SOIL TEST CROP RESPONSE CORRELATION STUDIES ON SUNFLOWER IN INCEPTISOLS

Thesis submitted in part fulfilment of the requirements for the **DEGREE OF MASTER OF SCIENCE (AGRICULTURE)** in Soil Science and Agricultural Chemistry to the Tamil Nadu Agricultural University Coimbatore

By

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1995

CERTIFICATE

This is to certify that the thesis entitled "**SOIL TEST CROP RESPONSE CORRELATION STUDIES ON SUNFLOWER IN INCEPTISOLS**" submitted in part fulfilment of the requirements for the **DEGREE OF MASTER OF SCIENCE (AGRICULTURE)** IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY to the Tamil Nadu Agricultural University, Coimbatore is a record of **bona fide** research work carried out by **S.MARAGATHAM** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scienctific or popular journal or magazine.

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Date :

External ~~Examiner~~.

DEDICATED TO MY BELOVED PARENTS AND AFFECTIONATE BROTHER

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S. Maragatham

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ABSTRACT

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SOIL TEST CROP RESPONSE CORRELATION STUDIES ON SUNFLOWER (*Helianthus annuus* L.) IN INCEPTISOLS

By

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DEGREE : M.Sc. (Agriculture) in Soil Science and Agricultural Chemistry

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The primary objective of the study was to investigate the fertilizer response of sunflower crop in Lower Bhavani project area, Tamil Nadu. Field experiment was conducted in fine loamy, mixed isohyperthermic, Udic Ustropepts, a member of Irugur soil series which represents the benchmark soil of the command area. The experimental approach followed was the inductive methodology adopted in All India Co-ordinated Project on Soil Test crop Response studies by which fertility gradients with

respect to nitrogen, phosphorus and sulphur were created in the experimental soil by applying different amounts of these nutrients and by growing maize (Var Co 1). The test crop sunflower (MSFH-8) was raised under irrigated conditions. Twenty four combinations of nitrogen, phosphorus and sulphur consisting of five levles of nitrogen, four levels of phosphorus and three levels of sulphur (including zero level) were superimposed over the fertility gradients inorder to make predictions on the fertilizer requirements for test crop sunflower.

In the present study, creation of soil fertility gradient was possible with respect to all the three nutrients **viz.**, nitrogen, phosphorus and sulphur. Alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S were found suited for determining available soil N, P and S respectively.

Among the three methods tried in the present study to estimate the basic parameters for getting desired yield targets, the yield maximum method was found to be the best method as it recorded a higher response yardstick of 4.25 kg/kg. Hence, the estimates of soil and fertilizer nutrient efficiencies calculated by this method was used for developing fertilizer prescription equation for sunflower crop. A soil test calibration was workedout for an yield target of 20 and 25 q ha^{-1} of sunflower grain.

Prediction of post-harvest soil test values from the pre-sowing soil test values and other associated parameters like the added fertilizer doses and crop yield could be done with high degree of accuracy by making use of linear polynomial model and routine soil test methods of $KMnO_4$-Olsen-P-Morgan's reagent-S.

To achieve an yield target of 25 q ha^{-1} the fertilizer N requirement would be 161 kg ha^{-1} when the alkaline $KMnO_4$-N was 250 kg ha^{-1}, P requirement would be 76 kg P_2O_5 ha^{-1} when the Olsen-P was 25 kg ha^{-1} and the S requirement would be 41 kg So_4 ha^{-1} when the Morgan's reagent-S was 15 kg ha^{-1}.

Whenever sunflower is grown under irrigated conditions in the Lower Bhavani ayacut area, sufficient amounts of fertilizer additions become necessary for obtaining desired yield targets.

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CHAPTER I

INTRODUCTION

The crop yield is a function of several factors such as crop variety, climate, soil fertility, soil moisture, other soil properties affecting plant growth and level of management. While climate is difficult to manipulate to our requirement under field condition, other factors may be made optimum to get maximum yield in crops. Fertilizers have played a key role in increasing food production in India. The constantly increasing demand for fertilizer resulting from agricultural development in the country has caused dramatic increase in the prices of fertilizers. Considering the high prices "precision farming" has more than ever become a necessity. Any schedule for crops which takes into account the soil nutrient supplying capacity will aim at achieving this "precision farming".

Arbitrary and indiscriminate use of fertilizers would result in wastage of this important and limited resource which could otherwise be used to fertilize additional area under crops. To obtain reliable information on soil nutrients, it is necessary to select a suitable soil test method which would fit with the soil and thus serve as an index for assessing nutrient availability. Hence, screening of soil test methods for soil available nutrients are focussed.

Tisdale (1967) aptly pointed out that soil testing is the art of crop production what the thermometer is to the medical profession. Hence, soil testing and soil fertility management programme for sustained crop production is therefore of great importance to any country. Soil testing is one of the approaches to rationalise the fertilizer use for obtaining profitable yield from a crop per unit area in unit time. The general agronomic fertilizer requirements were equated to the medium level of soil fertility and the fertilizers were adjusted empirically by increasing or decreasing these levels by 30-50% for condition of low and high soil fertility respectively (Muhr **et al.**, 1965). In order to provide a refinement on the scientific basis in efficient and economic use of fertilizers research on Soil Test Crop Response studies are of practical significance. Targetted yield concept envisages the identification of fertilizer needs for different yield targets, soils and climatic conditions (Truog, 1960). This approach takes into account the nutrient requirement of a crop for the production of unit quantity of economic produce and the soil and fertilizer nutrient efficiencies. Fertilizer recommendation based on soil test value gives prescription for a yield target, a maximum yield and for maximum profit/ or economic yield through fertilizer adjustment equations. A large number of chemical test procedures have been so far developed for assessing the available nutrients in the soil. However, what is needed is a mere selection of the most appropriate analytical procedure among the ones already developed to suit a given crop under specific soil condition.

Oil seed production ranks second in importance next to food production. Oil seeds form the raw materials for vegetative oil, both edible and non-edible and occupy a significant position in Indian national economy accounting for 10% of cultivable area. Though, India is one of the major oil producing countries in the world, third largest producer of oil seeds, the production is not sufficient for our domestic consumption and hence we import edible oil from other countries.

Among the oil seeds,sunflower (**Helianthus annuus** L.) is considered as one of the most important crop, gaining popularity among the farmers due to its highest oil content coupled with good quality fatty acids, besides amenable for cultivation both under rainfed and irrigated conditions.

Like any other crop, the yield of sunflower is also affected by multivarious factors, out of which the nutrient supply form the important. The nutrient requirement of the crop can be met from the soil native resource and or through external application of fertilizers. In the conventional methods, blanket recommendations are made without considering the contribution from the soil, and the resulted yield being harvested. However, in the soil test, calibration is made for desired yield targets taking into account of the contribution from the native resource, which would result in higher production as well as better cost benefit ratios. It has been proved that adequate N supply increases the amount of cell plasma and chlorophyll which is a vital factor for growth, whereas the fertilization with P helps in improving the seed weight and also development of deeper and proliferous root system leading to extraction of water and nutrients from deeper layers of soil profile. Oil seed crops have high sulphur requirement, as carbohydrates are not fully utilized for the formation of oil (Yadav and Singh, 1970). On an average, each unit of sulphur added to sulphur deficient soils increased the seed yield at 16 kg/kg (Tandon 1986). There is synergistic relationship between S and N.

Soil Test Crop Response studies have been carried out since 1967, for the crops like rice, maize, sorghum, ragi, groundnut, sugarcane, blackgram, tapioca, gingelly etc., for the desired yield targets, under different agroclimatic zones and soil environments (Annual reports of All India Co-ordinated scheme on Soil Test Crop Response studies, Coimbatore). So far, no work has been carried out on soil test crop response correlation studies and screening of suitable soil testing procedures for evaluating the available N,P and S in sunflower.

This has evoked interest to undertake the present investigation in sunflower crop with the following objectives.

1. To establish significant relationship between yield and crop response to fertilizer and to provide a calibration for fertilizer recommendation.
2. To derive a basis for fertilizer recommendation for desired yield targets.
3. To investigate the role of S on the growth and yield of sunflower.
4. To evaluate the quality parameters (oil content and protein) as influenced by fertilization.
5. To screen the different soil test methods for N,P and S.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The literature pertaining to the present investigation on the soil test crop response studies and the importance of N, P and S in plant nutrition and their effect on the yield of sunflower seed and oil is presented in this Chapter.

