is reduced, but extent of uptake is variable, phosphorus and potassium utilization is more limited than nitrogen (Tisdale et al, 1985). Shimsi (1969) illustrated that optimal level of nitrogen decreased to almost half as soil moisture tension increased from 0.2 to 2.0 bars, and crop yield decreased accordingly.

Apparently crop cannot utilize high rate of applied nitrogen under moisture stress conditions. Stan berry et al (1955) demonstrated that effect of soil moisture stress is more pronounced at high than at low level of nitrogen application. In case of phosphorus the

crop response to high and low level of phosphorus under moisture stress conditions was similar and no interaction between moisture stress and rate of applied phosphorus was recorded. Watanabe et al (1960) observes that nutrient uptake was maximum at 0.3 bar and reduced to more than 40 percent at 9.0 bars soil moisture tension. Similar observation in case of potassium were made Mederski and Stack house (1960).

It is usually documented that water increases the efficiency of nutrients especially fertilizer elements, The reverse statement is also valid. Fertilizer application increases water use efficiency ; dry matter production per unit of water used. (Mengel and Kirby, 1973; Hagin and Tucker, 1982).Viets (1962) also demonstrated increases water use efficiency by fertilizer application. It is viewed that nutrient supply to plant can offset the adverse effect of drought. This indicate that water and fertilizer are substitutional inputs and one can affect the efficiency of other to certain degree. However extent of efficiency under different climatic and soil especially rainfed conditions has not been tested. The low fertilizer use efficiency is matter of great concern to the farmers as ever increasing fertilizer costs affect their net returns. At the same time it is a challenge to the Scientists and investigations needs to be directed to increase fertilizer use efficiency under rainfed. conditions.

Keeping this in view, the study was conducted with the following objectives.

1- To study fertilizer use efficiency under rainfed conditions (Barani Areas).

2- To investigate water use efficiency in Barani Areas.

3- To evolve efficient fertilizer use technology for wheat and maize crops in Barani areas.

4- Strengthening of research facilities at Barani Agricultural College Rawalpindi.

The study was two phase phenomena; during phase I Fertilizer use efficiency in wheat under moisture stress conditions in the field and green house at Barani Agricultural College Rawalpindi was conducted. As regard phase II, similar type of investigation in maize in semi-arid conditions at Talagang in farmer's field was conducted and a green house experiment was also carried at Barani Agricultural College, Rawalpindi. The details of these investigations are discussed in the preceding sections.

FERTILIZER USE EFFICIENCY

IN WHEAT CROP UNDER

MOISTURE STRESS CONDITIONS.

(FIELD EXPERIMENT)

INTRODUCTION

Fertilizer use has played a vital role in increasing yields in Pakistan. Therefore, the use of fertilizer in Pakistan has increases considerably from as low as 5 kg ha^{-1} during 1965-66 1989-90 (NFDC, 1980-90). Fertilizer applied to soil are not fully recovered by the growing crops and a large proportion of applied fertilizer goes waste. It is estimated that on the average, only 50-60 percent of applied nitrogen is recovered by upland crops and 30-40 percent by rice (Saleem, 1992). As regard to phosphorus only 15-20 percent of the applied phosphatic fertilizer is utilized by crops (Zia et al., 1991). The recovery of potassium is about 20-80 percent (Saleem et al., 1988). Therefore, improving fertilizer use efficiency is of paramount importance to increase agricultural production in the country.

There are many climatic and soil factors affecting the fertilizer use efficiency. Soil moisture is one of the most important factor affecting the plant availability of different nutrients. A low soil moisture level has a limiting effect on plant responses to applied fertilizer. Storage of moisture increases diffusion and mass flow of nutrients from the soil to the plant root and results in root interception and ion exchange (Tisdale et al., 1985). In rainfed (Barani) area of Pakistan, rainfall is the most important agro climatic variable affecting crop production. Uncertainty of rainfall and inadequate soil moisture are a major impediment affecting fertilizer use efficiency in rainfed areas.

Since in Barani areas soil moisture is limiting factor affecting fertilizer use efficiency, therefore, a timely irrigation of even a few centimeters at a critical growth stage can greatly increase fertilizer use efficiency and improve crop yield considerably (Ahmad et at., 1987). Efforts are being made to store rain water in the form of small dams and ponds and use water for crop production. Water from stream can efficiently be used by sprinkler irrigation. Sprinkler irrigation can be practically used in all types of soil even uneven, sloppy and for almost all types of crops. (Ahmad et al., 1987). Sprinkler irrigation system uses only less than half the water needed for flood irrigation.

Out of the total consumption of NPK fertilizers in Barani areas, major portion of these fertilizers is applied to wheat crop because wheat is major winter crop in Barani areas, it contributes about 10-12 percent of total wheat production in the country (Saleem et al., 1986). Therefore, improving fertilizer use efficiency in wheat can save millions of rupees as foreign exchange involved in wheat import, by increasing wheat production in the country especially in Barani areas.

Keeping in view the importance of moisture in improving fertilizer use efficiency and its role in increasing wheat production through the possible use of sprinkler irrigation in Barani areas, the study was initiated with the following objectives.

1) To improve the NPK fertilizer use efficiency in wheat under rainfed conditions through supplemental irrigation at critical moisture stressed conditions.

2) To compare the water use efficiency at various levels of fertilizer application.

REVIEW OF LITERATURE.

Adequate supply of plant nutrients and water are important variable for crop production. At deficient soil moisture, the response to applied fertilizers is dwarfed, but increases with adequate availability of water. On the other hand when soil fertility is low, response to water is minimum, but is maximum at optimum fertility level. Nutrients are exhausted due to continues cultivation of crops and meager replenishment of nutrients. The nitrogen and phosphorus resources in almost all the soil are deficient and potassium is also limited to certain extent in some soils. The adequate supply of plant nutrients and water management in crop production has therefore assumed the foremost importance in profitable agriculture in the region.

The response of wheat to Nitrogen, Phosphorus and Potassium as an individual nutrient or in integration is reviewed as under.

WHEAT RESPONSE TO FERTILIZERS

In moisture stress conditions, not only the concentration of nutrients in the soil is affected, but also the rate of movement of nutrients to roots by diffusion and mass flow is also restricted. As regard nitrogen, No_3^{-1} mobility is retarded and becomes unavailable to crop under moisture stress conditions. However wheat crop has ability to withstand drought conditions to some extent and its yield can be improved by application of nitrogen fertilizers.

Richardson (1960), studied the inter-relationship between the soil moisture and fertilizer in wheat crop. He observed the yield increased only 5 % when the soil was deficient in nitrogen. When nitrogen was added to the dry soil, yield increased 3 to 7 times the former level, but when the same amount was added in combination with optimum soil moisture conditions, yield increased almost seven fold.

Sud et al (1990) in a field experiment on sandy loam soil applied a common irrigation at crown root stage to wheat crop. The irrigation was subsequently applied at 35, 50 and 65 percent depletion of available soil moisture. crop was fertilized with 40, 80 and 100 kg N ha^{-1}. They observed that increasing levels of irrigation and N fertilizer was synergistic in increasing grain yield, N uptake and utilization of N fertilizer. Nelson and

Halvorson (1991) studied the effect of nitrogen fertilization on water use and yield of dry land winter wheat and elucidated that grain yield increased with increase in nitrogen applied up-to 50 kg N ha^{-1}, water use efficiency also increased with increase in N fertilizers up-to 56 and 84 kg N ha^{-1} in 1988 and 1990.

Arnon (1972) elucidated that under semi-arid condition, the response of wheat to fertilization was observed to be positive. On soils that were deficient in P, the yield increased even when the moisture supply at sowing time was low. The studies, have shown that similar results were obtained with phosphorus in South Australia. In a year of extreme drought, on phosphorus deficient soil, the wheat yield greatly increased with increase in application of phosphatic fertilizer. Harmsen et al (1983) elucidated that yield response to phosphorus was significant at the drier sites, but at the wetter sites their seems to be little or no response to phosphorus, the available phosphorus status of soil at all sites was in low to medium range. In light of these results they suggested that crop may require higher level of available soil phosphorus under dry conditions. Singh and Singh (1989) in a field experiment applied 9, 50, 75 and 100 percent of recommended P rates to wheat under rainfed conditions. Phosphorus application at 50, 75 and 100 of recommended rates gave 31.7, 24.7 and 26.2 percent higher yield of wheat compared to control treatment.

Saleem (1983) elucidated the details of a long term experiment from 1975-76 to 1980-81. The results of the experiments indicated that wheat response to K fertilizer under rainfed conditions progressively increased from 57 kg ha^{-1} in 1975-76 to 505 kg ha^{-1} fertilizer application in 1980-81. Sekhon et al (1983) explained that although crop yields were relatively low in low rainfall areas and demand for K was also less, yet wheat crop responded considerable to K fertilizer. The studies also revealed that adequate amount of available K under moisture stress enable the guard cells around stomatae to be more turgid, so that the stomata open and close in response to rapid changing transpiration conditions, that reduce transpiration losses. They further recorded that at low moisture contents, plant root absorb K mainly from their immediate vicinity as diffusion of K is slow and there is less or no movement to the root under moisture stress conditions.

The application of nitrogen and phosphorus in combination also resulted in an increase in yield of wheat crop. Rajput et al (1989) examined different combinations of N and P in wheat at the sowing time. The N-P_2O_5 doses were 0-30, 0-60, 50-60, 100-30, 100-60, 150-30 and 150-60 kg N and P_2O_5 ha^{-1}, respectively the results indicated that yield components were significantly affected by various treatments. Application of 100 kg N and 60 kg P ha^{-1}, significantly enhanced plant height, number of tillers per plant, grain per spike, spike length and grain yield in comparison to other doses of fertilizer.

The application of potassium in combination with nitrogen and phosphorus also resulted in more crop harvest. Saleem (1983) elucidated the role of fertilizer in increasing wheat yield and fertilizer response under different moisture regimes in Pakistan. Yield of rainfed wheat increased from 1065 to 2329 kg ha^{-1} with the response to individual nutrient worked out was 459, 215 and 13 kg ha^{-1} each for nitrogen, phosphorus and potassium, respectively. Bhatti et al (1985) studied the performance of two wheat varieties Khushal and Mexi-65 under rainfed condition to different fertilizer treatments.

The study indicated that the application of 92 kg N ha^{-1} in combination with 90 kg P_2O_5 ha^{-1} and 67 kg K_2O ha^{-1} resulted in more yield for both the wheat varieties.

Wheat Growth Response to Moisture Stress In Relation to Water Use Efficiency and Fertilizer Use Efficiency

Khondaker et al. (1983) imposed moisture stress ranging from field capacity (F.C) to wilting CO-efficient (W.C) at different growth stages to study its effect on the availability and uptake of N, P and K by wheat plants, growth, yield and quality of wheat under fertilized and unfertilized conditions. Stress imposed beyond field capacity to 1/2 field capacity decreased N and P availability and their uptake. However K availability and uptake was little affected by moisture stress. Wheat plant grew well and produced better yield at moisture levels of field capacity and field capacity to half field capacity as compared to other moisture stress treatments. Moisture stress of 1/2 field capacity to wilting CO-efficient and 1/3 field capacity to wilting coefficient resulted in harmful effect on crop growth and yield. Moisture stress conditions imposed at tillering, flowering and harvesting stages were responsible for moderate adverse effects on the crop.

Sharma (1985) observed that average grain yield of wheat increased from 1600 Kg ha^{-1} to maximum of 1700 Kg ha^{-1} as soil moisture tension (SMT) decreased from 4.0 to 1.5 bars. With the application of N @ 40 and 80 Kg ha -1, grain yield of 1400 and 2000 Kg ha^{-1}, respectively was recorded. By decreasing SMT, the yield increased in the range of 1900-2400 and 2000-3000 Kg ha-1 with 40 and 80 Kg N ha^{-1}, respectively. Nitrogen uptake increased with increasing SMT and increasing nitrogen rates in both the experiments.

Ahmad et al. (1985) conducted field experiment in wheat during 1976-77 to 1978-79. The soil was subjected to three moisture levels i.e. 1, 4 and 7 bar tension and four

fertilizer levels of 67-34-34, 67-67-34, 134-34-34 and 134-67-34 Kg NPK ha^{-1}. The maximum grain yield of 5710 Kg ha-1 was achieved when the crop was irrigated at one bar tension and 134-67-34 Kg NPK ha^{-1} was applied. It was also observed that with the increase in moisture tension, the yield decreased at each fertilizer level but by increasing fertilizer level the yield increased at each level of moisture stress.

Talukder et al. (1989) in a field experiment subjected wheat CV. pitic to water stress through out crop growth period between emergence and elongation, between booting and flowering or grain formation. Water use efficiency ranged from 27.1 Kg mm^{-1} per hectare with full irrigation to 32.2-38.2 Kg mm^{-1} per hectare without irrigation.

Effect of Irrigation Regimes and Balance Fertilization on Yield and Uptake of Nutrients.

Mohammed et al. (1983) subjected wheat variety Pb-81 to five irrigations and fertilizer levels for determining suitable combination of irrigations and fertilizer use. The results of trial revealed that maximum yield was obtained when five irrigations, starting from crown root to milk stage, were applied along with 250-250-0 Kg NPK ha^{-1}, applied with first irrigation. One and three irrigation level in combination with 250-250-0 Kg NPK gave 3775 and 4069 Kg ha^{-1} grain yield, respectively.

Ahmad et al. (1989) studied the effect of different combination of NPK fertilizer at various irrigation levels on wheat crop CV. Kohinoor-83. Fertilizer treatments comprised of 0-0-0, 50-50-50, 100-50-50 and 100-100-50 Kg NPK ha^{-1} and two irrigation levels i.e. four and five irrigations were applied. They elucidated that irrigation treatments had not affected the yield and yield components and both the levels were at par due to heavy rainfall received during the crop growth period. They also observed that grain yield increased progressively with increasing NPK ha^{-1} which was 67.7 percent higher than control. Germination was not affected, while yield components like fertile tillers, grains per spike and 1000 grains weight were affected by fertilizer treatments.

Hassan et al. (1992) conducted three year experiment to evaluate the fertilization and irrigation interaction and found that interaction between the four number of irrigation with 150- 120-50 Kg NPK ha^{-1} showed maximum number of tillers per square meter. Maximum yield was obtained when six irrigation with 150-120-50 Kg NPK ha^{-1} were applied.

Water Use Efficiency and Fertilizer Use Efficiency under Different Fertilizer and Moisture Levels.

Shimshi (1966) studied the effect of fertility levels on water use efficiency and observed that water use efficiency increased with increase of water supply at higher fertility levels, By contrast, at low fertility level water use efficiency decreased with increasing water supply.

Laghari et al. (1979) conducted two field experiment during 1975-76. The soil was subjected to three levels of moisture depletion i.e. 50,70 and 75 percent, respectively with four fertilizer levels of 0-0-30, 50-25-30, 100-50-30 and 100-75-30 Kg NPK ha -1 in 1975-76 and three moisture depletion level 70, 80 and 90 percent, respectively with four fertilizer level 120-0- 30, 120-60-30, 60-0-30 and 60-60-30 Kg NPK ha^{-1} in 1976-77. They observed that maximum grain yield of 3250 Kg ha^{-1} was obtained when crop was irrigated at 50% moisture depletion and 100-50-30 Kg NPk ha^{-1} was applied in 1975-76, while a maximum yield of 3480 Kg ha^{-1} was obtained when wheat crop was irrigated at 70% moisture depletion with 120-60-30 Kg ha^{-1} fertilizer levels in the next year.