2.1. Evaluation of soil test methods

Soil tests are being employed to assess the status of soil available nutrients that can be utilised for plant growth and yield. They also help to make the optimum recommendation of individual nutrients leading to fertilizer economy. Soil tests are being used as guide to assess the fertilizer needs (Ramamoorthy **et al.**, 1969; Rani Perumal, 1975; Dixit **et al.**, 1984; Sidhu **et al.**, 1984; Tandon and Kanwar, 1984; Dhanapalan Mosi and Lakshminarayanan, 1985; Velayutham **et al.**, 1985; and Goswami, 1986). It paves way to formulate various fertilizer recommendation for different crops.

Soil fertility research and associated laboratory studies over the past 60 years have established the efficacy of soil testing as a means for predicting the nutrient needs of crops to be grown. Soil testing is generally recognised as the best available tool for diagnosing soil nutrient limitations before a crop is planted, so that correction can be made in that year by appropriate fertilization. Soil test was explained by Colwell (1967) as " a measurement that qualifies to be termed as a soil test for a particular nutrient if, and only if, it provides information on the fertilizer requirement of a crop of that nutrient." The ability to extract proportional amount of available nutrient, dependability and rapidity are characteristics for successful soil test. Calibration of soil test against crop response is essential to decide on the fertilizer requirements. Correlation of soil test with relative yield provides an indirect calibration, while the multiple regression adopted under soil test crop response correlation scheme provides a direct calibration.

2.1.1. Nitrogen

Eventhough different biological methods like Neubauer's seedlings and tissue testing are available for estimating the available nitrogen, the chemical methods are always preferred because of the rapidness, simplicity and accuracy. Most widely adopted methods of estimation of available nitrogen in India are organic carbon by chromic acid (Walkley and Black, 1934) by wet digestion and alkaline permanganate method (Subbiah and Asija, 1956). Srivastava (1975) observed a linear correlation between alkaline

$KMnO_4$-N, aminosugar-N, hydrolysable-N and aminoacid-N. Bajaj **et al.**(1967) established the superiority of alkaline $KMnO_4$-N as an index of N availability under varying soil types such as noncalcareous red (Irugur series), calcareous red (Somayanur series) and mixed black (Periyanayakanpalayam series). The crops tested varied from lowland rice to upland crops.

It was reported that significant positive correlation existed between soil available N with organic carbon (Walkley and Black, 1934). This result corroborates with the findings of Thakur **et al.** (1976), Sidhu **et al.** (1983), Gupta **et al.** (1989), and Sud and Grewal (1992).

2.1.2. Phosphorus

Soil phosphorus occurs in several chemical forms. The soluble P gets reversed to various insoluble forms based on soil conditions. As a result, an extractant that is suitable for a given soil condition is not suited for certain other conditions. Some of the important extractants used for the estimation of available P are 0.5 M sodium bicarbonate (Olsen **et al.**, 1954), 0.03 N ammonium fluoride in 0.025 N hydrochloric acid (Bray and Kurtz, 1945), 0.002 N sulphuric acid with ammonium sulphate (Truog, 1930), 0.5 N acetic acid with 0.75 N sodium acetate (Morgan, 1937) and water (Van Diest, 1963). Extensively used extractants are 0.5 M $NaHCO_3$ (Olsen **et al.**, 1954) and 0.025 N HCl and 0.03 N

NH_4F of Bray I (Bray and Kurtz, 1945). The Olsen's extractant which mainly extracts Ca-P (Sharma **et al.**, 1979) has been reported to be superior for crops like rice (Chandrabhan and Harishanker, 1973), wheat (Sidhu **et al.**, 1983; Palwe and Sonar, 1989), blackgram (Lakshminarashiman, 1982), sugarcane (Murugappan, 1985), sorghum (Selvaraj, 1988), greengram (Dhillon **et al.**, 1988), groundnut (Prasanthi, 1989; Dhillon and Sidhu, 1992) and cotton (Shanmugam, 1992).

The superiority of Olsen's extractant over others was established for the acidic hill soils of Himachal Pradesh by Sharma **et al.** (1985), and Patel and Savani (1987).

The suitability of Bray I method had been well established by Chandrabhan and Harishanker (1973), Rani Perumal (1975) and Perezsilva **et al.** (1979). The Bray I extractant removes Al-P, Fe-P and Ca-P (Debnath and Mandal, 1982). Ramanathan **et al.** (1984) reported that the Bray I was found to be the better extractant of P for soybean and rice crops. Jaggi (1992) affirmed that Bray I method was highly correlated with growth parameters of soybean.

2.1.3. Sulphur

Soils vary widely in their total sulphur content. As that of P, soils of temperate region show a declining trend in total sulphur content with degree of weathering. Generally, the total S content of tropical soil is lower because of lower organic matter content. Total sulphur varied from 190 to 5700 ppm in the Dasarapatti soil series of Tamil Nadu (Balasubramanian and Kothandaraman, 1985). Total sulphur in most of the soils of India has been shown to be a function of organic matter as both are significantly and positively correlated (Takkar, 1988).

Plant roots absorb sulphur in the form of SO_4^{2-} ions from the soil. The pool of SO_4 - S consisting of water soluble, adsorbed, easily released from organic matter, has an important bearing on the sulphur nutrition of the crop. The available sulphur in soils of India vary widely and it is especially deficient either in light textured soil or those in these areas which are intensively cultivated or under multiple cropping (Mohinder Singh **et al.**, 1985). Sureshlal and Mathur (1985) observed that SO_4-S content in Indian soil was in the range of 3.4 to 81 ppm. The water soluble-S content of Tamil Nadu soils ranged from 2 to 23 ppm (Balasubramanian and Kothandaraman, 1985).

Several chemical extractants and several biological methods have been recommended for the estimation of available-S from soil. The different extractants used for the estimation of available-S are 0.15% $CaCl_2$, MgOAc,

NH_4OAc, Morgan's extractant and salt solutions. Biswas **et al.** (1989) evaluated the different extractants for the estimation of available-S. Among the different extractants tried, (Morgan's reagent, 0.15% $CaCl_2$, 0.001 N HCl and 1% citric acid) Morgan's reagent extracted more quantity of available-S from the soil by registering a correlation value of 0.64**. Similar results were reported by Chesnin and Yien (1950), Hesse (1957) and Bartlett and Neller (1960).

Williams and Steinbergs (1959) and Barrow (1961) used 0.15% $CaCl_2$ extractant for the estimation of available-S.

Ghai **et al.** (1984) and Saha and Singh (1992) reported that sulphur extracted with 0.15% $CaCl_2$ was the best index of available-S by recording the highest correlation coefficient of 0.65^{**}. Singh and Srivastava (1993) reported that 0.5M $NaHCO_3$ was found to be the better extractant for available-S.

2.2. Combination of soil test methods for assessing N, P and S availability

Generally, the suitability of soil test method for one nutrient at a time is done, by obtaining simple correlation coefficient between soil test values and yield or nutrient uptake. But most often, there is simultaneous variations in more than one nutrient for both soil and fertilizer sources under field conditions. Simple correlation between soil test values for one nutrient with crop yield/nutrient uptake may not exhibit true picture owing to the interaction of other soil as well as fertilizer nutrients. Hence, multiple regression analysis involving all the three nutrients at a time has been suggested by Ramamoorthy (1968). Accordingly, the suitability of soil test methods for N, P and S is conjointly estimated on the basis of magnitude of R^2 values. Jeevakani Selvaraj (1988) reported that, among eighteen combinations of soil test methods studied, alkaline $KMnO_4$-N, organic carbon and Olsen-P registered higher predictability of R^2 (0.82^{**}) with yield of sorghum in Typic Ustorthent soil. Prasanthi (1989) reported that alkaline $KMnO_4$-N and Olsen-P significantly correlated with groundnut pod yield and uptake in Udic Haplustalf soil. Natarajan (1991) observed that alkaline $KMnO_4$-N and Olsen-P recorded the highest R^2 value for rice and groundnut in Typic Ustrochrept soil. According to Dhawan **et al.** (1992) alkaline $KMnO_4$ for available-N, Olsen's method for available P gave the highest prediction for rice in Typic Ustrochrept soil. The same authors observed that the combination of organic carbon and Brays-P recorded the higher R^2 for wheat soils.

Mohinder Singh **et al.** (1985) observed that the Morgan's reagent was the best extractant for the estimation of available-S. Saha and Singh (1992) reported that the 0.15% $CaCl_2$ extractant was the best index of available-S.

2.3. Fertilizer recommendation based on soil test values

The aim of soil fertility evaluation is to predict fertilizer requirement of crops. Soil testing is one of the tools of soil fertility evaluation. However, it has its own limitations in predicting the fertilizer requirement of crops because the crop yield is a function of soil, crop, climate and management practices and their interactions (Goswami, 1986). Even then soil test serves as a guide for determining fertilizer requirement of crops under a given set of conditions. Beneficial effects of soil testing is well documented by several workers (Balasundaram, 1978; Beringer, 1985 and Agboola and Ayodele, 1987).

Soil scientists employ several mathematical models which include linear, logarithmic, exponential, reciprocal and quadratic models for the calibration of soil tests. Cate and Nelson (1965) employed the analysis of variance method which is better than the most widely used quadratic model. Soil Test Crop Response Correlation Project developed adjustment equations derived from multiple regression equations. The equations developed through Mitscherlich-Bray and targetted yield approach have contributed additional strength to the soil testing in making fertilizer recommendation for field crops (Dhanapalan Mosi **et al.**, 1979 and Velayutham, 1979). Saravanapandian (1990), based on the initial soil test value, worked out the recommendation of 150 kg N ha^{-1} for rice-rice cropping sequence. Natarajan (1991) recommended the application of 193 kg N ha^{-1} for rice in rice-groundnut-blackgram cropping system based on initial soil test values, while Shanmugam (1992) recommended 140 kg N ha^{-1} for cotton in cotton-maize cropping sequence. Sharma **et al.** (1989) compared three rates of fertilizer application, **viz.**, (i) recommendation of the State Department, (ii) rates as per soil test and (iii) the method adopted by farmers, and observed that fertilizer doses as per soil test method gave significantly higher yield of rice.

Rani Perumal (1975) and Singh and Sharma (1978) developed fertilizer prescription equations for different yield targets of rice. Dev **et al.** (1978) reported that the nutrient requirement (NR) in kg to produce one quintal of rice grain in respect of N, P_2O_5 and K_2O were 2.11, 0.75 and 4.41, respectively. Prediction equations were also developed with respect to soil test P (Murugesa Boopathi, 1988; Moody **et al.**, 1990) and P and K (Hartzog and Adams, 1988). Based on the quadratic polynomial surface function for blackgram, Murugesa Boobathi (1988) calculated that the amount of P_2O_5 required was 68 kg ha^{-1} and 44 kg ha^{-1} when the P source was superphosphate and DAP respectively. Hartzog and Adams (1988) worked out the requirement of fertilizer P_2O_5 and K_2O for groundnut to be 56 kg ha^{-1} and 90 kg ha^{-1}, respectively, based on initial soil test values. Milapchand **et al.** (1986), besides establishing quantitative relationship between yield and soil test based fertilizer requirement for greengram, prepared ready reckoners for recommending fertilizer doses for soils with different soil test values, for varying yield targets of greengram.

2.4. Approaches for fertilizer prescriptions

To prescribe precise fertilizer recommendations, an accurate appraisal of fertility status is a prerequisite for which it has to be ably backed up by a repository of response information with an added emphasis on cost benefit details. The prime aim of soil fertility evaluation is to obtain higher yields and maintenance of soil fertility through balanced fertilization. Soil testing evaluation has been attempted through several approaches by soil scientists. The approaches developed for fertilizer prescriptions are briefly reviewed here under.

2.4.1. Soil analysis and correlation

This approach comprises the estimation of available nutrient concentration of soil by employing standard procedures and classifying their status as very low, low, medium, high and very high (Muhr **et al.**, 1965 and Perur **et al.**, 1973). Based on soil testing, fertilizer doses are recommended arbitrarily on an adhoc basis and this method requires further refinement.

2.4.2. Plant analysis for foliar diagnosis

In this approach, crops growing on a soil are used as biological indicators for assessing the soil fertility level (Malavolta **et al.**, 1960). In this case only a part of the plant is analysed for nutrient concentration and based on that the fertilizer doses are recommended. Clement (1961) reported that the foliar analysis has been successful for long duration crops like sugarcane, banana and perennial trees like rubber, coconut etc. However, it has very little applicability in the case of short duration crops.

2.4.3. Nutrient indexing system

Parker **et al.** (1951) proposed this concept. This has been found to be useful in formulating area wise recommendations and for making comparison of fertility status of different areas. In this concept, the samples with low fertility class are given weightage of 1, those of medium class 2, and the high class samples 3. The nutrient index is arrived at by multiplying the number of samples, in each class by the respective weightage for that class.

Totalling the three class sums thus arrived and dividing it by the number of samples analysed, the nutrient index is obtained.

$$\text{Nutrient index} = \frac{(N\ \text{low} \times 1) + (N\ \text{medium} \times 2) + (N\ \text{high} \times 3)}{\text{Total number of samples}}$$

Where N is the number of samples. The nutrient indices are calculated separately for individual nutrients. A nutrient index value of less than 1.67 indicates the low fertility status while the value more than 2.33 indicates high fertility status and the value between 1.67 and 2.33 is considered to be medium fertility class.

2.4.4. Agronomic approach

In this approach, the optimum fertilizer dose is worked out based on the crop response to applied fertilizer. Patil and Shah (1983) reported that sunflower responded upto 30 kg N ha^{-1} and it was the effective, economical and registered the highest seed yield. According to Mane **et al.** (1989) the response of sunflower varieties (BSH-1, Morden and EC-68414) to nitrogen was found to be linear upto 100 kg ha^{-1}. Chaniara **et al.** (1989) concluded that highest seed and stover yields of sunflower were recorded at 80 kg N ha^{-1} and there was no response beyond that level. Sagare **et al.** (1990) revealed that application of sulphur upto 40 kg ha^{-1} increased the seed yield of sunflower in Typic Chromusterts soil.

Gangadhara **et al.** (1990) reported that application of sulphur at 10 kg ha^{-1} along with N, P, K (37.5:50:37.5 kg ha^{-1}) produced the highest seed yield. According to Kameswara Rao and Gangasaran (1991), application of 80 kg N ha^{-1} and 25 kg S ha^{-1} were optimum for higher seed and stalk yield. Sarmah **et al.** (1992) inferred that application of medium fertilizer dose (60 kg N + 30 kg P_2O_5 ha^{-1}) was comparable with the highest fertilizer dose (80 kg N + 40 kg P_2O_5 ha^{-1}). Sreemannarayana and Sreenivasa Raju (1994) reported that total seed and stalk yield of APSH-11 and Morden showed increasing trend upto 40 kg S ha^{-1} and decreased at 60 kg.

2.4.5. Critical level approach

This concept is based on the fact that if the soil test value is below the critical level, the possibility of response is greater and vice-versa. Cate and Nelson (1965) detailed their procedure initially with a scatter diagram involving soil test value, the percentage yield and an overlay for partioning for fixing of the critical value. The same authors later in 1971, refined their technique through computer programme. This approach can only provide information on the profitability of response and not on the actual yield. Hence, the utility of this approach for individual situations is limited. Agboola and Ayodele (1987) found that the critical nutrient level and calibration obtained with Cate and Nelson technique for soil P in maize crop was better than the quadratic and Mitscherlich function. However, by using this approach exact fertilizer recommendation is not possible.

2.4.6. Fertility capability classification

This concept was proposed by Buol (1972) and further developed by Buol **et al.** (1975) and later modified by Sanchez **et al.** (1982). This system involves three categories ie., type, substrata type and modifiers. The category modifiers account for physical and chemical properties of plough layer and decide the specific fertility limitation. Type accounts for soil texture in the 20 cm depth and substrata type considers the soil texture in 20-50 cm depth. This system enunciates the fertility scientists to group experimental site that respond to similar soil fertility management practices. This approach was successfully verified by Lin (1984,1985) and Denton **et al.** (1987) and the same was found to be useful for rice soils of India (Shinde, 1987).

2.4.7. Inductive approach

This concept was developed by Ramamoorthy (1968). This involves creation of large variations in soil test values in one and the same field in a particular locality and then superimposing the complex soil fertility evaluation trial in the same field to deduce response information. This helps to minimise the variations caused due to uncontrollable factors like climate and management. This approach was further modified by Ramamoorthy and Velayutham (1971) and is being followed in the All India Coordinated Soil Test Crop Response Correlation Project of the Indian Council of Agricultural Research.