Ahmad and Khokhar (1988) studied the effect of water and fertilizer on wheat crop. In a field experiment they applied fertilizer @ 67-34-34, 67-67-34, 134-34-34 and 134-67-34 Kg NPK ha^{-1}, respectively at three different moisture depletion i.e. 40, 60, and 75 percent. Highest grain yield was obtained with a treatment combination of lowest moisture depletion (40%) and highest fertilizer dose of 134-67-34 Kg NPK ha^{-1}. They also observed that inspite of reduction in yield at higher depletion, fertilizer response was positive, Highest water use efficiency of 1.46 Kg m^{-3} for wheat was observed with a combination of high depletion and high fertilizer. They also recorded that WUE increased at each level of moisture with the application of fertilizer and it was reduced by increase in irrigation levels.

Effect of Sprinkler Irrigation on Crop Growth.

Viets (1967) compared sprinkler irrigation to furrow irrigation in relation to the fertilizer requirements for maximum yield in various crops. His conclusions indicate that no advantages were observed when the water supply regimes to crop were compared under both methods, However under sprinkler irrigation, it became very convenient to apply the fertilizer with the irrigation water.

Jankwiak (1983) observed in a field experiment that wheat yield increased with the application of sprinkler irrigation. He also observed that sprinkler irrigation is more effective when applied with fertilizes.

Stock (1983) observed in a field experiment with wheat and spring barley, that sprinkler irrigation resulted in highest yield increment when adequate water was supplied at the vegetative and grain formation stages.
Buniak et al. (1988) observed in three years experiment that increasing N rates with sprinkler irrigation increased the number of ear per plant, ear length, number of kernels per-ear and 100 grains weight of wheat, They also inferred that sprinkler irrigation was effective only with the application of fertilizer.

Smukalski et al. (1989) compared surface irrigation plus a single application of a NPK to wheat and forage maize with three split dressing applied through sprinkler irrigation. The result were found to be conclusive, but maize yield depicted a trend of increase with split NPK application. However, no significant differences were observed in case of wheat crop.

MATERIALS AND METHODS

To study the fertilizer use efficiency under moisture stress conditions, a field experiment was conducted on wheat crop, in the research area of Department of Soil Science of Barani Agricultural College Rawalpindi during 1991-92. The filed was prepared by one deep ploughing followed by planking and two ploughing by cultivator. The experiment consisted of nine treatment of different NPK combination and four moisture management levels and was laid out in a factorial Randomized Complete Block Design as described below.

1.0 Fertilizer Treatments :-

The fertilizer treatment were as follow :

Treatment	N	P_2O_5 (Kg ha^{-1})	K_2O
* F1	57	0	0
F2	57	57	0
F3	57	57	0
F4	85	57	57
F5	85	85	57
F6	85	85	85
F7	115	85	85
F8	115	115	85
F9	115	115	115

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* Hereafter these treatment will be considered as F1, F2,.... and F9

2.0 Moisture management treatments

In addition to rainfall, following moisture management treatments were included.

* I 0 Control- (rainfall received during crop growth period).

I 1 Sprinkler irrigation at 25 per cent of soil field ** capacity.

I 2 Sprinkler irrigation at 50 per cent of soil filed capacity.

I 3 Sprinkler irrigation at soil field capacity.

The field was divided into 36 equal plots of 12 x 1.25 meter and replicated three times.

Composite soil samples were taken from the research area from 0-15 and 15-20 cm depth before sowing the crop. The soil samples were air dried, ground to pass through 2 mm sieve to study the following physical and chemical characteristics.

1) Texture

2) Organic matter

3) EC_e

4) PH of the saturated soil paste

5) $CaCO_3$

6) Total nitrogen

7) Available Phosphorus

8) Extractable Potassium

---

* Here after the treatment will be considered as I_0, I_1 , I_2, and I_3.
** Field capacity is considered as half of the saturation percentage.

The data pertaining to above physical and chemical characteristics of soil is given in table 1.

The wheat variety Pak 81 was sown on November 27, 1991.

3.0 Irrigation and weeding

Rainfall was supplement with sprinkler irrigation on January 6, 1992 at 3 different levels when the crop was also at moisture stress conditions and a sever termites attack was observed. After that there was no need of irrigation due to heavy rainfall. Weeds were manually removed twice during crop growth period. The meteorological data regarding rainfall, humidity and temperature was collected which is presented in table 2.

4.0 Termites Attack

A server termites attack was observed in early January, 1992 With the application of water through sprinkler irrigation, it was controlled. In the control treatment it remained until the rainfall started.

5.0 Harvesting

The crop was harvested on May 12, 1992. During and at the end of the growth period the following data pertaining to crop was recorded.

1) Germination (count m^{-2} at the completion of seedling emergence)

2) Plant density (Plant m^{-2})

3) Number of tillers per plant.

4) Plant height.

5) Number of spikes per plant.

Table 1 : Physical and Chemical Characteristics of Soil.

	CHARACTERISTICS	VALUE	
		0-15 cm	15-30 cm
1.	Texture		
	Sand (percent)	60	60
	Silt (percent)	26	24
	Clay (percent)	14	16
	Texture Class	Sandy loam	Sandy loam
2.	Saturation percentage	36	36
3.	pH_s	7.8	7.5
4.	Organic matter (g/100g)	0.66	0.56
5.	EC_e (dSm^{-1})	0.24	0.20
6.	Total Nitrogen (mg/g)	0.35	0.30
7	Available phosphorus (ug/g)	5.50	4.7
8	Extractable potassium (ug/g)	100	96
9.	$CaCO_3$ (g/100g)	5.8	5.8

Table 2 : Meteorological data during the growth period of wheat crop

(December, 1991 to May, 1992)

	Month	Rainfall (mm)	Mean Relative Humidity %	Mean Temperature °C Min	Max
1	Dec.	22.8	73.8	6.2	19.1
2	Jan.	105.3	77.0	0.5	20.4
3	Feb.	96.8	68.8	5.7	18.2
4	March.	107	60.5	5.1	27.2
5	April.	44.4	59.9	14.2	27.5
6	May	47.4	44.4	15	39.8

Source : Regional Agromet Center Pakistan,
Meteorological Department, Rawalpindi.

6) Grain per spike.

7) hundred grains weight.

8) Fresh and dry weight of the plant.

9) Grain and straw yield expressed on hectare basis.

Plant straw and grain samples were taken from each treatment prior to harvest of the crop. Straw and grain samples were separately chopped, air dried, oven dried at 65°C and finally ground for the analysis of total nitrogen, phosphorus and potassium.

6.0 Analytical Work

The analysis of soil sample and plant materials were carried out according to the methods as described by Page et al. (1982), unless otherwise mentioned.

7.0 Soil Analysis

7.1 Mechanical analysis

A 40 gram soil sample was taken in a 400 ml beaker. Forty milliliters of one percent sodium hexamata phosphate ($NaPO_3$)6 and 150 ml of distilled water, were added. The sample was kept over night. The suspension was stirred with mechanical stirrer for 10 minutes and reading were recorded with Bouyoucos hydrometer (Moodie et al., 1959). Soil textural class was determined by using the international system of soil texture triangle.

7.2 Saturation percentage

The soil was taken in a beaker and distilled water was gradually added with constant stirring with spatula till a soil was formed.

A portion of the paste was transferred to a tarred soil cup with lid and weighed. The paste was dried in an oven at a temperature of 105°C to a constant weight and cooled in a dessicator and weighed again. The saturation percentage (SP) was calculated by dividing loss in weight of soil with weight of oven dried soil and multiplied by 100. (Hussain and Jabbar, 1985).

7.3 Determination of Electrical Conductivity-EC_e

Saturation extract was obtained from the saturated soil paste. Temperature of the extract was noted and adjusted at 25°C and EC_e was recorded by using a conductivity meter (Page et al., 1982).

7.4 pH of the Saturation Paste

Two buffer solution of PH 4 and 9 were prepared by dissolving buffer tablets in 100 ml distilled water. The pH meter was standardized with buffer solutions.

After calibration, the soil paste was taken in a beaker. The electrode of pH meter was inserted into the paste and reading of pH meter was recorded (U.S. Salinity Laboratory staff, 1954).

7.5 Estimation of Organic Matter

A 10 gram of soil sample was taken in 500 Erlenmeyer flask and 10 ml of 1,0 N potassium dichromate was added. The flask was swirled to treat the soil thoroughly. Then 20 ml of concentrated commercial sulfuric acid (H_2SO_4) was added in the suspension and swirling was done for one minute. The flask was allowed to stand for 30 minutes. Two hundred ml of distilled water was added and the suspension was filtered. Three drops of ferroin indicator were added and titrated against 0.5 N ferrous sulfate until the color changed from blue to red (Page et al., 1982).

7.6 Determination of $CaCO_3$ in the Soil

A sample of 10 g of soil was taken in a 150 ml beaker. Thirty milliliter of o.5 N Hydrochloric acid was added by means of a pipette. The beaker was covered with a watch glass and the solution was boiled gently for five minutes, then cooled, filtered and washed all the acid from the soil with water. Two drops of one percent phenolphthalein was added in 60 percent ethanol and titrated against 0.25 N Sodium hydroxide. (NaOH) solution. (Hussain and Jabbar, 1985).

7.7 Total Nitrogen

A soil sample of 10 gram was taken in a microkjeldahl; flask and 30 ml of conc. Sulfuric acid was added. Now 10 gram of digestion mixture (K_2SO_4, $CuSO_4$, $5H_2O$ Selenium metal powder, 10: 1.0: 0.1) was added, flask was heated until the digest was clear. After cooling, small lots of water were added dissolving by stirring the flask. The contents were transferred to a 250 ml flask and several washing were given to the flask and water was added to 250 ml flask and volume was made up to the mark.

Ten milliliters solution of 250 ml flask was transferred in the distillation chamber through the funnel of the microkjeldahl distillation apparatus. Water was added to the distillation chamber to make 50 ml volume. Five milliliters of boric acid solution was taken in a 50 ml Erlenmeyer flask that was placed under the condenser of the distillation apparatus so that the end of the condenser was about 4 cm above the surface of the boric acid. Now 20 ml of 40 percent NaOH and then water was added slowly in the distillation chamber through the funnel of apparatus until the volume was 80 ml. The funnel was closed and distillation was commenced until the distilled reached up to the 35 ml mark in the receiver flask. Ammonium-N in the distillate was determined by titrating with 0.01 N sulfuric acid. The color change at the end point was from green to pink (Page et al., 1982

7.8 Available Phosphorus

Five grams of soil sample and 100 ml of 0.5 M $NaHCO_3$ were taken in a 250 ml Erlenmeyer flask and then shaken in reciprocating shaker for half an hour. The suspension was filtered through Whatman No. 40 filter paper. A blank was run. Five ml of the above

filtrate was taken into a 25 ml volumetric flask. Then 5 ml of color developing regent (ascorbic acid , ammonium molybadate, antimony potassium tartarate and sulfuric acid) were added carefully. The volume was made up to the mark. The color intensity was measured as percent absorbance at 880 mu.

For preparation a standard curve 0, 0.5. 1.0, 2.0, 3.0, 4.0 and 5.0 ml of 10 ppm P standard solution each were taken in 50 ml volumetric flask. Now 10 ml of $NaHCO_3$ and 10 ml of color developing regent were added to the above mentioned 50 ml flask and the volume was made up to the mark. After shaking, were allowed to stand for 15 minutes, the color intensity was measured as percent absorbance at 880 mu. The standard graph was prepared by plotting the reading of standard solution against the concentration of phosphorous. From the graph, the concentration of phosphorous corresponding to value of test solution was recorded. (Page et al., 1982)

7.9 Extractable Potassium

Soil was extracted with normal ammonium acetate. (pH. 7.0) and potassium was determined by flame photometer using potassium filter (Page et al., 1982).

8.0 Plant Analysis

8.1 Estimation of total Nitrogen

One gram of dried sample was taken in a microkjeldahl flask and 30 ml of concentrated H_2SO_4 was added. Then 10 grams of digestion mixture was added. Flask was heated until the digest was clear. After cooling, water was added. The content were transferred to a 250 ml flask and volume was made up to the mark by several washing of water

Ten milliliters solution of 250 ml flask was transferred into the distillation chamber through the funnel of the microkjeldahl distillation apparatus, water was added to the distillation chamber to make volume 50 ml. Five ml of borric acid solution was taken into a 50 ml Erlenmeyer flask. The flask was placed under the condenser of the distillation apparatus so that the end of the condenser was about 4 cm above boric acid, then 20 percent NaOH was added slowly into the distillation chamber and the water was added to

make 80 ml volume. The funnel was closed and distillation was allowed to commence until the distillate reached up to 35 ml mark on the receiver flask. Ammonium -N in the distillate was determined by titrating with 0.01 N H_2SO_4. The color changed at the end point was from green to pink.

8.2 Wet Digestion of Plant Material

One gram of dried plant sample was taken in a conical flask. Five ml of concentrated nitric acid and 3 ml of perchloric acid was added. The material was swirled and placed on hot plate and until the solution was colorless. The solution was removed from the hot plate, cooled and transferred into a 50 ml volumetric flask. The volume was made with distilled water (Hussain and Jabbar, 1985).

8.3 Phosphorous In Plant Material

For phosphorous estimation one ml of the sample extract was taken in to a 10 ml tube. Two ml of 2N HNO_3 was added and diluted to 8 ml distilled water. To tube containing sample, added one ml of molybadate vanadate solution and volume was made to 10 ml with distilled water. The tube was shaken and allowed to stand for 20 minutes. The absorbance was measured at 430 mu and was compared with the absorbance of the standards phosphorous curve (Hussain and Jabbar, 1985).

8.4 Potassium In Plant Material

Potassium was determined in the aliquot extracted above, by flame photometer (Hussain and Jabbar, 1985).

9.0 Statistical Analysis

The data collected for various characteristics was analyzed statistically by " analysis of variance " technique. Duncan's multiple range (Duncan, 1955) test was applied to significance between the treatment means. (Steel and Torrie, 1980).

10.0 Fertilizer Use Efficiency (FUE)

Fertilizer use efficiency was calculated by the following methods.

$$\text{Agronomic Efficiency} = \frac{\text{Grain Yield F} - \text{Grain Yield C}}{\text{Fertilizer applied}}$$

$$\text{Nutrient Recovery} = \frac{\text{Nutrient uptake F} - \text{Nutrient uptake C}}{\text{Nutrient applied}} \times 100$$

11.0 Water Use Efficiency (WUE)

Water use efficiency was calculated by the following method.

$$\text{WUE} = \frac{\text{Grain Yield I} - \text{Grain Yield C}}{\text{Water applied}}$$

F is treatment in which fertilizer was applied.

C is control.

I is treatment in which sprinkler irrigation was applied.

The results of the study are presented in the forthcoming chapter.

RESULTS AND DISCUSSION

The results obtained of the study are discussed as under.

The data pertaining to germination and plant density revealed that fertilizer and irrigation treatment had no significant effect on these plant characteristics. However all other plant growth and yield parameters were affected by different fertilizer and irrigation treatments, as is evident from the preceding discussion.

Effect of NPK fertilizers and sprinkler irrigation on plant height of wheat (cm).

The data pertaining to plant height is presented in table 3. The data indicated that with increase in quantity of fertilizer, plant height increased. Maximum plant height of 75.50 centimeter was recorded in treatment F8. While minimum plant height of 71.92 centimeter was observed in treatment F1. There was no significant difference in height in F1 to F7 treatments but F8 and F9 produced significant greater plant height than F1. Again there were non-significant difference in height from F2 to F9 treatments. These difference were minor that might be due to the balance in NPK fertilizer which increased utilization efficiency of these nutrient elements. Similar results were obtained by Rajput et al. (1989).

The data in table 3 also revealed that all the levels of sprinkler irrigation were different to one another with respect to plant height. Maximum plant height of 78.85 cm was recorded at highest level of irrigation which decreased with the decrease in amount of irrigation applied and minimum plant height of 68.67 cm was observed in control treatment. This was probably because of the better crop growth at higher moisture level as water is important for cell division and cell enlargement by increasing turgidity of cells.