2.4.8. Deductive approach

This approach developed by Colwell (1968) involves the conduct of multilocational trials scattered over a larger area. The experimental data are pooled and utilised to establish the soil test crop response correlation. Based on the regression of yield with fertilizer doses and their interactions, the fertilizer doses were adjusted in accordance with soil test values. Significant relationships have been established under this approach, for different crops like rice, wheat, ragi, maize, groundnut, gingelly soybean etc., all over India.

2.4.9. Mitscherlich - Bray approach

The most useful concept for guiding the fertilization is that of a ceiling of production was first conceived by Mitscherlich (1909) in the law of subproportional yields. Later, Bray (1954) incorporated soil as well as fertilizer efficiency in the Mitscherlich equation and modified it. The modified Mitscherlich-Bray approach has wide applicability and this concept is expressed in the form of an equation as

$$\log (A-Y) = \log A - C_1 b - C x$$

Where A represents maximum yield

Y is the yield produced by a given quantity of x

b is soil nutrient level

x is fertilizer nutrient level

C_1 and C represents the soil and fertilizer nutrient efficiency coefficient

This method has been found to be useful for predicting yield response and fertilizer requirement based on soil test values (Dhanapalan Mosi **et al.**, 1979; Venu Reddy **et al.**, 1979 and Moody **et al.**, 1990). However, this method does not take into account of the nutrient interaction and is not possible for assessing maximum yield.

2.4.10. Targetted yield approach

This principle of prescribing fertilizer recommendations for different yield targets, soils and climatic conditions was outlined by Truog (1960) and has evoked considerable interest in India (Ramamoorthy **et al.**, 1967 and Aggarwal and Ramamoorthy, 1978). This procedure takes into account the nutrient requirement (NR) of a crop for the production of unit quantity of economic produce, the efficiency of nutrient contribution from soil (Cs) by a given soil test and the efficiency of nutrient contribution from the added fertilizer (Cf). These three parameters are used to relate yield target (Y) with soil nutrients (S) and fertilizer nutrients (F) :

$$F = \frac{1}{Cf} (NR)\ Y - CsS$$

Among the various methods of formulating fertilizer recommendation, the one based on yield targetting is unique, in the sense that this method not only involves soil test based fertilizer dose, but also the level of yield that the farmer can hope to achieve if good agronomy is followed in raising the crop (Velayutham, 1979).

Fertilizer prescription equations for desired yield target of rice, cotton, sorghum, groundnut and soybean were derived by Rani Perumal **et al.** (1982). Similar studies had also been made by Murugappan (1985) on sugarcane, Murugesa Boopathi (1988) on maize, Sumam (1988) on maize-sugarcane cropping system, Jaiswal (1989) on sorghum-blackgram-cotton cropping sequence, Natarajan (1991) on rice-groundnut-blackgram cropping sequence and Shanmugam (1992) on cotton-maize cropping sequence.

2.5. Role of response models in predicting fertilizer requirements of crop

A 'response model' has a characteristic shape and is defined by a mathematical expression of a particular form with suitably restricted coefficient (Wimble, 1980). Methods of fitting mathematical models to experimental data are detailed in many books on statistics (Snedecor and Cochran, 1973; Goulden, 1952; Heady and Dillon, 1972). FAO, (1966) has published the most comprehensive work in the subject and which deals with all the main aspects of crop response to fertilizers, from the design of experiments to the fitting of the models and economics of fertilizer use.

Application of response curves to the planning of experiments and the superiority of these models over simple estimates like response per kg of fertilizer was well illustrated by Finney (1953). This study further illustrated the use of P response curves to determine the most profitable dressings, defined as the level giving highest net profit.

Several mathematical models can express the well established law of diminishing return which states that yield increases diminish for each additional dose of fertilizer. The most commonly used are the exponential, Mitscherlich, square root and quadratic models. The Mitscherlich model adds constant to the logarithmic function to adjust the interpretation of fertilizer response in accordance with variations in native soil fertility and require very complex calculations and shows that yield increases tends towards an asymptote which would be the maximum potential of the crop (Pimental Gomes, 1953). The other two models viz., quadratic and square root, state that yield increase with fertilizing up to a maximum beyond which any additional application depresses production. Neeteson and Wadman (1987) reported that curve fitting is subjective and time consuming. They reevaluated the results of the fertilizer trials by determining the response curves on the basis of mathematical function. Their study elucidated that the modified exponential form was much better than quadratic form when the residual sum of squares was taken as measure of degree of fit. These two models have been compared by a number of workers who found that the quadratic model tends to yield greater estimates of optima (Boyd **et al.**, 1976). Guinard (1982) reported that quadratic model is preferred over other models because of its mathematical simplicity allowing a more detailed economic analysis and its closer fit to the data eventhough this function is not a precise expression of a complicated biological process. Wimble (1980) indicated four important features of a fertilizer response model and these are (1) the slope of rising part, (2) the slope past the peak, shown as declining though it may reach a plateau or even rise, (3) the yield near the optimum dressing and (4) approximate fixation of optimum dressing itself. These four quantities can, in principle, vary independently of each other and a good response model must have sufficient flexibility to cope with this. The models such as inverse quadratic, modified exponential and two straight lines are all four parameter ones. Comparison between these models for fitting fertilizer response in cereal experiments by Boyd **et al.** (1976) revealed that the optima estimated from these models did not differ greatly from average. The two straight line models have peculiar properties of yielding a simple optimum over a wide range of cost:value ratios determined by the turning point.

Among the algebraic forms, Cobb-Douglas function has been the most popular one, as it allows either constant increasing or decreasing marginal productivity (Heady **et al.**, 1972). It provides a compromise between adequate fit of the data, computational feasibility and sufficient degrees of freedom unused to allow for statistical testing. In other words, Cobb-Douglas function is relatively "efficient user" of degrees of freedom. It also implies that atleast some quantity of each input must be used if output is to be non zero or otherwise difficulty will arise in the conversion of raw data to logarithmic form, the logarithm of zero being minus infinity. Hence the zero inputs are usually replaced by some figure of arbitrary small size.

Middleton (1983) proposed a hypothetical model as a general solution to the problem of estimating an optimum fertilizer rate for crop and is termed "Mitscherlich - Liebig". This model combines the ideas of Liebig Mitscherlich, Baule and Spillman and proposes pooling of response data according to a relative yield theory and the Baule unit concept, rather than grouping data according to a soil type theory. For this model, soil tests are unnecessary since such fertility is quantified through a parameter B in the equation itself. Murugappan **et al.** (1989a) observed that the conventional detection procedure of computation of soil (α) and fertilizer (β) nutrient efficiencies for the amount of fertilizers required for specified yield targets does not take cognizance of the amount of soil nutrient derived from the available pool of soil nutrient. The results proved the superiority of assessing nutrient requirement for specific yield targets of sugarcane over the conventional method.

Wood **et al.** (1985) proposed transfer models with controlled and uncontrolled site factors. These models help in extrapolation of response input relationship estimated from experimental situations to other similar situations.

Jansen and Wolf (1987) developed a simple equation for calculating the residual effect of phosphorus fertilization.

$$Rt = (0.8 - Rl)^{t-1} * R - 1,$$

Where Rt and R_1 are the recovery fractions in years t and 1.

Probert (1985) proposed a model for assessing initial and residual response to phosphorus fertilizers. Lekha and Palaniappan (1988) introduced certain modifications in this model and calculated the effective phosphorus (PE) for the first crop (PE_1), second crop (PE_2) and third crop (PE_3) of rice-rice-greengram sequence. The effective phosphorus values were then related to drymatter yield, grain yield and P uptake in the three crops using linear and Mitscherlich equation.

Muthusamy **et al.** (1990) developed a mathematical model for predicting soil N Status, under varying fertilizer practices in a continuous cropping sequence. The model takes the formula,

$$St = St-1 + Ft - Ut + E$$

where St is the available nutrient level in the soil at the end of the t^{th} crop, St-1 is the available nutrient level in the soil before sowing of t^{th} crop, Ft is the applied fertilizer nutrient for the t^{th} crop, Ut is the uptake of this nutrient by t^{th} crop and E is the average nutrient level that is built up in (+E) or depleted from (-E) the soil due to factors other than those considered in the balance equation. The model was applied to six years nitrogen availability data of four fertilizer practices in fingermillet-maize-cowpea sequence. The agreement between the predicted soil nitrogen status by the model and the actual was proved by employing reliability index.

Though several models have been proposed in soil fertility and crop response studies, none of them gained wide acceptance because of the fact that which is strictly appropriate. It can be only be answered in terms of logic, economic, physical or biological underlying the production process being examined.

In an attempt to predict the post-harvest soil test values by relating the pre sowing soil test values, fertilizer doses added and yield/uptake of sorghum and blackgram, Balasundaram (1978) obtained reliable relationship in both the crops only in the case of phosphorus. The consequences of depletion or built up in soil fertility for rice-wheat and bajra-wheat cropping system in alluvial soils of Delhi with indicated yield targets and fertilizer use have been reported by Velayutham and Singh (1981). These works openup new vistas of research and informations on the built up and depletion patterns of various nutrients, will have to be generated for making sound fertilizer recommendation for sunflower crop.

2.6. Response studies on sunflower

2.6.1. Effect of nitrogen

2.6.1.1. Drymatter production

Smith **et al.** (1988) observed that urea application had no effect on drymatter production during the first 39 days after application, but gave increase of 24 percentage at harvest. Goswami and Srivastava (1988) stated that foliar application of urea at 0.5 per cent level during different stages of growth particularly after flowering retarded the loss of chlorophyll in both upper and lower levels of sunflower and increased their photosynthetic rate by stimulating ribulose 1,5 biophosphate carboxylase activity and by reducing leaf diffusive resistance.

Sankpal and Mahalle (1991) opined that the application of 60 kg nitrogen to a clay loam soil recorded the highest yield. Kharwara and Bindra (1992) reported that application of nitrogen upto 90 kg ha^{-1} increased the plant height, leaf area index, number of primary and secondary branches and drymatter production.

2.6.1.2. Seed yield and yield attributes

Application of nitrogen has a definite role in influencing the yield attributes of sunflower like head diameter, number of filled seeds/head, thousand seed weight and seed yield.

Rao and Reddy (1982) inferred that application of nitrogen 60 kg ha^{-1} at sowing and 30 kg ha^{-1} as top dressing registered the highest yield. According to Sabale and Jadher (1983), application of 50 per cent of nitrogen at sowing and the remainder in three foliar sprays at 30, 40 and 50 days after sowing recorded higher yield. Steer and Hocking (1983) observed that application of lower dose of nitrogen decreased final leaf number and floret number.

Singh and Quadri (1984) did not observe any difference between single dressing and 2-3 split dressings of N in increasing the seed yield.

According to Sarkar (1985), application of 80 kg N ha^{-1} along with lime in acid lateritic sandy loam soil recorded the highest yield when compared to application of nitrogen without lime. Sagare **et al.** (1986) opined that application of nitrogen along with foliar spray of 1.5 per cent urea and 0.5 per cent diammonium phosphate 30, 40 and 60 days after sowing gave higher yield of 1.57 t ha^{-1}. Application of nitrogen more than 90 kg ha^{-1} increased the percentage of hollow seeds and reduced the seed yield (Ogunremi, 1986). Singh **et al.** (1987) found that increase in yield was significant only upto 80 kg N ha^{-1}.

Sharma and Gaur (1988) reported that drilling of nitrogen 5 cm below the seed recorded the highest yield of 2.19 t ha^{-1}.

Chaniara **et al.** (1989) stated that the highest yield was obtained with 80 kg N ha^{-1} but its effect varied with number of irrigation. El-Naggar and Allam (1991) revealed that application of nitrogen significantly increased the seed yield (Ujjinaiah **et al.**, 1989; Uppar and Kulkarni, 1989).

Bhola and Faroda (1990) found that application of 60 kg N ha^{-1} increased the yield by about 25 per cent and 80 kg decreased the yield by about eight per cent.

Sankpal and Mahalle (1991), Manoharan **et al.** (1991), Hirary **et al.** (1992) and Wagh (1992) obtained similar results. Ram **et al.** (1992) inferred that application of 40 kg N resulted in higher capitulum diameter, 1000 seed weight and seed yield. Ulemate **et al.**(1991) and Lewis **et al.** (1991) reported that there was no difference in yield while comparing the applications of nitrogen at 40 kg and 60 kg ha^{-1} .

2.6.1.3. Protein and oil contents

Nitrogen plays an important role in the seed protein and oil content. Palanivel and Ramanathan (1981) and El-Sayed **et al.** (1984) reported that application of higher levels of nitrogen had a depressing effect on the oil content and favourable effect on protein content.

Maheswarappa **et al.** (1985) found that nitrogen at 120 kg ha^{-1} favoured an increase in protein content and a non-significant decrease in oil content. Sagare **et al.** (1986) concluded that foliar application of urea and DAP did not significantly influence oil content of seeds.

Tripathi and Sawhney (1989) concluded that nitrogen application increased protein content and decreased oil content.

According to Ujjinaiah **et al.** (1990) application of 45 kg N ha^{-1} registered the highest oil content of 41.81 per cent, beyond which it decreased the oil content. Kene **et al.** (1990) found that application of nitrogen at 40 kg ha^{-1} along with foliar application of 2 per cent ammonium dihydrogen orthophosphate resulted in the highest oil concentration when compared with water spray.

Manoharan **et al.** (1991) concluded that application of 50 per cent of nitrogen at sowing, 25 per cent at 21 days after sowing and 25 per cent at 45 days after sowing registered the highest oil and protein content.Hiremath **et al.** (1991) reported that application of nitrogen (60 kg ha^{-1}) adversely affected the oil content .

2.6.1.4. Nutrient content and uptake

Li **et al.**(1984) reported that the N, P, K ratios needed by matured plants were 4.7:1:11. Peak N uptake occurred one at budding and another at flowering. According to Sarkar (1985), application of nitrogen @ 80 kg ha^{-1} favoured the N,P and K uptake in acid lateritic sandy loam soil.

Steer **et al.** (!986) reported that N content of the separate organs were not affected by plant density but were increased by higher N application rates. The amount of N accumulated in different plant parts was as below, seed 30-36% > Flower disc 20-21% > leaves 18-22% > Stalks 11-16% > roots 9-15%.

Homenauth **et al.** (1986) opined that there was response to N fertilizer application when inorganic nitrogen content was less than 50 kg ha^{-1}.

According to El-Shinnawi **et al.** (1988) application of nitrogen increased aminobutyric acid, aspartic acid, glycine, methionine and serine content in plant but decreased leucine, phenyl alanine, hydroxy proline and tyrosine. Smith **et al.** (1988) concluded that 24 g N m^{-2} was recovered at maturity in the above-ground biomass and loss could be reduced by delaying the bulk of N application to coincide with the period of rapid plant uptake.

Tripathi and Sawhney (1989) reported that N uptake increased with N application and P and K uptake increased only upto 20 kg N ha^{-1}. El-Shinnawi **et al.** (1990) noted that application of Ca $(NO_3)_2$ gave highest NO_3-N in plants.

Hiremath **et al.** (1992) and Khokhani **et al.** (1993) opined that application of nitrogen increased nitrogen content in leaf and stem, total N uptake and also P content and uptake.

2.6.2. Effect of phosphorus

2.6.2.1. Drymatter production

Devasundaram (1976) reported that higher level of phosphorus (30 and 50 kg ha^{-1}) significantly increased the total drymatter at harvest.

Dravid and Goswami (1988) in their ^{32}P labelled studies found that application of P increased drymatter yield at salinity level of 10.6 dSm^{-1}. Sakra **et al.** (1990) reported that application of monocalcium phosphate recorded the highest drymatter yield. Lewis **et al.** (1991), Hibberd **et al.**(1991) and Ateeque **et al.** (1992) stated that application of P increased drymatter production.

2.6.2.2. Seed yield and yield attributes

Palanivel and Ramanathan (1981) stated that application of 60 kg P_2O_5 ha^{-1} registered the highest seed yield. El-Sayed **et al.** (1984) observed that application of phosphorus increased plant height, stem diameter, head diameter, 1000 seed weight and seed yield.

Sagare **et al.** (1986) noted that application of 30 kg P_2O_5 ha^{-1} along with 0.5 per cent DAP spray resulted in a seed yield of 1.57 t ha^{-1}.

Chaniara **et al.** (1989) reported that application of P_2O_5 upto 60 kg ha^{-1} significantly increased the yield. Naphade and Naphade (1991) reported that application of P (80 kg ha^{-1}) increased root CEC, root length, root weight and seed yield.