The data in above table also indicated that fertilizer and irrigation interactive effect on plant height was non-significant. However by increasing moisture, plant height increased at each fertilizer level (Fig. 1). Maximum plant height of 82.00 cm was recorded at maximum irrigation level, I3 and with fertilizer level of 115-115-85 Kg NPK ha^{-1}. Plant height increased with increase in fertilizer level at all moisture levels.

Table 3 : Effect of NPK Fertilizer and Sprinkler Irrigation on Plant Height (cm) of Wheat

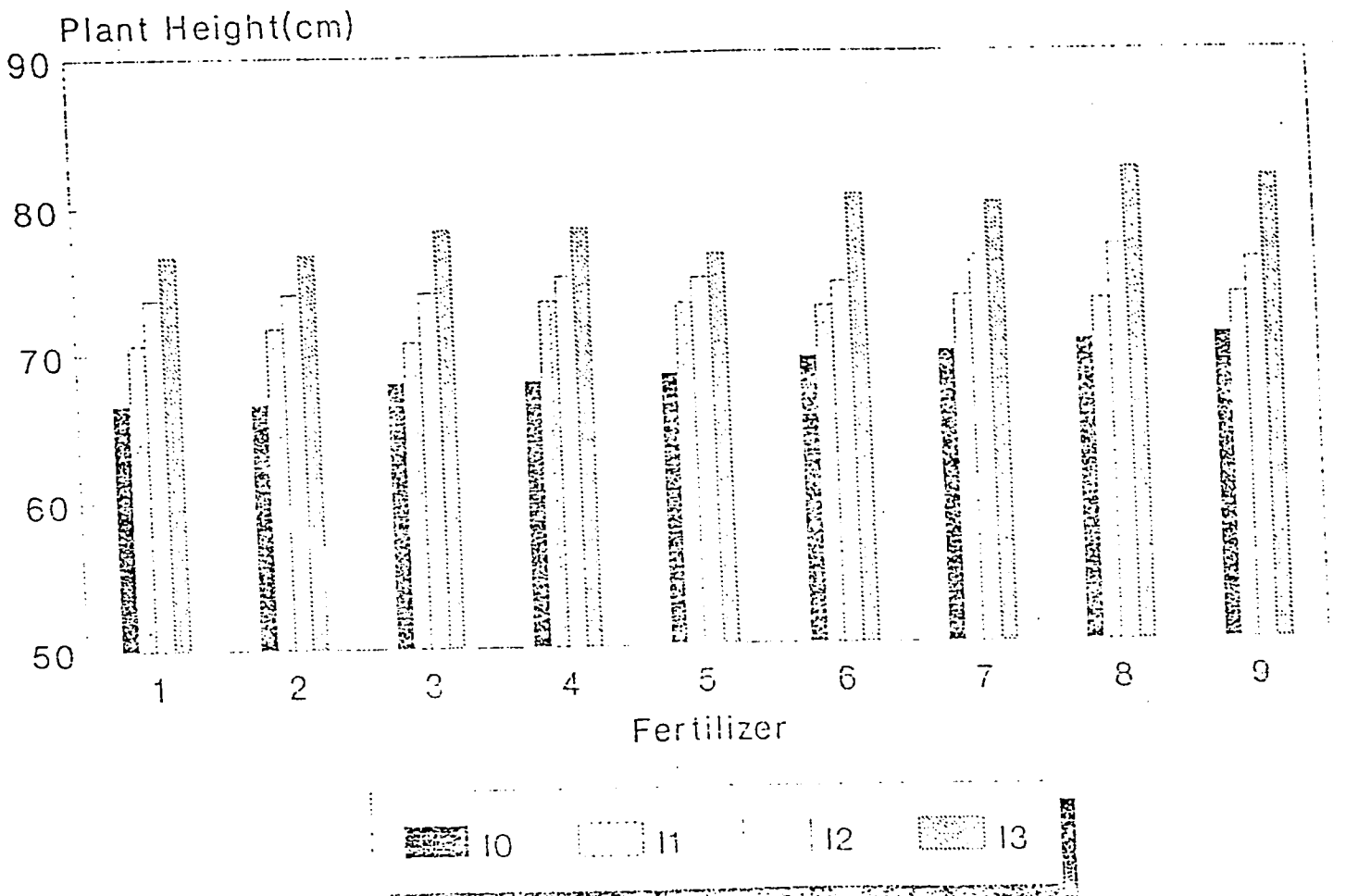
Fertilizer Treatments	Irrigation Treatments				
	I0	I1	I2	I3	Means
F1	66.67	70.67	73.67	76.67	71.92 b
F2	66.67	71.67	74.00	76.67	72.25 ab
F3	68.00	70.67	74.00	78.33	72.75 ab
F4	68.33	73.33	75.00	78.33	73.75 ab
F5	68.33	73.00	74.67	76.33	73.08 ab
F6	69.33	72.67	74.33	80.33	74.17 ab
F7	69.67	73.33	76.00	79.67	74.67 ab
F8	70.33	73.00	76.67	82.00	75.50 a
F9	70.67	73.33	75.67	81.33	75.25 a
Mean	68.67 d	72.41 c	74.89 b	78.85 a	

Analysis of Variance

S.O.V	DF	SS	MS	F Value	Prob.
Replication	2	47.57	23.79	3.32	0.042
Moisture	3	1483.93	494.64	69.10	0.000**
Fertilizer	8	160.35	20.04	2.80	0.000**
Moit. x Frt.	24	51.57	2.15	0.30	N.S
Error	70	501.09	7.16		
Total	107	2244.52			

** = Highly Significant NS = Non-significant

Fig.1: Effect of NPK Fertilizer and Sprinkler Irrigation on Plant Height



Effect of NPK Fertilizer and Sprinkler Irrigation on Number of Tillers per Plant of Wheat.

The yield of plant is dependent upon the combined effect of many yield components. Number of tillers per plant is one of the most important among these components. Number of tillers per plant determine the stand of crop that ultimately determines the crop yield.

The data regarding the number of tillers per plant is presented in table 4. The data revealed that number of tillers per plant increased from treatment F1 to F7. Differences in tiller per plant in F7. F8 and F9 treatments were non-significant. However differences in tillers in these treatments as compared to other. Treatments were highly significant.

The results also showed that all the three fertilizer i.e. N, P, and K are responsible for increasing numbers of tillers per plant. This was probably due to the better utilization of phosphorous and potassium in combination with nitrogen. The availability of these nutrients enhanced the growth of wheat crop. This is because that nitrogen is an essential part of chlorophyll and growth hormones, phosphorous plays an important role in cell division and also in a large number of enzyme reactions and potassium is important in process of photosynthesis by stomatal regulation. Increase in tillers per plant under better nutrition has also been reported by Ahmad et al, (1989).

The data in the table also indicated that different levels of sprinkler irrigation significantly affected the number of tillers per plant. The highest number of 6.26 tillers per plant were obtained with maximum irrigation level I 3. Treatment I 3 was highly significant over other irrigation treatments. With the decrease in irrigation applied, number of tillers per plant decreased. The number of tillers in I_1 and I 0 were non-significant.

The data in table 4 also indicates that the interaction between moisture and fertilizer was non-significant. However the highest number of 8 tillers per plant were recorded with maximum water level through sprinkler irrigation at fertilizer treatment of F7. while minimum number of 3 tillers per plant were recorded in treatment with rainfall alone and with fertilizer treatment of F1 (Fig 2). Similar results were obtained by Hassan et al (1992).

Table 4: Effect of NPK Fertilizer and Sprinkler Irrigation on Number of Tillers per Plant of Wheat.

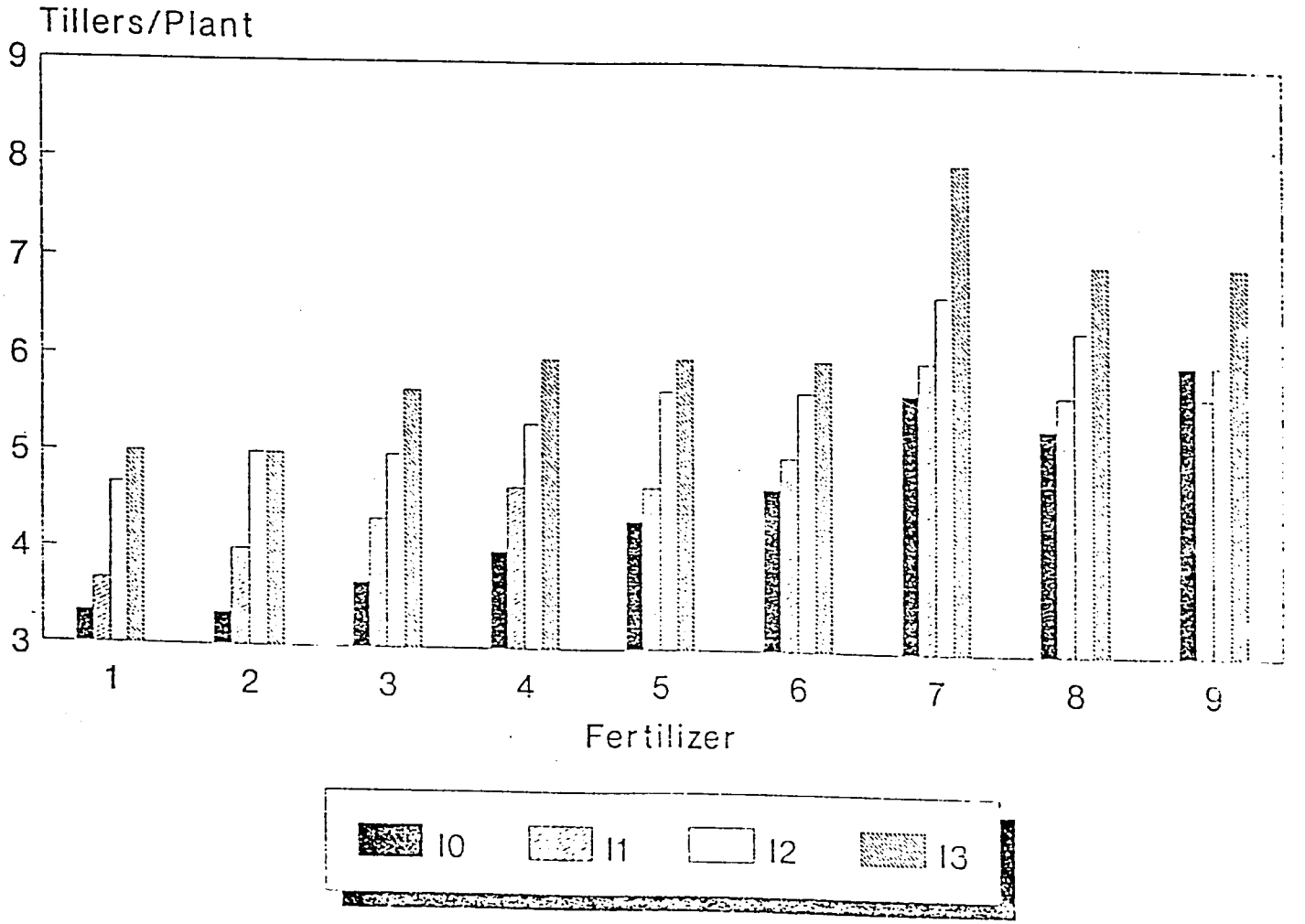
Fertilizer Treatments	Irrigation Treatments I0	I1	I2	I3	Mean
F1	3.33	3,67	4.67	5.00	4.17 d
F2	3.33	4.00	5.00	5.67	4.50 cd
F3	3.67	4.33	5.00	5.67	4.67 bcd
F4	4.00	4.67	5.33	6.00	5.00 bc
F5	4.33	4.67	5.67	6.00	5.17 bc
F6	4.67	5.00	5.67	6.00	5.33 b
F7	5.67	6.00	6.67	8.00	6.52 a
F8	5.33	5.67	6.33	7.00	6.08 a
F9	6.00	5.67	6.00	7.00	6.17 a
Mean	4.48 c	4.85 c	5.59 b	6.26 a	

Analysis of Variance Table

S.O.V	DF	SS	MS	F Value	Prob
Replication	2	1.90	0.95	2.08	0.1326
Moisture	3	550.67	16.86	36.84	0.000**
Fertilizer	8	65.35	8.17	17.82	0.000**
Moit. x Frt.	24	4.50	0.19	0.41	NS
Error	70	32.09	0.46		
Total	107	154.52			

** Highly significant NS = Non significant

Fig.2: Effect of NPK Fertilizers and Sprinkler Irrigation on Tillers/Plant



Effect of NPK Fertilizers and Sprinkler Irrigation on Fresh Weight of Wheat (Kg ha^{-1}).

The date regarding fresh weight of wheat crop is presented in table 5. The data revealed that fertilizer application affected fresh weight significantly. The minimum fresh weight of 9838 Kg ha^{-1} was obtained in treatment where only nitrogen was applied, with increase in NPK rates, fresh weight of wheat crop increased. Maximum fresh weight of 13534 Kg ha^{-1} was observed in treatment F7 that was 37.57 percent higher than F1.

There was non-significant difference in fresh weight among F4 to F9 treatments. Fresh weight in F1, F2 and F3 was significantly lower than all other treatments. The maximum fresh weight of wheat in F7 was probably due to the efficient utilization of NPK fertilizer, that resulted in better wheat growth that produced higher fresh weight of crop. The data also demonstrated that additional nitrogen increased fresh weight as it is an important component of amino acid and chlorophyll and promotes vegetative growth and imparts a healthy green color. Additional phosphorous produced significantly higher fresh weight of the crop, because it stimulates early growth and root development. It was further noticed that the increasing levels of potassium from 57 to 85 Kg ha^{-1}, the fresh weight of the crop markedly increased over fertilizer treatment with nitrogen alone and indicated a positive effect on fresh weight due to the reason that potassium in plants regulates the water absorption. The results indicated a positive interaction among N, P and K up to fertilizer treatment F7.

The data in table 5 also indicated that fresh weight of crop was markedly affected by different levels of sprinkler irrigation. Fresh weight increased with an increase in the quantity of irrigation applied. The maximum fresh weight of 13520 Kg ha^{-1}, was recorded in treatment I 3. There was no significant difference in fresh weight between I3, and I2 treatments. However, both these produced significantly more fresh weight than I0 and I1 that were non-significant with each other. Increase in fresh weight of plants at higher levels of sprinkler irrigation can be attributed to enhanced nutrient availability for the plants. More over water is involved in photosynthetic activity of plants.

The data in above table also indicated that fertilizer and irrigation interaction was non-significant, probably because of heavy rainfall received during the growth period. However with the increase in irrigation, fresh weight increased with increase in fertilizer dose. The highest fresh weight of 15016 Kg ha^{-1} was recorded by applying maximum level of sprinkler irrigation I 3, with a fertilizer dose of 115-85-85 Kg per hectare

Table 5 : Effect on NPK Fertilizer and Sprinkler Irrigation on Fresh Weight of wheat (Kg ha^{-1})

Fertilize Treatments	Irrigation Treatments I0	I1	I2	I3	Mean
F1	8713	9320	10133	11186	9838 d
F2	9216	10356	11643	12043	10815 cd
F3	10143	11303	10913	12803	11290 bc
F4	11556	11523	12760	13496	12334 ab
F5	11150	11703	13286	13520	12415 ab
F6	11576	12453	13633	14210	12968 a
F7	11900	13180	14040	15016	13534 a
F8	12120	11973	14053	14916	13265 a
F9	12043	13316	13953	14503	13454 a
Mean	10936 b	11681 b	12713 a	13522 a	

Analysis of Variance

S.O.V	DF	SS	MS	F Value	Prob
Replication	2	56306401.85	28153200.93	18.99	0.0000
Moisture	3	104701306.48	34900435.49	23.54	0.0000**
Fertilizer	8	161571418.52	20196427.32	13.62	0.0000**
Moit. x Frt.	24	9754685.19	406445.22	0.27	NS
Error	70	103768398.15	1482405.69		
Total	107	436102210.19			

** = Highly Significant NS = Non significant.

Effect of NPK Fertilizer and Sprinkler Irrigation on Dry Weight of Wheat Crop (Kg ha^{-1}).

The data regarding dry weight of wheat crop is presented in table 6. The data indicated that different rates of fertilizer and irrigation affected the dry weight of wheat crop to considerable degree.

Dry weight increased as the fertilizer dose increased. Maximum dry weight of 12093 Kg ha^{-1} was recorded in treatment F 7. The dry weight observed in F 7 was highly significant over treatment F 1 and F 2 and little or non-significant in comparison to all other fertilizer treatments. Treatment F 7 resulted in 41.78 percent more dry weight than F 1, it was also evident from the above data that all the three N, P and K fertilizer elements were involved in increasing dry weight. The differences in treatments were probably due to the better nutrient availability with more fertilizer application as soil is deficient in the above nutrients as indicated by analytical data in table 1. These result are in accordance with the finding of Ranjodh et al. (1975).

The data also revealed that the irrigation treatments I 3 and I 2 were statistically non-significant with respect to dry weight but both significantly greater in dry weight in comparison to I 1 and I 0, maximum dry weight of 12127 kg ha^{-1} was obtained in treatment I 3, a decrease in dry weight was observed with the decrease in quantity of applied irrigation. These difference may be possible because of an increase in supply of moisture that permits better nutrient uptake by the crops.

The data also indicated that fertilization and irrigation interaction was non-significant. However at each fertilizer level, more dry weight was produced with increase in quantity of water applied through sprinkler (Fig. 3) Maximum dry weight of 13520 kg ha -1 was produced with a combination of maximum sprinkler irrigation and fertilization treatment of 115-85-85 kg ha^{-1}.

Effect of NPK Fertilizer and Sprinkler Irrigation on Hundred Grain Weight of wheat.

The data regarding 100 grain weight is presented in table 7. The data elucidated that nitrogen in combination with Phosphorus and Potassium had significant effect on 100

Table 6 : Effect of Npk Fertilizer and Sprinkler Irrigation on Dry Weight of Wheat (Kg ha^{-1})

Fertilizer Treatments	Irrigation Treatments I0	I1	I2	I3	Means
F1	7410	7973	8673	10050	8526d
F2	7813	8906	10216	10586	9380 cd
F3	8746	9623	9626	11206	9800 bcd
F4	8923	10133	11396	12190	10660 bcd
F5	9823	10330	11570	12323	11011 ab
F6	9976	10986	12203	12746	11478 a
F7	10470	11843	12540	13520	12093 a
F8	10426	10793	12603	13470	11823 a
F9	10320	11860	12546	13053	11945 a
Means	9323 c	10272 b	11264a	12127 a	

Analysis of Variance

S.O.V	DF	SS	MS	F value	Prob
Replication	2	55022535.19	27511267.59	17.6477	0.000
Moisture	3	119478528.70	39826176.23	25.5473	0.000**
Fertilizer	8	152521857.41	19065232.16	12.2298	0.000**
Moist .x Frt.	24	6817112.96	284046.36	0.1822	NS
Error	70	109124131.48	1558916.16		
Total	107	4429644165.74			

** Highly significant NS = Non significant

Fig.3 Effect of NPK Fertilizer and Sprinkler Irrigation on Dry Weight

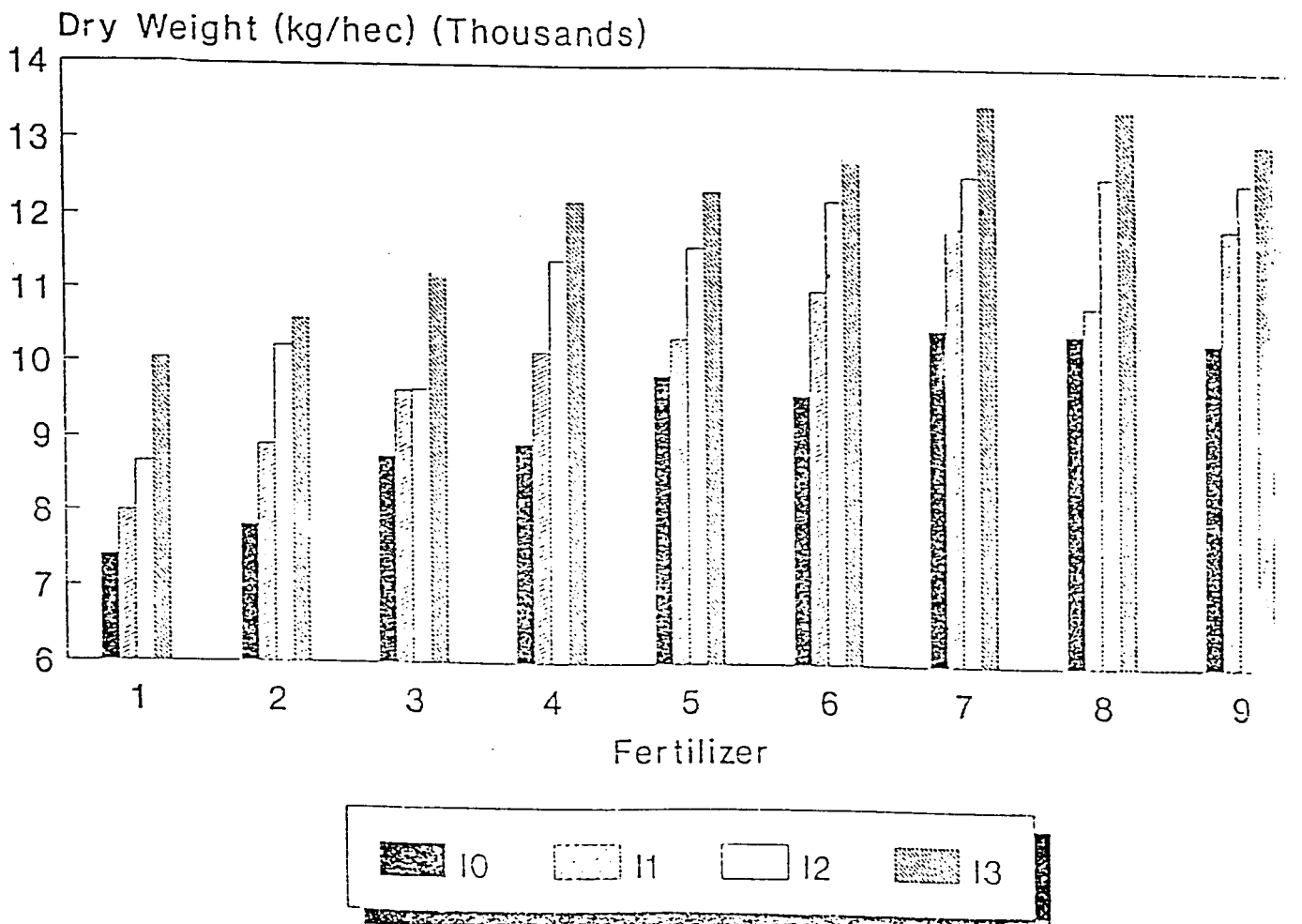


Table 7 : Effect of NPK Fertilizer and Sprinkler Irrigation on Hundred Grain Weight (grams) of Wheat.

Fertilizer Treatments	Irrigation Treatments I0	I1	I2	I3	Means
F1	3.40	3.43	3.47	3.60	3.48 d
F2	3.37	3.43	3.67	3.80	3.57 cd
F3	3.53	3.60	3.80	3.87	3.70 bcd
F4	3.70	3.67	3.83	3.90	3.78 abc
F5	3.60	3.70	3.80	3.97	3.77 abc
F6	3.73	3.73	3.90	4.07	3.86 ad
F7	3.80	3.90	4.03	4.20	3.98 a
F8	3.67	3.87	4.00	4.13	3.92 ab
F9	3.83	3.87	3.97	4.17	3.96 a
Means	3.63 c	3.69 bc	3.83 ab	3.97 a	

Analysis of Variance

S.O.V	DF	SS	MS	F Value	Prob
Replication	2	0.354	0.177	4.3827	0.0161
Moisture	3	1.872	0.624	15.4546	0.000**
Fertilizer	8	2.917	0.365	9.0364	0.000**
Moist.x Fert.	24	0.178	0.007	0.1839	NS
Error	70	2.826	0.040		
Total	107	8.147			

** Highly Significant NS = Non Significant.

grain weight, It is evident from the data that with the addition of NPK fertilizer, 100 grain weight increased from fertilizer treatment F 1 to F 7. Maximum 100 grain weight of 3.98 grams was observed in F 7 which was significantly higher in comparison to first three fertilizer treatments and non-significant with regard to other treatments. Fertilizer level F 7 produced 14.36, 11.48 and 7.57 percent higher 100 grain weight than F 1, F 2 and F 3, respectively. Treatments F 1, F 4 and F 7 showed that every increment of nitrogen fertilizer markedly increased 100 grain weight, Treatments F 2, F 5., F 8 and F 3, F6, F 9 indicated that an increased in phosphorus and potassium, respectively from 57 to 85 Kg ha^{-1} increased 100 grain weight but their further addition depicted a decrease in 100 grain weight. This is probably due to the reason that NPK fertilizer in a balanced proportion increased 100 grain weight. Ahmad et al. (1989) also observed that 100 grain weight increased with better crop nutrition.

The data in table 7 also revealed that sprinkler irrigation affected 100 grain weight significantly Hundred grain weight is function of water applied through sprinkler irrigation. Maximum 100 grain weight of 3.97 grams was obtained in irrigation treatment I3 which was significantly greater than I0 and I1 but was not different in relation to I2. Irrigation treatment I3 produced 9.37 and 7.59 percent higher 100 grain than I0 and I1 while I2 produced 5.51 and 3.80 percent higher grain weight than I0 and I1, respectively. This was probably due to the reason that water increased availability of nutrients because it is a key factor in all the three mechanisms of nutrient uptake. The results are in accordance with the observation of Buniak et al. (1989).

The data also showed that maximum 100 grain weight of 4.2 grams was obtained with fertilizer treatment F7 and irrigation treatment I3. It is also evident from the data that with the increase in the quantity of irrigation water applied, hundred grain weight increased in all fertilizer treatments (Fig. 4).

Effect of NPK Fertilizer and Sprinkler Irrigation on Wheat Grain Yield (Kg ha^{-1})

The data regarding wheat grain yield is presented in table 8. The data indicated that different fertilizer treatment and different levels of irrigation affected grain yield to a considerable degree.

The data revealed that there was an increase in grain yield with subsequent application of different NPK fertilizer rates up to fertilizer treatment F7. It was evident

Fig4: Effect of NPK Fertilizer and Sprinkler Irrigation on 100 Grain Weight

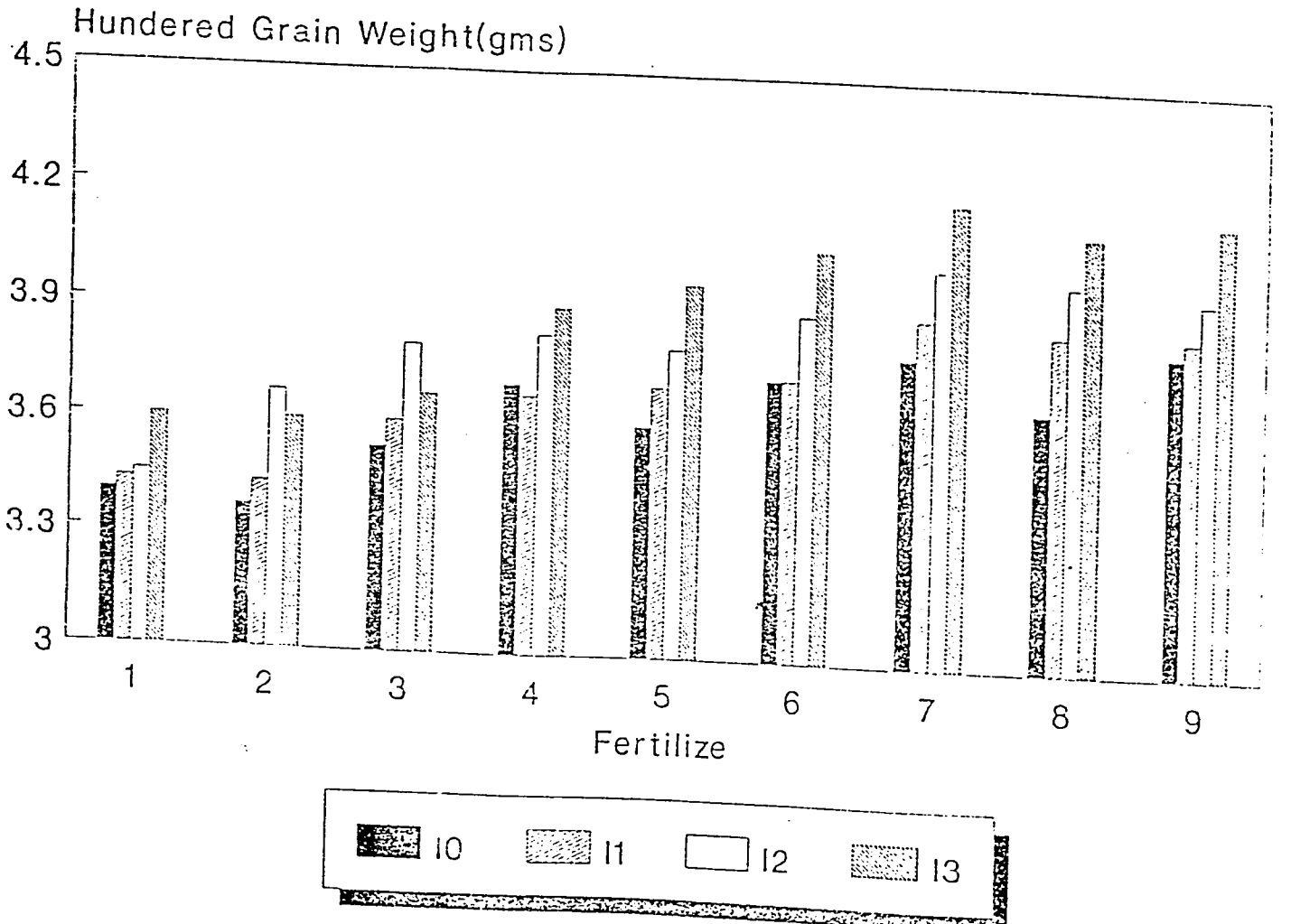


Table 8 : Effect of NPK Fertilizer and Sprinkler Irrigation on Grain yield of wheat (kg ha^{-1})

Fertilizer Treatment	Irrigation Treatment I0	I1	I2	I3	Means
F1	2986	3217	3501	3707	3353 d
F2	3277	3564	3900	4272	3753 c
F3	3366	3695	4002	4272	3834 bc
F4	3584	3983	4269	4538	4094 ab
F5	3716	4117	4409	4707	4237 a
F6	3772	4189	4486	4774	4305 a
F7	3863	4309	4592	4875	4410 a
F8	3864	4329	4555	4872	4405 a
F9	3803	4271	4467	4805	4337 a
Mean	3581 d	3964 c	4242 b	4536 a	

Analysis of Variance

S.O.V	DF	SS	MS	F Value	Prob
Replication	2	125041	62521	0.8665	
Moisture	3	13401313	4467104	61.9092	0.0000**
Fertilizer	8	12626104	1578263	21.8730	0.0000**
Moist.x. Fert.	24	164311	6846	0.0949	NS
Error	70	5050904	72156		
Total	107	31367674			