Ateeque **et al.** (1992) concluded that boronated superphosphate (90 kg ha^{-1}) produced the highest seed yield among the different sources of P. Jones Nirmalnath and Sreenivasa (1993) opined that inoculation of P solubilizing bacteria along with superphosphate application increased the plant height, seed yield and oil content.

2.6.2.3. Protein and oil contents

Mukundan (1972) reported that application of phosphorus (75 kg ha^{-1}) increased the oil content. Srivastava (1978) obtained the highest seed crude protein (26.2 per cent) and lipid (45.8 per cent) contents by application of 60 kg phosphorus ha^{-1}.

According to Maheswarappa **et al.** (1985) application of phosphorus 30 kg ha^{-1} increased protein content and had no effect on oil content. Maatouk and El-Latif (1985) and Sagare **et al.** (1986) also reported similar results.

Application of 160 kg P_2O_5 ha^{-1} increased oil content by about 0.83 per cent (Tarakeswara Rao **et al.** 1989). Ujjinaiah **et al.** (1989) opined that application of 80 kg P_2O_5 ha^{-1} decreased oil content.

Kene **et al.** (1990) found that application of 60 kg P_2O_5 ha^{-1} at sowing and foliar application of 2 per cent ammonium dihydrogen orthophosphate at flowering resulted in higher seed oil content. El-Naggar and Allam (1991) and Hiremath **et al.** (1991) stated that application of phosphorus increased the oil content and seed protein.

2.6.2.4. Nutrient content and uptake

According to Li **et al.** (1984) the amount of P accumulation in different plant parts was as below. Seed (38-42%) > flower (25-27%) > leaves (17-19%) > Stalks (7-8%) > roots (8%) and peak uptake occurred at ripening.

Dravid (1989) reported that application of P increased N, P and K contents. Diammonium phosphate was significantly better than simple superphosphate with respect to total P absorption and utilization of fertilizer P. Sakra **et al.** (1990) opined that application of monocalcium phosphate gave highest Zn, P content and Zn uptake in alluvial and calcareous soils.

According to Hiremath **et al.** (1992), application of P did not increase the N content in leaf and stem but increased the P content and uptake. Boronated superphosphate increased plant and seed N, P and B(Ateeque **et al.**, 1992). Jacob and Lawlor (1993) concluded that phosphate deficiency decreased the amount of ATP and ADP per unit leaf area.

2.6.3. Effect of sulphur

Oil seed crops like sunflower, mustard, soybean and groundnut have high sulphur requirement as their oil storage organs are mostly rich in protein containing sulphur (Subbiah and Singh, 1970).

2.6.3.1. Drymatter production

Hocking **et al.** (1987) stated that application of sulphur resulted in a large increase in drymatter production at the end of floret initiation and decreased supply at the end of floret initiation reduced drymatter production by about 17 per cent.

Sreemannarayana and Sreenivasaraju (1994) reported that drymatter yields at star, bud, flowering and maturity stages were influenced by the sources and levels of sulphur.

2.6.3.2. Seed yield and yield attributes

Channel and Balakrishna Rao (1981) recorded increased seed and oil yield upto 20 kg S ha^{-1} along with a basal dose of NPK. Application of S gave the ratio of filled seed to unfilled seed of 11.2 as against the ratio of 6.5 in control. Muthuvel and Rajukkannu (1983) inferred that application of sulphur had no significant effect on seed yield in soils containing 15 ppm available sulphur.

Badiger **et al.** (1985) opined that application of graded levels of sulphur had no significant effect on yields in acid soils dominated by kaolinitic clay mineral.

Application of sulphur at 25 kg ha^{-1} increased the seed yield by 38 per cent in Karnataka, while in Rajasthan higher rates were required to regulate a yield increase of 12 to 13 per cent (Tandon, 1986).

Hocking **et al.** (1987) opined that increased S supply from a deficient to adequate state resulted in five fold increase in seed yield per plant and oil concentration was not affected. They also reported that in S deficient plant nitrate reductase activity decreased from 0.11 to 0.09 mg.

Tiwari (1989) observed a 21.1 per cent increased seed yield by the application of 30 kg S ha^{-1}. Kene **et al.** (1990) stated that foliar application of 0.05 per cent copper sulphate or zinc sulphate or 1% magnesium sulphate increased the seed yield. Gangadhara **et al.** (1992) recorded the highest seed yield (1.92 t ha^{-1}) by the application of 50 kg $ZnSO_4$ or $FeSO_4$ or 25 kg $MnSO_4$ ha^{-1}.

According to Prabhuraj **et al.** (1993) 10 ppm of S promoted the growth, height, head diameter, 1000 seed weight, seed and oil yield in P and S deficient soil.

2.6.3.3. Protein and oil contents

Revenko (1977) reported 6.7 per cent increase in oil content when sulphur was applied along with N and P. Raut and Ghonsiker (1978) concluded that in calcareous soil sulphur application @ 75 kg ha^{-1} was beneficial to raise the oil content.

According to Ajab Singh Yadav and Harishankar (1980) sulphur and boron application increased the oil and protein contents. Foliar spray of 0.1 per cent sulphuric acid was effective in increasing oil content from 41.14 to 43.08 per cent (Singh and Sahu, 1986).

Prabhuraj (1988) obtained a significant increase in oil content when sunflower cultivar KBSH-1 was applied with sulphur at 10 ppm. Sagare **et al.** (1990) stated that application of sulphur (40 kg ha^{-1}) recorded highest oil content.

2.6.3.4. Nutrient content and uptake

Hilton and Zabriski (1983) found that application of sulphur increased the uptake of B, Zn and Mn. According to Badiger **et al.** (1985), application of sulphur increased the concentration of sulphate and heat soluble forms of sulphur in the soil.

Chandrashekhar and Reddy (1987) reported that total water soluble sulphur and sulphate sulphur contributed considerably to the pool of sulphur in acid soils and available S to sunflower.

According to Hocking **et al.** (1987), seeds were much less responsive to S supply when compared to vegetative organs. He also reported that ratios of N to S concentrations decreased with increasing S supply.

Application of sulphur increased SO_4-S, Zn, Fe, Mn and Boron contents in the 4^{th} leaf from the top and increased uptake of SO_4-S, Zn, Fe and Ca in the seed. Sagare **et al.** (1990) observed higher N, P and K uptake with sulphur application.

From the above review it is clear that the effect of N,P and S on the seed and oil yield of sunflower has to be investigated employing Soil Test Crop Response Correlation Studies for giving rationalised fertilizer recommendation for a desired yield targets based on fertilizer prescription equation. In this context only the present investigation was undertaken.

EXPERIMENTAL DETAILS

CHAPTER III

EXPERIMENTAL DETAILS

The details of field experiments conducted and the methods of analysis of soil and plant samples are presented in this Chapter.

3.1. Field experiments

The field experiments were conducted at the 'T' block of Agricultural Research station, Bhavanisagar, Tamil Nadu Agricultural University, during 1993 and 1994.

3.1.1. Location

This Station is located at $11^{\circ}29'$ North latitude, $77^{\circ}8'$ East longitude and at an altitude of 256 m above m.s.l. The farm is irrigated by canals from Lower Bhavani Project.

The total ayacut area of Lower Bhavani Project (LBP) is 83,000 hectares. The major portion of ayacut lies in Sathyamangalam, Gobichettipalayam, Erode, Bhavani and Dharapuram taluks of Periyar district and a small extent in Karur taluk of Trichy district.

3.1.2. Soil

The soils of the ayacut belong to Irugur, Sathyamangalam, Kodiveri, Syamalakavendenpudur, and

Kallivalasu series. Among the soils, Irugur series (Inceptisols) occupies an area of 53, 120 hectares and it is regarded as the benchmark soil series of LBP command area, occupying 64 per cent. The present study was therefore, conducted in a soil belonging to Irugur series at Agricultural Research Station, Bhavanisagar for enabling the transfer of research results to the farmers of LBP area.

3.1.3. Climate

The normal climate in the study area is as follows. The mean annual rainfall is 685 mm. The mean maximum and minimum temperatures are 31.9^{o}C and 21.1^{o}C, respectively. The relative humidity ranges from 63 per cent to 72 per cent. The evaporation ranges from 4.4 to 9.7 mm with a mean of 6.4 mm. The sunshine ranges from 5.3 to 9.6 hours per day.

A total rainfall of 439.9 mm was received during the cropping period. The meteorological data recorded during the cropping period are presented in Table 1.