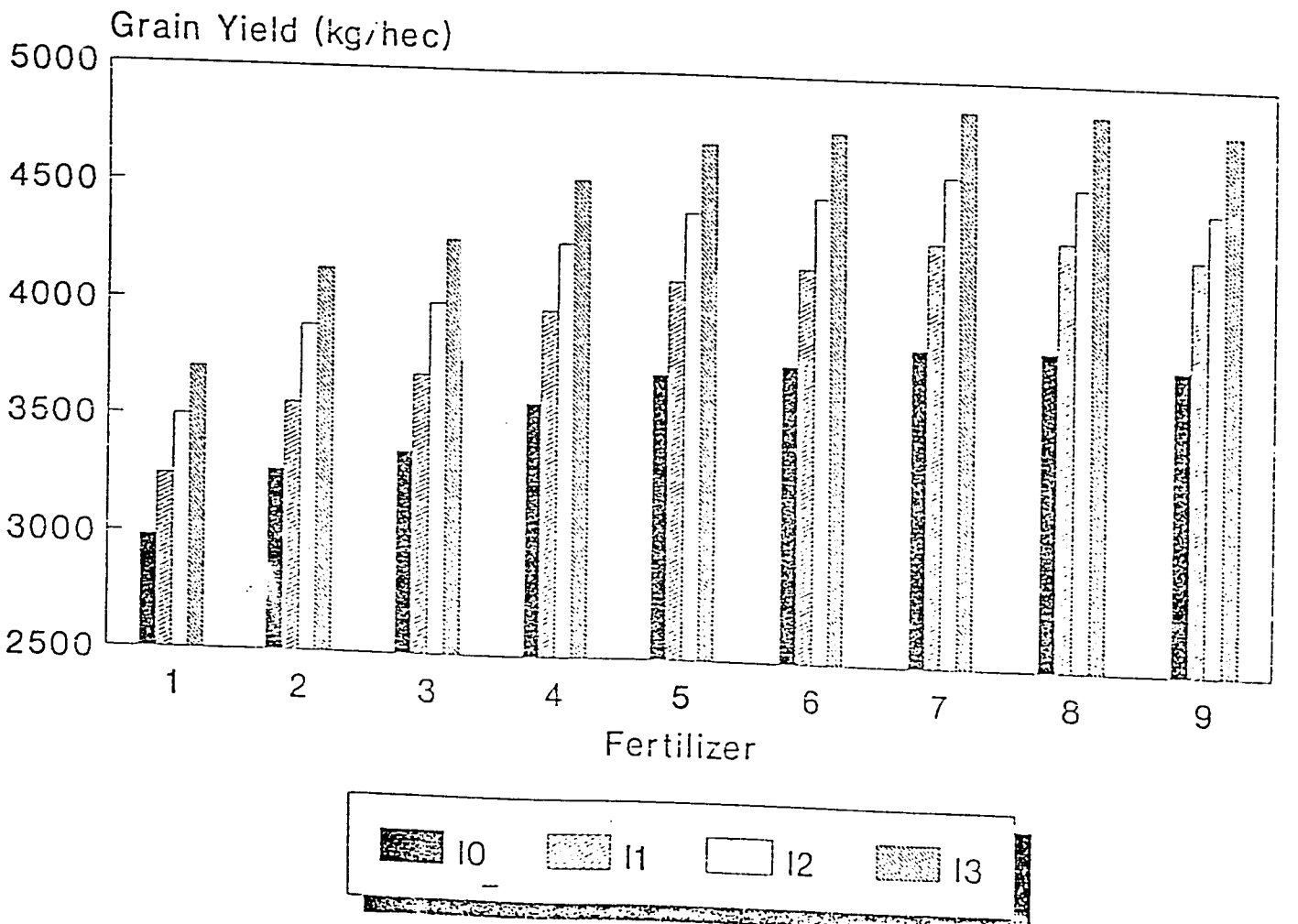
** Highly significant NS = Non significant

from the data that increasing the nitrogen rates from 57 to 115 Kg N ha^{-1}, there was a significant increase in grain yield. Addition of 57 Kg Phosphorus ha-1 resulted 12 percent higher yield compared to nitrogen application alone. Similarly when Potassium was added to it, the grain yield was 14 percent higher with regard to fertilizer treatment F1. This indicated that phosphorus and potassium had positive effect on grain yield. They also influenced the uptake of each other and that of nitrogen. The combined application of NPK revealed that maximum grain yield of 4410 Kg ha^{-1} was produced in fertilizer treatment F7 which was 32, 28 and 26 percent higher than fertilizer treatment F1, F2 and F3, respectively. Treatment F7 was significantly different with respect to F1, F2 and F3 and non-significant in comparison to all other fertilizer treatments. Increased grain yield in fertilizer F7 may be attributed to more grain weight in this treatment. More over biomass, number of grains per spike, number of spike per plant were also observed to be higher in this treatment which certainly contributed to substantially higher yield in this treatment. The increases in grain yield under optimum nutrition has also been demonstrated by Saleem (1983), Sharma (1984). Bhatti et al (1985), Rajput et al (1989) Sud et al (1989) and Ahmad et al (1989).

The data in above table indicated that all the sprinkler irrigationswere significantly different amongst one another, maximum grain yield of 4536 Kg ha-1 was observed in irrigation treatment I3 which was 27 percent higher with respect to control. Treatment I2 was 18 percent higher while I1 was 11 percent higher than I0. This indicated that even application of sprinkler irrigation at 50 percent of field capacity substantially increased the grain yield. The reason being that plant absorbed nutrients and water more efficiently when they become available easily under optimum moisture conditions in the soil system. Under conducive growth conditions nutrients and water uptake was more with the result that physiological and biochemical reaction in the plant take place more rapidly which increased grain yield of the crop. More over, termites attack was severe before irrigation as there was no rainfall after sowing. With application of water through sprinkler the termite attack subsidized more so in treatment where quantity of water applied was more. The increase in grain yield with higher level of moisture application has been demonstrated by Mohammed et al (1983), Jankwiak (1984), Sud et at (1990) and Nelson (1991).

The data in table above also indicated that fertilizer and irrigation interaction was non-significant. However the highest wheat yield of 4875 Kg ha^{-1} was achieved by combination of irrigation treatment I3 and Fertilizer treatment F7 and lowest yield of 2986 Kg ha-1 was obtained with irrigation I0 and fertilizer treatment F1. The yield increased with the increase in NPK fertilizer up to fertilizer treatment F7 in rainfall alone and at each irrigation treatment that demonstrated the beneficial effect of fertilizer application even under conditions of inadequate moisture availability (Fig 5).

Fig.5: Effect of NPK Fertilizer and Sprinkler Irrigation on Grain Yield



Good wheat crop can be harvested by providing sprinkler irrigation even at 50 percent of field capacity (I2) and with balanced fertilizer dose of 115-85-85 Kg ha^{-1}. The enhancement in grain yield at higher level of moisture with balance fertilizer may be attributed to improvement in the availability of nutrients to crop under optimum moisture conditions in soil. Laghari et al. (1970). Ahmad et al. (1988) also obtained similar results.

Effect of NPK Fertilizer and Sprinkler Irrigation on Straw Yield of Wheat

The data pertaining to effect of fertilizer and sprinkler irrigation on straw yield is presented in table 9. The data indicated that different levels of fertilizer and sprinkler irrigation increased the straw yield significantly.

All the three N, P and K nutrients had a positive influence on the uptake of one another. These nutrients were expected to be responsible for increasing straw yield as nitrogen is involved in vegetable growth, phosphorus in photosynthesis and potassium in the formation of carbohydrates and their accumulation in plant (Saleem et al. 1986). It was also evident from the data that every increment of NPK fertilizer increased straw yield up to fertilizer treatment F7. The highest straw yield of 7.334 Kg ha^{-1} was recorded in treatment F7 that was significant different compared to F1, F2 and F3 and non-significant with all other fertilizer treatments.

The data in table above also indicated straw yield variations at various level of irrigation. the maximum straw yield of 7262 Kg ha^{-1} was recorded in irrigation treatment I3 that was 31 and 22 percent higher than I1 and I2, respectively treatment, I3 produced significantly more straw yield in comparison to I0 and I1.

The data in the above table also indicated that fertilizer and irrigation interaction could produce significant difference in straw yield (Fig 6). however maximum straw yield of 8093 Kg ha-1 was obtained with I3 and fertilizer application of 115-115-85 Kg ha^{-1}. this indicated that supplementing with irrigation water is conducive in increasing straw yield. the high straw yield may be due to the reason that nutrient uptake is higher when fertilizers are applied in balanced proportion with sufficient moisture.

Table 9 : Effect on NPK Fertilizer and Sprinkler Irrigation on Straw Yield of Wheat (Kg ha^{-1})

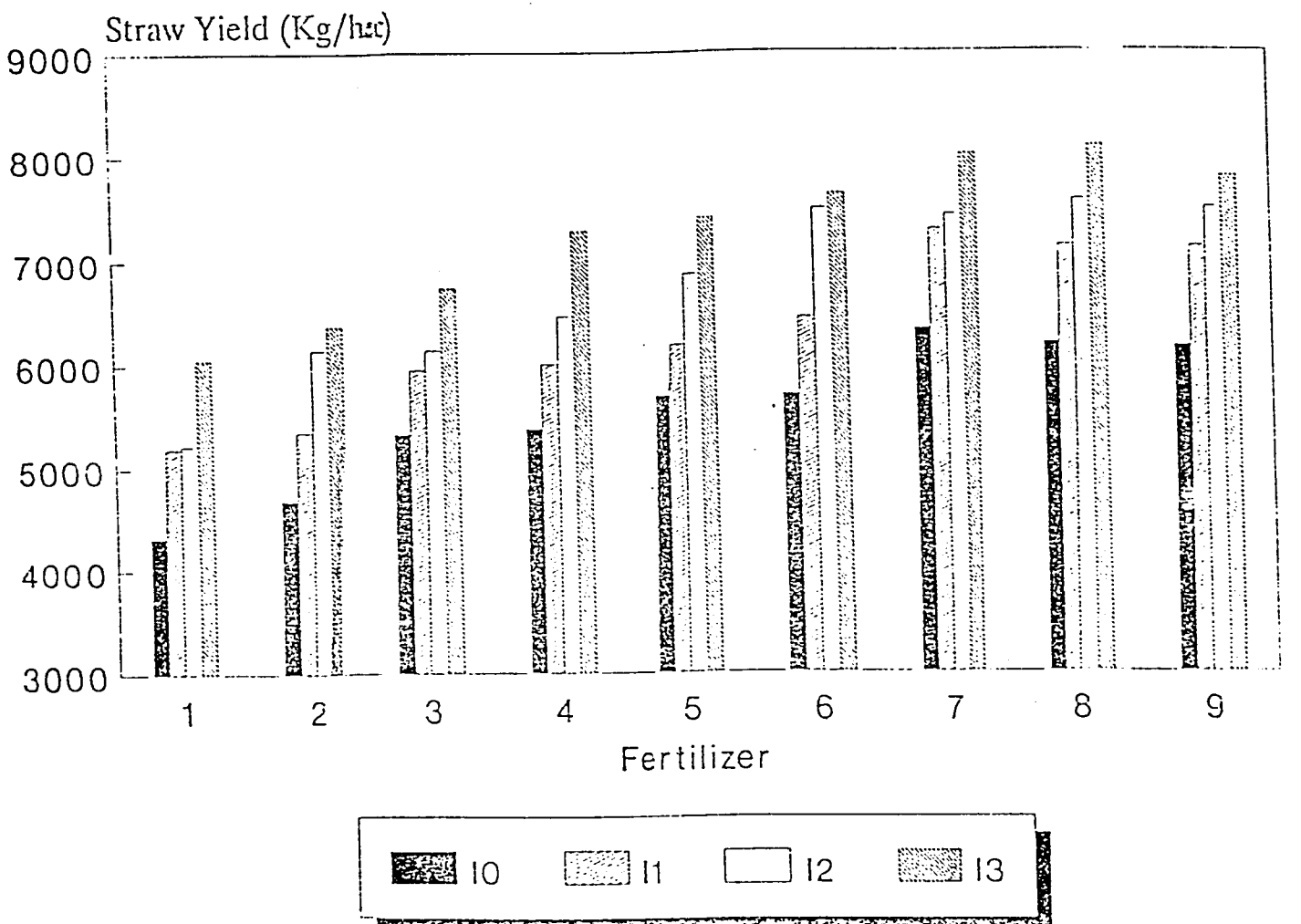
Fertilizer Treatments	Irrigation Treatment I0	I1	I2	I3	Mean
F1	4325	5193	5219	6050	5197 d
F2	4691	5349	6133	6371	5636 cd
F3	5327	5944	6128	6736	6034 bcd
F4	5380	5996	6460	7282	6280 abc
F5	5688	6166	6857	7395	6526 abc
F6	5696	6435	7481	7630	6810 ab
F7	6329	7277	7419	8010	7334 a
F8	6185	7125	7566	8093	7242 a
F9	6150	7118	7489	7792	7137 a
Mean	5530 c	6278 b	6750 ab	7262 a	

Analysis of Variance

Source	DF	SS	MS	F Value	Prob
Replication	2	16524365.80	8262182.89	12.2148	0.0000
Moisture	3	43884502.32	14628167.44	21.6262	0.0000**
Fertilizer	8	51416563.41	6427070.43	9.5018	0.0000**
Moit.x Frt.	24	2121459.26	88394.14	0.1307	N.S
error	70	47348572.20	676408.17		
Total	107	1612295462.99			

** Highly significant NS = Non significant

Fig.6: Effect of NPK Fertilizer and Sprinkler Irrigation on Straw Yield



Effect of NPK Fertilizer on Nitrogen concentration in Wheat Grain

The data pertaining to N-concentration in wheat grain is given in table 10. The data indicated that fertilizer applied and sprinkler irrigation affected nitrogen concentration in grain to a considerable degree.

The data in table 10 elucidated that by increase in fertilizer dose the nitrogen contents in grain increased. With each increment on N fertilizer, the N-concentration in grain increased. Phosphorous and potassium also enhanced N concentration. The maximum N-concentration of 2.40 percent were observed in fertilizer treatment F7, F8 and F9 that were significant over all other fertilizer treatments. These differences were more pronounced as the soil was deficient in nitrogen (Table 1) and application of nitrogen fertilizers resulted in increased uptake of nitrogen by the crop. Similar findings were obtained by Sud et al (1990).

The above data elucidated that Nitrogen concentration at different irrigation treatment also varied.Maximum N contents of 2.37 percentage was recorded in irrigation treatment I3 followed by I2, I1 and I0 in decreasing order. In I0 treatment the nitrogen concentration was 2.33 that was less compared to other irrigation levels and different among treatments were statistically significant.

The data also revealed that as far as N concentration was concerned, interaction between fertilizer and irrigation was non significant, probably due to the heavy rainfall of 376 mm after a single irrigation at the initial stage of crop growth. However maximum N concentration of 2.42 percent was observed with highest level of sprinkler irrigation and highest fertilizer dose of F9 that was identical to F8 and F7 treatment.

Effect on NPK Fertilizer and Sprinkler Irrigation on Phosphorus concentration in wheat Grain

The data regarding P concentration of wheat grain is given in table 11. The data showed that fertilization and irrigation affected P concentration to a considerable extent.

The data indicated that maxjmum P concentration of 0.31 percent was recorded in fertilization treatment F6 and F8 was non significant with fertilizer treatment F5, F7 and

Table 10 : Effect of NPK Fertilizer and Sprinkler Irrigation on Nitrogen Concentration in Wheat Grain (%).

Fertilizer Treatments	Irrigation Treatment I0	I1	I2	I3	Mean
F1	2.28	2.28	2.29	2.30	2.29 e
F2	2.29	2.28	2.31	2.31	2.30 e
F3	2.30	2.31	2.31	2.32	2.31 d
F4	2.33	2.34	2.36	2.36	2.35 c
F5	2.34	2.35	2.36	2.37	2.35 bc
F6	2.34	2.35	2.37	2.38	2.36 b
F7	2.37	2.39	2.40	2.42	2.40 a
F8	2.37	2.39	2.40	2.42	2.40 a
F9	2.37	2.39	2.40	2.42	2.40 a
Mean	2.33 d	2.34 c	2.36 b	2.37 a	

Analysis of Variance

Source	DF	SS	MS	F Value	Prob
Replication	2	0.0004	0.0002	1.6000	0.2092
Moisture	3	0.0170	0.0057	50.9418	0.0000**
Fertilizer	8	0.1793	0.0224	201.7501	0.0000**
Moit.x Frt.	24	0.3180	0.0001	1.1917	0.2799 NS
Erroe	70	0.7780	0.0001		
Total	107	0.2076			

** Highly significant NS = Non significant

Table 11 : Effect of NPK Fertilizer and Sprinkler Irrigation on Phosphorous concentration in Wheat Grain (%)

Fertilizer Treatments	Irrigation Treatment I0	I1	I2	I3	Mean
F1	.23	.24	.25	.26	.24 d
F2	.26	.27	.28	.29	.28 c
F3	.26	.28	.29	.30	.28 c
F4	.27	.26	.27	.29	.27 c
F5	.29	.30	.31	.31	.30 ab
F6	.30	.31	.32	.32	.31 a
F7	.29	.29	.31	.31	.30 ab
F8	.30	.30	.32	.31	.31 a
F9	.30	.29	.32	.31	.30 ab
Mean	.28 b	.28 b	.29 a	.30 a	

Analysis of Variance

S.O.V	Df	SS	MS	F Value	Prob.
Replication	2	.0002	.0001	1.1279	0.3295
Moisture	3	.0093	.0031	29.6832	0.0000**
Fertilization	8	.0475	.0059	56.9782	0.0000**
Moist.x. Fert.	24	.0019	.00008	0.7556	NS
Error	70	.0073	.0001		
Total	107	.0662			

F9, the resgt of the treatment were significantly different than these treatments. Treatments F2, F3 and F4 gave statistically same results to one another and markedly higher as compared to F1. The data also demonstrated that with the addition of phosphorous, the P concentration significantly increased because the soil was deficient in phosphorous (Table 1) as its availability increased with application of Phosphorous fertilizer. Addition of Potassium also increased the phosphorous concentration to some extent but addition of nitrogen decreased its concentration probably due to dilution effects in wheat crop.

The above data also revealed that P concentration in grain increased with increase in quantity of irrigation water. The highest P concentration of 0.30 percent was obtained in irrigation treatment I3 and minimum of 0.28 percent in I0 and I1. Teatments I3 and I2 were observed to be similar statistically. the low P concentration is attributed to non-availability of P due to limited mobility of phosphorous under moisture stress conditions. When water is applied to such a soil, plants absorb more phosphorous by root interception and mass flow.

No significant fertilizer and irrigation interaction was observed, probably due to the heavy rainfall after a single sprinkler irrigation at critical growth stage. However P concentration increased with increase in moisture levels I2 and I3. Theses result indicated that wheat crop utilize nutrients more efficiently in the presence of sufficient moisture conditions.

Effect on NPK Fertilizer and Sprinkler Irrigation on Potassium Concentration in Wheat Grain (%)

The data pertaining of NPK fertilizer and sprinkler irrigation on K concentration in grain is presented in table 12. Different levels of fertilization and irrigation affected the K concentration in wheat grain significantly.

The data in table above indicated every increment of Potassium fertilizer enhanced K concentration in grain up-to 85 Kg K_2O ha^{-1}. Hence 85 Kg K_2O ha^{-1} was observed to be the best fertilizer dose in this regard. The positive role of phosphorous in increasing K concentration in wheat grain was quite apparent from the data. The highest K concentration of 0.47 percent was recorded in F6, F8 and F9, that was 12 percent higher than F1 & F2 and 4 percent greater than F3, F4 & F5. The data further indicated that K concentration in F1 and F2 was identical but significantly lower than F3, F4 and F5. It was

Table 12 : Effect of NPK Fertilizer and Sprinkler Irrigation on Potassium concentration in wheat grain (%)

Fertilizer Treatments	Irrigation Treatment I0	I1	I2	I3	Mean
F1	.41	.41	.42	.43	.42 c
F2	.41	.42	.42	.44	.42 c
F3	.44	.44	.45	.46	.45 b
F4	.43	.44	.44	.46	.45 b
F5	.44	.45	.45	.47	.45 b
F6	.46	.47	.48	.48	.47 a
F7	.45	.45	.47	.47	.46 ab
F8	.46	.46	.48	.47	.47 a
F9	.47	.46	.47	.47	.47 a
Mean	.44 b	.44 b	.45 a	.46 a	

Analysis of Variance

S.O.V	DF	SS	MS	F Value	Prob.
Replication	2	0.0002	0.0001	0.6564	
Moisture	3	0.0072	0.0024	15.1968	0.0000**
Fertilizer	8	0.0367	0.0046	29.0558	0.0000**
Moist.x Fert.	24	0.0023	0.0001	0.6080	NS
Error	70	0.0110	0.0002		
Total	107	0.0575			

also evident from the data that addition of nitrogenous fertilizer decreased K concentration probably due to dilution effects.

The data in above table also depicted that levels of sprinkler irrigation affected K concentration markedly. With increased in quantity of irrigation, the K concentration increased. The highest concentration of 0.46 percent was obtained when crop was supplemented through sprinkler irrigation at field capacity levels that was non-significant with regards to I2 but significant in relation to I1 and I0, that were identical in their effect on K concentration.

Effect of NPK Fertilizer and Sprinkler Irrigation on Nitrogen, Phosphorous and Potassium Concentration In Wheat Straw.

The data pertaining to N,P and K concentration in wheat straw revealed that different levels of fertilizer and sprinkler irrigation affected K concentration in wheat straw significantly. Nitrogen and Phosphorous concentration in wheat straw was half to that in grain, while K concentration in wheat straw was almost four time that in wheat grain.

Fertilizer Use Efficiency (FUE)

The yield with nitrogen applications alone (Table 8) was 3353 Kg ha^{-1}. The yield with application of phosphorous and phosphorous and potassium in addition to nitrogen was 3753 and 3834 Kg ha^{-1}, respectively. The yield with phosphorous was 10.71 percent higher compared to nitrogen alone. Similarly yield with phosphorous and potassium fertilizer was 14.07 percent higher in comparison to nitrogen fertilization. The fertilizer use efficiency for phosphorous was computed by difference of F2 and F1 in relation to fertilizer applied and was 5.10 kg ha^{-1} in rainfed plot (Table 13). It increased with the increase in irrigation level and was 5.53, 7.00 and 7.63 for irrigation treatment I1, I2 and I3, respectively. Similarly nutrients recovered for phosphorous was also computed. It increased with increasing moisture levels. The maximum nutrient recovery of 4.83 was obtained with maximum irrigation level and minimum nutrient recovery of 2.90 was observed in rainfed plot (Table 13). The reason of low efficiency in Barani areas is attributed to unavailability of nutrients because moisture is key factor in all three mechanisms; root interception, mass flow and diffusion of nutrient uptake. hence under rainfed conditions when there was no rainfall, a moisture deficit occur in the soil which decreased the availability of nutrients to plant. These investigation indicated that fertilizer

Table 13 : Fertilizer Use Efficiency (FUE) at Different Levels of Moisture

(a) Agronomic Efficiency for Phosphorous (Kg Kg^{-1})

Fertilizer Levels (NPK Kg ha^{-1})	Irrigation Treatments I0	I1	I2	I3
F2 57-57-0	5.11	5.53	7.00	7.63

(b) Nutrient Recovery for Phosphorous (%)

Fertilizer Levels (NPK Kg ha^{-1})	Irrigation Treatments I0	I1	I2	I3
F2 57-57-0	2.90	3.33	3.81	4.83

(c) Conventional Fertilizer Use Efficiency for N, P and K

Fertilizer Levels (NPK Kg ha^{-1})	Irrigation Treatments I0	I1	I2	I3
F2 57-57-0 (P)	5.11	5.53	7.00	7.63
F3 57-57-57 (K)	1.56	2.3	1.79	-
F4 85-57-57 (N)	7.79	10.29	9.54	9.50

use efficiency was less under Barani environments compared to irrigation conditions. Ahmad and Khokhar (1988) also observed a decrease in FUE by increasing soil moisture depletion from 40-75 percent in wheat crop. Similarly Malik and Hassan, (1990) elucidated that with increase in rainfall FUE increased in wheat crop. Malik (1982-84) also observed similar results for wheat crop.

A balance in plant nutrient is also required for efficient use fertilizers. Chaudhary et al. (1988) elucidated that applying of nitrogen and phosphorous in balance proportion increased yield by 77 percent over the farmers practice as compared to increase of just 28 percent with nitrogen alone. According to annual report of 1979, 1981 and 1982 of Soil Fertility Survey and Soil Testing Institute, an application of nitrogen alone increased yield by 87 percent over control and adding of P increased the yield by 161 percent over control. As per farmers practice the conventional fertilizer use efficiency (13-C) was low in all the fertilizer ailment in Barani areas compared to irrigation area.

Water Use Efficiency (WUE)

The data pertaining to water use efficiency is given in table 14. The data showed that water use efficiency increased with increase in fertilizer dose up-to treatment F8. The highest water use efficiency of 18.18 Kg cm^{-1} was observed in fertilizer treatment F8 followed by F7 and F6. The higher water use efficiency at higher level of fertilizer is probably based on the concept that adequate fertility made better use of available water through extensive root system. Crop used water more slowly from the lower three quarters of the root depth. The fertilization of surface soil in a balanced proportion is important to encourage deep root system in crop. Proper nutrition encourage not only greater top growth but also a more vigorous and extensive root system. The high concentration of nitrogen and phosphorous in the cell, hasten division and extention of cells. Hence with appropriate fertilization the plant root can obtain water from a depth of lower three quarter of the root depth. If the plant can utilize extra water from the lower depth, the crop can endure drought for a longer period of time without disastrous effect on plant growth. These results are in agreement to Ahmad et al. (1970) and Laghari et al. (1979).

The data also indicated that with increase of irrigation level WUE increased. maximum WUE of 22.86 Kg cm-1 was achieved in irrigation treatment I3, that depicted a decreased trend with the decrease in quantity of irrigation water, The minimum WUE was 10.13 Kg cm-1 in irrigation treatment I1. These results are contrary to the finding s of

Table 14 : Water Use Efficiency at Different levels of Fertilizer (Kg cm^{-1})

Fertilizer Treatments	Irrigation Treatments			
	I1	I2	I3	Mean
F1	6.98	13.20	17.54	12.57
F2	7.62	15.97	21.05	14.88
F3	8.70	16.31	22.04	15.68
F4	10.55	17.31	23.21	17.02
F5	10.61	17.77	24.11	17.50
F6	11.03	18.31	24.28	17.87
F7	11.79	18.69	24.62	18.13
F8	12.30	17.72	24.52	18.18
F9	11.59	17.03	24.38	17.67
Mean	10.13	16.92	22.86	

Ahmad et al. (1979) and Laghari et al. (1979). They observed that WUE decreased by increase in quantity of water applied. This contrast is probably due to reason that in our experiment a single irrigation through sprinkler system at the level of 44,22 and 11 mm was applied at a crucial stress stage and during the growth period a rainfall of 376.6 mm was received. The irrigation water applied was substantially small compared with the rainfall to have a significant effect on water use efficiency at later growth stag of the crop. High values of WUE may be attributed to sprinkler irrigation system, as this system is quite and most suited to Barani areas.

The result of research indicated that soil moisture levels and application of nutrients in balanced proportion had considerable effect on wheat productivity. It was evident from the results discussed above that reduction in level of NPK and irrigation, decreased grain yield of wheat significantly. The data pertaining to physical properties of soil is given in table 1, that showed that the soil under study was deficient in macro nutrients especially in N and P. Therefore fertilizer application had a pronounced contribution in increasing crop yield by replenishing plant nutrient in the soil, that they are utilized and exhausted by continuos cropping. In this study NPK fertilizer at the rate of 115-85-85 and 85-85-57 Kg NPK ha^{-1} were observed to be most suited combination, at all moisture levels due to their balanced proportion. It was also indicated by the study that the three nutrient viz N, P and K play a vital role and ultimately resulted in increase of crop yield probably because of the following reasons.

(a) The adequate supply of irrigation is associated with vigorous vegetative growth and protein synthesis

(b) A good supply of Phosphorous is associated with increased root growth and act as a fuel and energy source for all biochemical work in living cells because it is an integrated part of ATP which released energy for metabolic activities in plant.

(c) Potassium function as a catalyst in the physiological function like carbohydrate metabolism and nitrogen metabolism and also adjust the stomatal movement and water relation (Tisdale et al. 1985 and Foth, 1982)

These investigation elucidate that grain yield in rainfed areas is function of appropriate, balanced fertilization and optimum soil moisture level. Similarly improvement in yield components and grain yield of wheat were also obtained by Ahmad et al. (1979),

Laghari et al. (1979) Mohammed et al. (1983), Ahmad et al, (1989), and Hassan et al. (1992).

The other most important factor that play vital role at every stage of plant growth, is soil moisture. It is required for manufacturing carbohydrates and to maintain hydration of protoplasm, gives turgidity to the cell and act as a vehicle for the translocation of food and movement of mineral element in the plants. Soil moisture has also a pronounced effect on the uptake of plant nutrients. Nutrient uptake increased as soil moisture tension decreased from the permanent wilting percentage to field capacity. Ammonification and nitrification are also badly affected by moisture stress. Hence any degree of water stress especially at critical growth stage may limit growth potential of wheat that may result in reduced crop yield. Therefore the optimum application of water at appropriate stage demand special attention. Ahmad et al. 1979), Laghari et al (1979), Mohammed et al. (1983), Ahmad et al. (1988),also obtained higher yield with increase in irrigation water applied, similar to the results obtained during this study at Barani Agriculture College Rawalpindi.

The rainfall data in table 2 indicated that in the month of December the rainfall received was only 22 mm that was insufficient for crop growth and moisture shortage was expected in the very beginning of the month of January. hence at this critical growth stage a single sprinkler irrigation at the levels of 44, 22 and 11 mm was applied that increased crop yield significantly at each fertilizer level probably by increasing water uptake along with nutrients that enhanced crop growth by cell division and cell elongation. After 20th of January, sufficient rainfall was received throughout the growth period and hence there was no need of irrigation at later stage of wheat growth.

As 25 percent of the total cultivated area of Pakistan is rainfed, Uncertainty of rainfall and inadequate moisture are a major problem that impair crop productivity in these areas. The contribution of rainfed area toward total agriculture production can be tremendous if rain water is stored in small dams and ponds and then supplemented to the crop at a critical growth stage with water saving technology like sprinkler irrigation.

SUMMARY

The research was conducted during 1990-91 in the research area of Department of soil Science. Barani Agriculture College Rawalpindi. The objective of investigation were :

1) To ascertain the NPK fertilizer use efficiency in wheat under rainfed conditions and improve it through supplemented irrigation at critical moisture stressed conditions.

2) To compare the water use efficiency at various levels of fertilizer application.

The wheat variety Pak-81 was sown on sandy loam soil with ECe 0.24 dSm^{-1}, pH 7,8, Nitrogen. 35 mg/g of soil, Phosphorous and Potassium 5.5 and 100 μg g-1 of soil, respectively. Two Factorial Randomized Complete Block Design with nine treatment of fertilizer and Four treatments of irrigation were trireplicated, data pertaining to germination, plant density, tillers per plant, spikes per plant, grain per spike, 100 grain weight, grain yield and straw yield were recorded. The N, P and K concentration in grain and wheat straw were estimated. Water use efficiency and fertilizer use efficiency were computed as well. The data was also subjected to statistical analysis.

The observation based on the investigations led to the conclusions :

(i) Germination was not affect by fertilizer and irrigation treatments because the seeds during germination mostly depend on its own food reserves and irrigation was applied after the germination was completed.