3.1.4. Soil of the experimental site

The soil of the experimental area has been developed from the sedimentary rocks of varying composition. The effect of climate, topography and the parent material are fully reflected in the soil. A profile in the experimental site was dug open up to the parent material and

Table 1. Meteorological data recorded during the cropping period

Sl.No.	Month and year	Temperature (^{o}C)		Relative humidity (%)	Rainfall (mm)	Evaporation (mm)	Sunshine hours per day
		Max.	Min.				
1.	August 1993	34.2	21.8	69.8	31.4	7.1	6.3
2.	September 1993	35.0	20.4	72.0	35.2	8.3	7.2
3.	October 1993	32.0	22.5	72.0	125.0	4.5	6.1
4.	November 1993	29.5	20.5	69.0	136.1	4.4	5.3
5.	December 1993	29.0	20.4	63.0	47.4	4.0	5.5
6.	January 1994	29.5	19.9	66.6	43.4	6.1	6.9
7.	February 1994	31.9	21.8	65.2	21.4	7.3	8.3
8.	March 1994	34.7	22.0	63.3	Nil	9.7	9.6

described morphologically as per the guidelines for the profile description (FAO, 1966). The details are furnished in Figure 1.

The soil of the experimental area was sandy clay loam in texture, neutral in reaction (6.8 to 7.2) and medium in electrical conductivity (0.2 dSm^{-1}). The soil was low in available nitrogen (170 kg ha^{-1}) and organic carbon (0.4%), medium in phosphorus (18 kg ha^{-1}) and high in potassium (286 kg ha^{-1}).The available magnesium and calcium contents were 0.15 and 0.94 per cent respectively.

3.1.5. Field layout

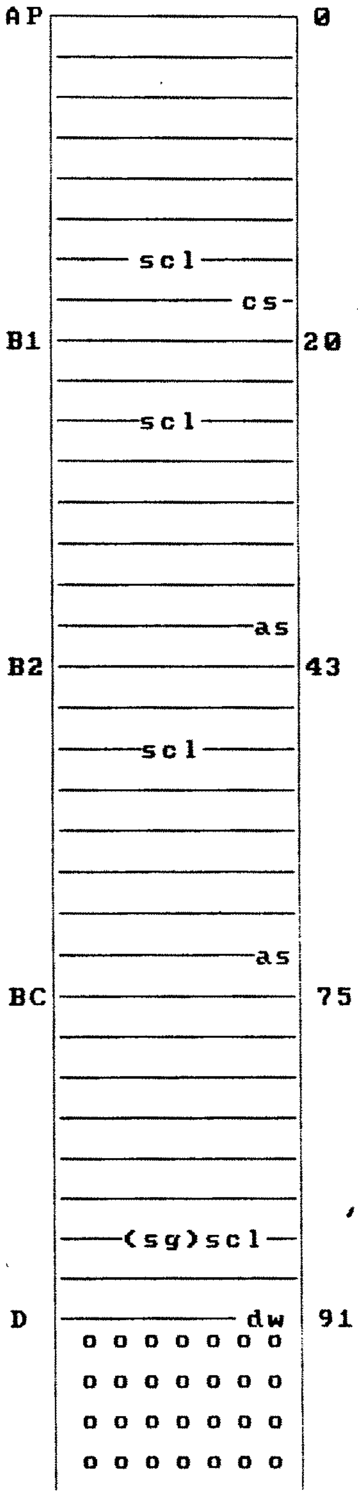
The experiment was laid out in fractional Factorial Randomised Block Design, confounding certain treatments.

3.1.5.1. Nutrient content of fertilizers

The nutrient content of the fertilizers used are given here under.

Urea	-	46% N
Superphosphate	-	16% Water soluble P_2O_5 and 18% total P_2O_5
Muriate of potash	-	60% k_2O
Gypsum	-	20.51% S

FIG.1 PROFILE DESCRIPTION



AP (0): Dark red (2.5YR3/6) moist;sandy clay loam; massive; Slightly sticky and Slightly firm moist; few coarse and medium, common fine pores; common, medium and fine roots, moderately rapid permeability;Clear smooth boundary.

B1 (20): Dark reddish brown, (2.5YR3/4) moist, Sandy clayloam; massive; Slightly firm moist; few medium and common, fine pores; very few, fine and very fine roots; moderate permeability; abrupt smooth boundary.

B2 (43): Dark red (2.5YR3/6) moist; Sandy clay loam; massive; Slightly firm moist; few medium and common fine pores; very few, fine and very fine roots; moderate permeability; abrupt smooth boundary.

BC (75): Dark red (2.5YR3/6) moist; (Slightly gravelly) Sandy clay loam; massive; Slightly sticky and Slightly firm moist; few, medium and fine pores; very few, fine and very fine roots; moderate permeability; diffuse wavy boundary.

D (91): Bed rock (granite gneiss)

3.1.5.2. Exhaust Crop

Prior to growing of test crop, the selected field of 2000 m^2 was partitioned into 4 strips of size 500 m^2 each. Variations in fertility of the strips were created adopting the methodology followed in the All India Coordinated Soil Test Crop Response Correlation Project (Ramamoorthy, 1968) by applying graded doses of fertilizers to each strip as listed in Table 2. The P_1 level of 138 kg ha^{-1} was fixed as equal to the phosphorus desorption index in phosphorus fixation studies.

An exhaust crop of maize (**Zea mays** -Var.Co 1) was sown on 11.8.93 adopting a seed rate of 20 kg ha^{-1} and a spacing of 60 cm row to row and 20 cm seed to seed within the row. The seeds were treated with agroson before sowing at the rate of 2 g kg^{-1} of seeds. All the routine cultural operations were followed and the crop was harvested at tasseling stage on 21.10.93.

3.1.5.3. Test crop

After the harvest of maize crop, each strip was subdivided into 24 plots of equal size. Twenty four treatments listed in the table 4 were superimposed randomly over the blocks as shown in Fig. 2.

Nitrogen was applied as urea in 2 equal splits, one at basal and another at 30^{th} day after sowing. Entire

Table 2. Graded doses of fertilizers applied to the exhaust crop of maize (kg ha^{-1})

Strip	Levels of fertilizers	In terms of nutrients N	P	S
I	$N_0P_0S_0$	0	0	0
II	$N_{1/2}\ P_{1/2}\ S_{1/2}$	45	69	25
III	$N_1P_1S_1$	90	138	50
IV	$N_2P_2S_2$	180	276	100

quantity of phosphorus (SSP) and sulphur ($CaSO_4$) were applied as basal. All the plots received K_2O at the rate of 40 kg ha^{-1}. Normal cultural operations such as weeding, earthingup, spraying against pest and diseases were takenup at the appropriate time as per the schedule recommended for the crop and the important characters of sunflower crop (MSFH-8) are presented in Table 3.

3.1.5.4. Seeds and sowing

Sunflower (**Helianthus annuus** L.) MSFH-8 seeds were dibbled with a spacing of 60cm between rows and 30cm between seeds on 25.11.93. Two seeds were dibbled at each point.

3.1.5.5. Gap filling and thinning

Gap filling and thinning was done within 10 days of planting.

3.1.5.6. Harvesting and threshing

The crop was harvested on 9.3.94 leaving border rows. The earheads were separated from the stover and the weights were recorded. The dry weight of stover was also recorded. The earhead were threshed mechanically, cleaned and dry weights were recorded.