Likewise fertilizer and moisture had no significant effect on plant density.

(ii) All the yield components such as plant height, number of tillers per plant, fresh and dry weight and hundred grain weight of wheat crop were affected significantly by different fertilizer and irrigation levels. these growth/yield parameters depicted an increase with increase in fertilizer dose and moisture level.

(iii) The yield of crop increased with increase in fertilizer applied.

(iv) The application of fertilizer at the rate of 115-85-85 Kg NPK ha^{-1} produced the highest yield of crop at all levels of irrigation.

(v) The yield increased with increase in quantity of water applied through sprinkler and maximum was observed at soil field capacity level.

(v i) Application of sprinkler irrigation at field capacity resulted in higher crop yield at all fertilizer levels.

(vii) The N, P and K concentration both in wheat and straw was function of fertilizer and sprinkler irrigation applied.

(viii) Fertilizer use efficiency in Barani areas was quite low compared to that in irrigated areas.

(ix) Water use efficiency was highly improved by the application of fertilizers.

The study was carried out in Rawalpindi where average annual rainfall is about 1000 mm per annum and about 25 percent of the rain is received during winter. This water is sufficient for the maturity of winter crops if the rain water is stored in small dams and ponds and applied to crop at critical growth stage with water saving techniques like sprinkler irrigation.

Further more, it is suggested to carry out similar studies in medium to low rainfall areas as well.

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PHASE I - B

GREEN HOUSE EXPERIMENT.

INTRODUCTION.

Fertilizer use Efficiency (FUE) is generally low in rainfed areas and perhaps more so under moisture stress conditions. Fertilizer use efficiency may be determined by chemical, biological and economic considerations. As regards Chemical aspects FUE refer to the percentage of applied nutrients taken up by a crop Biologically fertilizer efficiency is determined as kg of produce per kg nutrient (s) applied. While economic efficiency is based on the return in rupees per rupees invested in applied nutrient (s). There are various methods to increase fertilizer use efficiency. One of simple way is to select suitable fertilizer combination to suit to the given soil-crop water situation.

Crop yield in rainfed areas are very low because of moisture stress and inappropriate fertilization. Fertilizers has a substantial contribution in increasing crop yield, by replenishing plant nutrients in the soil, and hence their use has depicted ever increasing trend. However crop yield in Pakistan have not increased proportionate to fertilizer applied. This indicate that fertilizer use efficiency is quite low under our conditions. The soil moisture is important variable affecting fertilizer use efficiency hence the study was conducted with different fertilizer treatments and variable irrigation levels,

The following objectives were kept in view.

1. To investigate the efficiency of Nitrogen, Phosphorus and Potassium fertilizer under moisture stress conditions.

2. To Compute water use efficiency at various levels of fertilizer application.

REVIEW OF LITERATURE.

Khondaker et al (1983) in pot experiment imposed moisture stress ranging from field capacity to wilting point with and without fertilizer application either in the repeated cycles or at different growth stages of wheat. Shoot weight, grain yield and uptake of N, P and K at flowering and at harvesting stage were higher than compared to other soil moisture stress treatments. Saleem (1983) elucidated the role of fertilizer in increasing wheat production and fertilizer response under different moisture regimes in Pakistan. An increase in the yield of rainfed wheat was 1065 to 2329 kg ha^{-1} with the application of 60-60-30 N, P_2O_5 and K_2O kg ha^{-1}. The response to individual nutrient worked out was 459,215 and 138 kg ha^{-1} for 30 kg ha-1 each of N,P_2O_5 and K_2O, respectively.

Sharma (1985) observed that average grain yield increased from 1600 kg ha^{-1} to a maximum of 1700 kg ha^{-1} as soil moisture tension (SMT) decreased from 4.0 to 1.5 bars and it was 1400. 2000 and 1800 kg ha-1 for 0.40 and 80 kg N ha^{-1} respectively. By decreasing SMT, the yield increased in the ranges of 1900-2400 and 2000-3300 kg ha^{-1} with 40 and 80 kg N ha^{-1}, respectively. Nitrogen uptake increased with decreasing SMT and increasing nitrogen rates in both the experiments. Moursi et al. (1976) observed that increasing water stress by decreasing the amount of soil available water, decreased the wheat and its components. grain yield decreased from 11.25 g pot-1 at 25 percent soil moisture stress to 6.41 g pot-1 at 100 percent stress conditions.

Ahmad and Khalaf (1985) in a pot experiment planted Maxi-Pak and saberbeg wheat varieties that were subjected to six water stress treatments. The water use efficiency increased with increasing water stress for both wheat varieties. Reddy and Bharwaj (1982) studied water use in wheat as influenced by levels of nitrogen and phosphorus under limited and adequate irrigation. In their trial, consumptive use of water (CUW) increased with increasing water application from one irrigation to adequate, while water use efficiency (WUE) decreased simultaneously. The consumptive use efficiency increased slightly with 40 kg N and 25-50 kg P_2O_5 ha^{-1}, but water use efficiency increased markedly. Studied on CUE for wheat clearly indicated that fertilizer increased water use efficiency.

Korentafar et al (1988) in a experiment observed the effect of five levels of nitrogen viz 0, 30, 60, 90 and 120 kg ha^{-1} on dry land wheat in which the magnitude of response to N in moisture stress condition was monitored. They concluded that addition of nitrogen under moisture stress conditions significantly increased grain yield.

Ghanem et al (1983) applied Phosphorus @ 30, 60, 120, 240 and 480 kg ha^{-1} P_2O_5 to study the crop response to phosphorus in a very dry year. Maximum wheat yield of 3280 and 3610 kg ha^{-1} was recorded with phosphorus application of 120 kg ha^{-1}, respectively in two wheat varieties, likewise increasing the potassium fertilizer from 30 to 180 kg ha^{-1}, the wheat yield increased .

Itkov (1984) tested the role of mineral and organic fertilizer application under drought conditions. Data from the investigation indicated that in very dry years, fertilization increased the yield of wheat by 80-250 percent.

Ibrahim et al (1986) studied the effect of four irrigation regimes and four fertilizer levels on yield of wheat crop. they concluded that plant height, higher number of Kernals, 100 kernal weight and grain yield increased with increase in number of irrigation and fertilizer dose.

Comparison of sprinkler irrigation to furrow irrigation in relation to fertilizer requirement for maximum yield in various crop was performed by viets (1962), the differences in methods of irrigation were non significant, However fertilizer application with irrigation was convenient in sprinkler method.

The most of literature on the subject outlined related to field experiments and has already been discussed in field experiment section of the text.

MATERIALS AND METHODS

The present study was conducted in the green house of the Barani Agriculture College Rawalpindi during the year 1991-92. Bulk soil sample was collected from 0-15 cm depth from the research area of the Department of Soil Science, of the college. Soil was air dried. ground passed through a 2 mm screen and 8 kg soil (<2mm) was then filled in each plastic pot. The experiment consisted of nine fertilizer treatments and three moisture levels by sprinkler and surface irrigation method, and was laid out in Factorial Complete Randomized Design. The plan of the experiment is given below :

1.0 Fertilizer Treatments

Fertilizer treatments were as follows

Treatment	Fertilizer		
	N	P_2O_5	K_2O
	(Kg ha^{-1})		
F1	57	0	0
F2	57	57	0
F3	57	57	57
F4	85	85	57
F5	85	85	57
F6	85	85	85
F7	115	85	85
F8	115	115	85
F9	115	115	115

2.0 Moisture Treatments :

The moisture levels by sprinkler and surface irrigation methods, were.

I1 Irrigation at 25 percent of soil field capacity.

I2 Irrigation at 50 percent of soil field capacity.

I3 Irrigation at soil field capacity*

The experiment was replicated three times. Composite soil sample was taken from the bulk soil before sowing. The soil sample was air dried, ground to pass through 2mm sieve and analyzed to study the following physical and chemical characteristics.

- Electrical Conductivity of Saturation extract (EC_e)
- pH of the saturated soil paste.
- Texture.
- Cation exchange capacity (CEC)
- Organic matter.
- Calcium Carbonate ($CaCO_3$)
- Total nitrogen.
- Available phosphorus.
- Extractable potassium.

The data pertaining to above physical and chemical characteristics of soil is given in table 1.

Nitrogen as urea, Phosphorus as diammonium phosphate and potassium as potassium sulfate were mixed evenly with soil in each pot according to the fertilizer treatment just before sowing. Wheat variety Pak-81 was sown on November 27, 1991. Eight grains of wheat were sown in each pot.

* Field capacity was considered as 50 percent of saturation percentage.

Table 1 : Physical and Chemical Characteristics of Soil

Soil Characteristics	Unit	Value
Texture		
Sand	%	54
Silt	%	29
Clay	%	17
Texture Class		sandy loam
Saturation percentage		32
CEC	me 100-1 g	4.35
Organic matter	g 100-1 g	0.66
EC_e	dSm-1	0.24
pHs		7.84
CaCO3	g 100-1 g	10.60
Total nitrogen	mg g-1	0.36
Available phosphorus	µg g-1	5.45
Extractable potassium	µg g-1	99.00

3. Thinning and Weeding.

After germination thinning was done by hands, uprooting the plant from the pot and only three were allowed to grow in each pot, the uprooted plants were added to the concerned pots. weeds were manually removed twice during the experiment.

4. Irrigation

Irrigation was applied by sprinkler and surface irrigation method according to the moisture treatment, as and when the moisture in optimum irrigation field capacity pots reached 1/4 of field capacity.

5. Aphids Attacks :

A moderate aphids attack was observed in the 3rd week of February 1992. It is was controlled by spraying 1% Nogas in water.

6. Harvesting :-

The crop was harvested on May 5, 1992. During and at the end of the growth period, the data pertaining to following crop parameters was recorded.

1. Number of tillers per plant
2. Plant height
3. Hundred grains weight
4. Fresh and dry weight of crop per pot
5. Fresh and dry weight of grain

The straw and grain samples of wheat were collected at random from each treatment during harvesting. These samples were oven dried at 65°C and finally ground for the analysis of total nitrogen, phosphorus and potassium.

7.0 Analytical Work :

The analysis of soil samples and plant materials was carried according to the methods described by Page et al (1982). The details of methods for soil, plant and statistics analysis has already been mentioned in Materials and Methods section of fertilizer use efficiency in wheat under field conditions.

RESULTS AND DISCUSSION

The research obtained during the investigation are discussed as under.

EFFECT OF NPK FERTILIZER AND SPRINKLER AND SURFACE IRRIGATION ON TILLERS PER PLANT OF WHEAT.

The data in table 2 indicate number of tillers per plant were affected by fertilizer application and also by level and method of irrigation.

The number of tillers per plant in sprinkler irrigation was 3, 4 and 5, respectively for F1, F2 and F3 treatments. It was recorded 4 tillers for F4 and for all remaining fertilizer treatments was 5 tillers and they were non significant, likewise with surface irrigation the number of tiller per plant was 3 for F1 and 4 each for F2 & F3 for all other fertilizer treatment the number observed was 5 tillers. This indicate that for higher fertilizer treatments the number of tillers was similar.

The minimum number of tillers viz 2 tillers per plant for both irrigation methods was observed in treatment to which only nitrogen was applied. The maximum number of tillers, 7 was recorded for F7, F8 & F9 for both irrigation methods at I3 irrigation level.

There was no difference in number of tillers with regard to irrigation method, however level of irrigation in both methods affected number of tillers significantly. The higher number was observed for maximum irrigation at field capacity and minimum at I1, the lowest irrigation levels.

Effect of NPK fertilizer and sprinkler irrigation, surface irrigation on plant height.

The data of plant height in relation to fertilizer and irrigation is presented in table 3.

The minimum plant height was observed in treatment of nitrogen application alone in case of both irrigation methods, while highest was recorded in F7 treatment of 115-85-85 fertilizer application

Table 2 : effect of NPK Fertilizer and Sprinkler and Surface Irrigation Tillers per plant of Wheat.

Fertilizer Treatment	Sprinkler Irrigation I1	I2	I3	Mean	Surface Irrigation I1	I2	I3	Mean
F1	2	3	4	3 d	2	3	4	3 d
F2	3	4	4	4 c	3	4	5	4 c
F3	3	5	6	5 b	3	5	5	4 c
F4	3	5	5	4 c	3	5	6	5 b
F5	3	5	6	5 b	3	5	6	5 b
F6	3	5	6	5 b	3	5	6	5 b
F7	3	5	7	5 b	3	5	7	5 b
F8	3	5	7	5 b	3	5	7	5 b
F9	3	5	7	5 b	3	5	7	5 b
Mean	3 d	5 b	6 a		3 d	5 b	6 a	

* = Mean value of three repeats.

** = Mean followed by same letter are non significant at 5% level of significance

ANALYSIS OF VARIANCE

Source	Degrees of freedom	Sum of Squares	Mean Square	F Value	Prob.
F	8	43.53	5.441	26.71 *	0.00
I	2	210.42	105.210	516.48 **	0.00
F X I	16	21.13	1.321	6.48	0.00
I M	1	0.09	0.099	0.48	
F X M	8	0.56	0.071	0.34	
M X I	2	0.34	0.173	0.84	
F X M X I	16	3.65	0.228	1.12	0.3451
Error	108	22.00	0.204		
Total	161	301.75			

* = Significant

** = Highly significant

Table 3 :Effect of NPK Fertilizer, Sprinkler and Surface Irrigation on Plant height of Wheat. (cm)

Fertilizer Treatment	Sprinkler Irrigation I1	I2	I3	Mean	Surface Irrigation I1	I2	I3	Mean
F1	49.66	55.66	57.00	54.10e	50.00	55.00	57.00	54.00e
F2	51.00	56.66	58.33	55.33d	50.66	57.00	59.00	55.60d
F3	51.66	57.00	59.33	56.00cd	52.00	58.00	59.33	56.44bcd
F4	51.66	58.66	60.66	56.00bcd	50.66	59.00	60.33	56.70bc
F5	51.00	60.66	60.66	57.44bc	50.66	61.00	60.66	57.44bc
F6	48.33	61.00	60.33	56.55bc	51.00	60.66	61.33	57.66bc
F7	52.66	61.66	62.66	59.00a	53.00	61.33	63.33	59.22a
F8	52.66	62.00	61.66	58.88ab	52.66	60.66	62.30	58.54ab
F9	52.00	60.33	61.66	58.00ab	52.66	60.66	62.66	58.66ab
Mean	51.18c	59.29b	60.25a		51.48c	59.26b	60.66a	

* = Mean value of three repeats.

** = Mean followed by same letter are non significant at 5% level of significance

ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Prob.
F	8	395.93	49.49	17.81*	0.00
I	2	2609.34	1304.67	469.68**	0.00
F X I	16	113.65	7.10	2.55	0.00
I M	1	5.55	5.55	2.00	0.16
F X M	8	6.11	0.76	0.27	
M X I	2	0.11	0.05	0.02	
F X M X I	16	12.88	0.80	0.29	
Error	108	300.00	2.77		
Total	161	3443.60			

* = Significant

** = Highly significant

Treatment F1, nitrogen alone was significantly lower, while F7 was significantly higher compared to other fertilizer treatment. However F7, F8 and F9 were non significant among one another in both irrigation methods. This revealed that is green house any irrigation is equally good and it is only the irrigation levels that affect the plant growth. The plant height was 51.18, 59.29 and 60.25 cms in sprinkler for I1, I2 and I3 treatment. Almost similar results were recorded for surface irrigation. The differences in plant height in respect of level of irrigation were highly significant. The interaction between fertilizer level and method of irrigation was non-significant, although both fertilizer and irrigation affected the plant height to considerable degree. These results corroborate to that of Saleem (1983).

EFFECT OF NPK FERTILIZER AND SPRINKLER, SURFACE IRRIGATION ON HUNDRED GRAIN WEIGHT OF WHEAT.

The data in table 4 elucidated that highest hundred grain weight of 2.86 and 2.84 g was observed in F7 for sprinkler and surface irrigation method, respectively hundred grain weight of 2-83 g, the next highest was in F8 treatment for both irrigation methods. Treatment F7 & F8 with regard to hundred grain weight were non significant between each other and significantly different compared to all other fertilizer treatments. The lowest hundred grain weight of 2.58 g was observed in treatment of nitrogen application alone. That evidently revealed that hundred grain weight is enhanced with phosphorous and potassium application.

As the quantity of irrigation water applied increased, hundred grain weight increased significantly and order of increase was I3, I2 and I1 under moisture stress conditions as predominantly prevail in rainfed areas, the wheat grains are shriveled and their weight is less in comparison to non stressed wheat grains, these findings are in conformity to that obtained by Ibrahim (1986).

EFFECT OF NPK FERTILIZER AND SPRINKLER, SURFACE IRRIGATION ON FRESH/DRY GRAIN WEIGHT OF WHEAT.

The data pertaining to fresh and dry grain weight of wheat in relation to Fertilizer and irrigation treatment is presented in table 5 and 6, respectively.

Table 4 : Effect of NPK Fertilizers, Sprinkler and surface Irrigation on 100 Grain weight of wheat. (g)

Fertilizer Treatment	Sprinkler Irrigation I1	I2	I3	Mean	Surface Irrigation I1	I2	I3	Mean
F1	2.44	2.59	2.72	2.58 d	2.43	2.60	2.73	2.58 d**
F2	2.55	2.65	2.78	2.66 c	2.55	2.63	2.76	2.65 c
F3	2.59	2.65	2.78	2.67 c	2.58	2.65	2.78	2.67 c
F4	2.61	2.79	2.84	2.75 b	2.59	2.79	2.86	2.75 b
F5	2.60	2.83	2.94	2.79 b	2.60	2.81	2.93	2.78 b
F6	2.60	2.83	2.93	2.78 b	2.59	2.80	2.92	2.77 b
F7	2.62	2.90	3.05	2.86 a	2.62	2.86	3.04	2.84 a
F8	2.61	2.87	3.02	2.83 a	2.61	2.84	3.05	2.83 a
F9	2.60	2.89	2.89	2.82 b	2.58	2.73	3.02	2.77 b
Mean	2.58 c	2.78 b	2.89 a		2.57 c	2.74 b	2.56 a	

* = Mean value of three repeats.

** = Mean followed by same letter are non significant at 5% level of significance

ANALYSIS OF VARIANCE

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value	Prob.
F	8	1.14	0.14	92.60*	0.00
I	2	2.83	1.41	914.78**	0.00
F X I	16	0.23	0.015	9.62	0.00
I M	1	0 001	0.001	0.69	
F X M	8	0.003	0.00	0.20	
M X I	2	0.001	0.001	0.39	
F X M X I	16	0.007	0.00	0.27	
Error	108	0.167	0.002		
Total	161	4.398			

* = Significant

** = Highly significant

Table 5 : Effect of NPK Fertilizer, Sprinkler and Surface Irrigation on Fresh grain weight of wheat. (g) per pot.

Fertilizer Treatment	Sprinkler Irrigation I1	I2	I3	Mean	Surface Irrigation I1	I2	I3	Mean
F1	2.36*	9.41	13.37	8.38 d	2.38	9.49	13.35	8.41 d**
F2	2.61	12.08	15.36	10.01 c	2.60	12.12	15.42	10.05 c
F3	2.71	13.32	16.76	10.93 c	2.69	13.26	1676	10.90 c
F4	2.85	15.39	20.19	2.81 b	2.83	15.38	20.16	12.79 b
F5	2.87	17.43	21.63	13.98 ab	2.84	17.44	21.67	13.98 ab
F6	2.86	17.43	21.81	14.03 ab	2.85	17.26	21.83	13.98 ab
F7	2.01	17.92	22.99	14.64 a	3.04	17.92	23.12	14.69 a
F8	2.99	17.84	23.0	14.61 a	2.92	17.89	23.02	14.61 a
F9	2.89	16.33	22.12	13.78 ab	2.92	16.37	22.23	13.84 ab
Mean	2.79 c	15.24 b	19.69 a		2.79 a	15.23 b	19.72 a	

* = Mean value of three repeats.

** = Mean followed by same letter are non significant at 5% level of significance

ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Prob.
F	8	1.14	0.14	92.60*	0.00
I	2	2.83	1.41	914.78**	0.00
F I	16	0.23	0.015	9.62	0.00
I M	1	0.001	0.001	0.69	
F X I	8	0.003	0.00	0.20	
M X I	2	0.001	0.001	0.39	
F X M X I	16	0.007	0.00	0.27	
Error	108	0.167	0.002		
Total	161	4.398			

* = Significant

** = Highly Significant.

Table 6 :Effect of NPK Fertilizer, Sprinkler and Surface Irrigation on dry Grain weight of wheat. Per pot (g)

Fertilizer treatment	Sprinkler Irrigation I1	I2	I3	Mean	Surface Irrigation I1	I2	I3	Mean
F1	2.11	8.19	11.53	7.27e	2.03	8.12	11.95	7.37e**
F2	2.34	10.51	13.30	8.72d	2.32	10.02	13.52	8.62d
F3	2.42	11.59	14.53	9.51c	2.45	11.75	15.11	9.77c
F4	2.55	13.38	17.46	11.13b	2.54	14.34	17.42	11.43b
F5	2.57	15.27	18.86	12.23ab	2.51	15.02	18.80	12.11ab
F6	2.56	14.87	18.81	12.08ab	2.51	15.02	18.65	12.06ab
F7	2.69	15.60	20.01	12.76a	3.64	15.61	20.46	12.90a
F8	2.60	15.03	20.04	12.56a	2.63	15.70	20.50	12.94a
F9	2.59	14.43	19.41	12.14ab	2.58	14.99	19.34	12.30ab
Mean	2.49c	13.20b	17.11a		2.47c	13.39b	17.31a	

* = Mean value of three repeats

** = Mean followed by same letter are non significant at 5% level of significance.

ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Prob.
F	8	552.68	69.08	59.79*	0.00
I	2	6247.79	3123.89	2703.73**	0.00
F X I	16	238.88	14.93	12.92	0.00
I M	1	0.44	0.44	0.38	
F X M	8	0.84	0.10	0.09	
M X I	2	0.34	0.17	0.14	
F X M X I	16	2.27	0.14	0.12	
Error	108	124.78	0.15		
Total	161	7168.04			

* = Significant

** = Highly significant

This is evident from the data that minimum grain yield of 8.38 and 8.41 grains per pot was observed in sprinkler and surface irrigation method in F1 treatment. The yield increased to considerable extent with application of phosphorus fertilizer in F2, yield still increased in F3, but these differences were non significant in relation to F2, but significant in relation to treatment with nitrogen application alone. The treatment F4 to F9 were higher significant with regard to F1, F2 and F3 treatments the highest grain yield of 14.64 and 14.69 g/pot in sprinkler and surface irrigation method was in case of F7 treatment. Treatment F7 was non significant in respect of F5 to F9 treatment. This indicate application of fertilizer in excess of 85-85-57 Kg ha^{-1} of N, P_2O_5 and K_2O call for consideration that fertilizer should only be applied if economic return is ensured and economic efficiency is more that unity. It also indicate that N, P ratio of 1:1 is good for stress environments as is the case for irrigated wheat. The results in the table are also testimony to the hypothesis that nutrients utilization effect is pronounced in appropriate soil moisture environments.

The irrigation methods are alike as far as grain yield is concerned, however irrigation level affected the grain yield to a considerable degrees. The grain yield per pot was 2.79, 15.24 and 19.69 grain for I1, I2 and I3 in sprinkler irrigation, respectively. Almost similar results were obtained in case of surface irrigation. The difference with regard to irrigation levels were highly significant. The grain yield per pot was 5.48, 5.46 and 7.06 times higher in I2 and I3 compared to I1 for sprinkler and surface irrigation method. This elucidate that wheat grain yield is curtailed manifold under moisture stress environments. Only remedy to offset the detrimental effect of low moisture is to devise way and means to conserve soil moisture and store excess water for use at critical growth stage of the crop. Another important observation from the table 5 data was that in sprinkler irrigation highest grain yield of 17.92 grain is recorded in F7 at I2 moisture level, while highest 23.0 g/pot in F8 in I3 irrigation treatment. This revealed that at high moisture level more fertilizer is needed to obtained maximum yield. Hence fertilizer recommendations in Barani areas should be synchronized in relation to quantity of rainfall received, more the rainfall, higher will be the fertilizer dose.

Comparison of table 5 and 6 indicate that dry grain yield is more affected statistically than fresh grain yield by fertilizer and irrigation water application. The percent decrease in weight on drying was little more at lower fertilizer treatments. The reverse statement is valid with regard to irrigation treatment.

The increase in wheat grain yield with application of fertilizer and irrigation have been demonstrated by Khondaker et al (1983), Ibrahim et al (1986) and many others investigations.

The data pertaining to wheat straw is presented in table 7. The fertilizer and irrigation treatments affected the straw yield significantly, as was the case in grain yield. However straw yield was almost 1.5 times higher compared to grain yield.

FERTILIZER USE EFFICIENCY.

Fertilizer use efficiency data is presented in table 8.

Fertilizer use efficiency is computed on conventional basis, as it is more related to practical farmers situation. It is different than Agronomy efficiency or nutrient recovery as envisaged in field experiment, already discussed. The fertilizer use efficiency was considered as conventional, as it is common and usual practice with the farmers that they normally apply nitrogen fertilizer to wheat crop. So in calculation of conventional fertilizer use efficiency, application of nitrogen alone viz F 1 treatment was considered as reference treatment.

The data in the table elucidate that fertilizer use efficiency was usually more with sprinkler irrigation compared to surface irrigation. The fertilizer use efficiency also increased with increase in quantity of irrigation water applied. In comparison to field experiment, fertilizer use efficiency in nitrogen and potassium at I2 & I3 irrigation levels was manifold for both irrigation methods. However reverse statement was also valid at I1, irrigation level. Almost similar results were obtained for phosphorus except that phosphorus efficiency of 5.26 was lowest in I2 with surface method of irrigation. Fertilizer use efficiency in potassium was low compared to N and P, may be attributed to medium level of potassium in soil as in table-1 of the text.

COMPARISON OF WHEAT YIELD IN FIELD AND GREEN HOUSE EXPERIMENTS.

The wheat yield in field experiment was more compared to green house experiment as is evident from data in table 9. This may be assigned to more number of tillers per plant in field experiment. The chilling temperature of 0.5 °C in January, 1992 may be instrumental in induction of more tillers in field compared to green house conditions, the temperature was kept controlled. Hundred grain weight was also more in field crop, than wheat sown in green house. In surface irrigation slightly higher yield was observed than

Table 7 Effect of NPK Fertilizer, Sprinkler and Surface Irrigation on dry weight of wheat straw per pot (g)

Fertilizer Treatment	Sprinkler Irrigation I1	I2	I3	Mean	Surface Irrigation I1	I2	I3	Mean
F1	3.81*	12.95	18.48	11.75e	3.88	13.10	18.45	11.81e**
F2	4.14	15.73	21.64	13.84d	4.16	15.72	20.90	13.60d
F3	4.28	17.06	22.85	14.73d	4.29	17.00	22.82	14.70d
F4	4.46	18.98	26.72	16.72c	4.48	20.11	25.98	16.86c
F5	4.49	21.70	30.76	18.97b	4.50	20.73	24.18	16.47b
F6	4.49	21.53	30.91	18.97b	4.45	24.65	31.01	20.04b
F7	4.68	23.38	33.08	20.38ab	4.72	23.20	33.24	20.39ab
F8	4.68	23.25	32.94	20.29ab	4.69	23.63	33.12	20.48ab
F9	4.73	23.73	33.15	20.54a	4.76	23.68	33.23	20.56a
Mean	4.42c	19.81b	27.84a		4.44c	20.20b	26.99a	

* = Mean value of three repeats.

** = Mean followed by same letter are non significant at 5% level of significance

ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
F	8	1519.53	189.94	99.09*	0.00
I	2	15252.65	7626.32	3978.66**	0.00
F X I	16	728.65	45.54	23.75	0.00
I M	1	0.00	0.00	0.00	
F X M	8	0.76	0.09	0.04	
M X I	2	0.32	0.16	0.08	
F X M X I	16	1.27	0.08	0.04	
Error	108	207.01	1.91		
Total	161	17710.21			

* = Significant
** = Highly significant.

Table 8 :FERTILIZER USE EFFICIENCY (Kg Kg $^{-1}$)

Fertilizer Levels (NPK kg ha^{-1})	Sprinkler Irrigation I1	I2	I3	Surface Irrigation I1	I2	I3
57-57-0 (P)	1.1	11.71	8.73	0.96	5.26	9.08
57-57-57 (K)	0.44	5.44	6.44	0.40	5.0	5.88
85-57-57 (N)	1.25	20.70	30.63	1.25	18.93	30.36

Table 9 : COMPARISON OF WHEAT YIELD IN FIELD AND GREEN HOUSE EXPERIMENT.

Grain (Kg ha^{-1})

Fertilizer Treatments	Field Expt.	Sprinkler Irrigation	Surface Irrigation
F1	3353	1818	1843
F2	3753	2180	2155
F3	3834	2378	2443
F4	4094	2783	2858
F5	4237	3058	3028
F6	4305	3020	3015
F7	4410	3190	3225
F8	4405	3140	3235
F9	4337	3035	3075
Irrigation Level.			
I0	3581	-	-
I1	3964	623	618
I2	4242	3300	3348
I3	4536	4278	4328

sprinkler irrigation except F2, F5 and F6 treatments. The effect of irrigation was almost similar to that described above. The maximum wheat yield in field and sprinkler irrigation in green house was observed at F7 while with surface irrigation, highest grain yield of 3235 Kg ha^{-1} was recorded in F8 fertilizer treatment.

SUMMARY.

The green house experiment was carried out by collection of same soil as that in field experiment. The fertilizer treatments and irrigation levels were similar, except that in field experiment the incidental rainfall was supplemented only once with sprinkler irrigation. The irrigation in green house was monitored with reference treatment of field capacity soil moisture levels with sprinkler and surface irrigation methods.

The study led to the conclusions.

1. The sprinkler and surface irrigation methods were similar as far astheir effect on plant growth and yield of wheat crop was concerned.

2. The yield increased with fertilizer application and highest yield was obtained in 115-85-85 and 115-115-85 Kg ha^{-1} N, P_2O_5, $_2O$ in sprinkler and surface irrigation methods, respectively.

3. The yield was substantially higher at high level of irrigation compared to low level.

4. The data and observation of study elucidate that 85-85-57Kg ha^{-1} N, P_2O_5 and K_2O was suitable fertilizer dose to obtain economic maximum yield of wheat crop and fertilizer used in excess may be of little economic value.

5. Fertilizer use efficiency varied with method of irrigation and was more with sprinkler than surface irrigation method.

OUT COME OF STUDY.

The message from the investigations conducted is .

Based on the economic maximum, the fertilizer recommendation for wheat in rainfed areas should be 85-85-57 Kg ha^{-1} N, P_2O_5 and K_2O respectively. Under moisture stress conditions substantial reduction in wheat yield occur, hence supplementing rainfall even with light irrigation by sprinkling device may result in good wheat harvest. The sprinkler irrigation equally match to surface irrigation and was not only more efficient rather better suited to uneven, sloping and undulating topography of potohar and such like regions. The way and means needs to be devised to store rain water and its usage by sprinkler irrigation at critical growth stage of wheat or other crops.

Last but not the least to mention is that cherished goal of self sufficiency in food can only be achieved, if the yield of wheat in rainfed areas is increased, as Barani areas Constitute 25 percent of cultivated area in Pakistan.

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