3.2. Collection of soil samples

The initial soil sample was collected from the field before the commencement of experiment. The surface

Table 3. Important characters of sunflower crop

Sl.No.	Characteristics	MSFH-8
1.	Days to 50 per cent flowering	55-65 days
2.	Total duration	90-94 days
3.	Average height of plant	180-190 cm
4.	Size of flowers	Large
5.	Oil content in seeds	37-44%
6.	Weight of 100 grains	4 to 5 g
7.	Yield per hectare	20-25 q
8.	Seed setting	Excellent

FIG 2. FIELD LAYOUT PLAN SHOWING THE TREATMENT COMBINATIONS

STRIP I		STRIP II		STRIP III		STRIP IV	
$N_3P_3S_0$	$N_0P_0S_0$	$N_3P_0S_0$	$N_1P_0S_0$	$N_3P_1S_1$	$N_1P_1S_1$	$N_0P_0S_0$	$N_4P_2S_2$
$N_2P_2S_0$	$N_2P_0S_0$	$N_4P_2S_2$	$N_0P_0S_0$	$N_4P_3S_2$	$N_3P_3S_2$	$N_3P_0S_0$	$N_1P_1S_1$
$N_0P_0S_0$	$N_2P_0S_1$	$N_2P_2S_0$	$N_0P_0S_0$	$N_4P_2S_1$	$N_3P_3S_1$	$N_2P_1S_1$	$N_3P_3S_2$
$N_4P_2S_2$	$N_1P_1S_0$	$N_4P_3S_1$	$N_1P_1S_0$	$N_2P_0S_0$	$N_3P_2S_2$	$N_2P_2S_1$	$N_0P_0S_0$
$N_2P_2S_1$	$N_2P_1S_1$	$N_2P_2S_2$	$N_1P_1S_1$	$N_2P_2S_0$	$N_0P_0S_0$	$N_3P_1S_1$	$N_0P_0S_0$
$N_4P_2S_1$	$N_0P_0S_0$	$N_2P_2S_1$	$N_2P_0S_1$	$N_3P_3S_0$	$N_2P_1S_1$	$N_4P_3S_2$	$N_3P_3S_0$
$N_2P_2S_2$	$N_3P_1S_1$	$N_3P_2S_2$	$N_0P_0S_0$	$N_0P_0S_0$	$N_4P_3S_1$	$N_2P_1S_0$	$N_2P_2S_0$
$N_2P_1S_0$	$N_4P_3S_2$	$N_4P_2S_1$	$N_2P_0S_0$	$N_3P_0S_0$	$N_0P_0S_0$	$N_3P_3S_1$	$N_2P_2S_2$
$N_0P_0S_0$	$N_3P_3S_1$	$N_3P_3S_2$	$N_2P_1S_1$	$N_0P_0S_0$	$N_2P_1S_0$	$N_2P_0S_1$	$N_1P_0S_0$
$N_3P_3S_2$	$N_3P_0S_0$	$N_3P_3S_1$	$N_3P_1S_1$	$N_2P_2S_1$	$N_1P_1S_0$	$N_0P_0S_0$	$N_3P_2S_2$
$N_4P_3S_1$	$N_1P_0S_0$	$N_4P_3S_2$	$N_3P_3S_0$	$N_4P_2S_2$	$N_1P_0S_0$	$N_1P_1S_0$	$N_2P_0S_0$
$N_1P_1S_1$	$N_3P_2S_2$	$N_2P_1S_0$	$N_0P_0S_0$	$N_2P_0S_1$	$N_2P_2S_2$	$N_4P_2S_1$	$N_4P_3S_1$

STRIP I STRIP II STRIP III STRIP IV

Table 4. Treatment structure

Treatment number	Treatment combination			Level of nutrients (kg ha^{-1})		
	N	P	S	N	P	S
1.	1	0	0	40	0	0
2.	1	1	0	40	20	0
3.	1	1	1	40	20	25
4.	2	0	0	80	0	0
5.	2	0	1	80	0	25
6.	2	1	0	80	20	0
7.	2	1	1	80	20	25
8.	2	2	0	80	40	0
9.	2	2	1	80	40	25
10.	2	2	2	80	40	50
11.	3	0	0	120	0	0
12.	3	1	1	120	20	25
13.	3	2	2	120	40	50
14.	3	3	0	120	60	0
15.	3	3	1	120	60	25
16.	3	3	2	120	60	50
17.	4	2	1	160	40	25
18.	4	2	2	160	40	50
19.	4	3	1	160	60	25
20.	4	3	2	160	60	50
21.	0	0	0	0	0	0
22.	0	0	0	0	0	0
23.	0	0	0	0	0	0
24.	0	0	0	0	0	0

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soil samples were collected after the harvest of gradient crop, before sowing of test crop and after the harvest of test crop.

The soil samples were air dried in shade, ground well with a wooden mallet, sieved through 2 mm sieve and stored in clean polythene bags. For the estimation of organic carbon, the sample was ground and sieved through 0.5 mm sieve.

3.3. Collection of plant samples

After recording the yield of grain and stover from individual plots, samples of stover and grain were collected separately from all the 96 plots. The samples were dried to a constant weight at 70° C in an electric oven. Then dried samples were powdered in a wiley mill and packed in butter paper cover for further analysis.

3.4. Analytical techniques

The procedures employed in the estimation of soil and plant samples are given in Table 5.

Table 5. Methods of soil and plant analysis

Sl.No.	Parameters	Method	Reference
A. Physical properties of soil			
1.	Mechanical fractions	International pipette method	Piper (1966)
2.	Moisture content	Gravimetry	A.O.A.C (1962)
B. Chemical properties of soil			
1.	Total nitrogen	Kjeldahl digestion	Jackson (1973)
2.	Total phosphorus	Perchloric acid digestion, colorimetry	Jackson (1973)
3.	Total potassium	Hydrochloric acid digestion, Flame photometry	Stanford and English (1949)
4.	Total sulphur	Potassium nitrate and nitric acid digestion	Chaudry and Cornfield (1966)
		Turbidimetry	Chesnin and Yien (1950)
5.	Total calcium	HCl extract - Versenate titration	Jackson (1973)
6.	Total magnesium	HCl extract - Versenate titration	Jackson (1973)
7.	Sesquioxide (R_2O_3)	Gravimetric method	Piper (1966)
8.	Iron oxide (Fe_2O_3)	Volumetric method	Piper (1966)
9.	Alumina (Al_2O_3)	Difference between sesquioxides and iron oxides	Piper (1966)
10.	$KMnO_4$-N	Alkaline permanganate	Subbiah and Asija (1956)

11. *Organic carbon*	*Chromic acid wet digestion*	*Walkley and Black (1934)*
12. *Olsen-P*	*Sodium bicarbonate method*	*Olsen* **et al.** *(1954)*
13. *Bray-P*	*0.03 N NH_4F + 0.025 N HCl*	*Bray and Kurtz (1945)*
14. *Morgan's reagent-S*	*Morgan's reagent (Sodium acetate + Acetic acid) Tubidimetry*	*Chesnin and Yien (1950)*
15. *$CaCl_2$-S*	*0.15% $CaCl_2$ extraction*	*Williams and Steinbergs (1959)*
16. *NH_4OAc-K*	*Neutral normal ammonium acetate, Flamephotometry*	*Stanford and English (1949)*
17. *Available calcium*	*Versenate titration*	*Jackson (1973)*
18. *Available magnesium*	*Versenate titration*	*Jackson (1973)*
C. Physico-chemical properties		
1. *Soil reaction (pH)*	*Potentiometry*	*Jackson (1973)*
2. *Electrical conductivity (dSm^{-1})*	*Conductometry*	*Jackson (1973)*
3. *Cation exchange capacity (C mole $(P^+)kg^{-1}$)*	*Using neutral normal ammonium acetate*	*Schollanberger and Dreibelbis (1930)*
4. *P fixing capacity*	*Equilibrium with potassium - dihydrogen phosphate*	*Waugh and Fitts (1966)*

D. Plant analysis

1. Total nitrogen	Micro kjeldahl	Humphries (1956)
2. Total phosphorus	Perchloric acid digestion colorimetry	Jackson (1973)
3. Total sulphur	Acid extraction HNO_3 : $HClO_4$ and HCl (3:2:1)	Blanchar **et al.** (1965)
	Estimation - Turbidimetry	Chesnin and Yien (1950)

3.4.1. Oil

The oil content in seed was determined using Nuclear Magnetic Resonance Spectrometer (Model : Oxford-4000) at Tamil Nadu Agricultural University, Coimbatore. (Sagare and Naphade, 1983)

3.4.2. Crude Protein

This was determined in the seed by multiplying the total nitrogen content of seed by a factor of 6.25.

3.4.3. Method of analysis for available sulphur

The available S status of the soil was determined by using two different extractants viz., 0.15% $CaCl_2$ and Morgan's extractant (Sodium acetate with acetic acid). In these cases, 5 g of soil sample was treated with 25 mL of the respective extractants, shaken for half an hour in a mechanical shaker. The contents were filtered through Whatman No.42 filter paper and the S content was estimated by following the methods given below.

3.4.3.a. Morgan's reagent-S

5 mL of filtrate was pipetted out in 25 ml volumetric flask and 15 mL of distilled water was added and shaken for a minute. One gram of sieved (40-50 mesh) barium chloride was then added and the volume was made up to 25 mL. Turbidity readings were taken within 5-30 minutes after the

precipitation had occurred, in a photoelectric colorimeter using blue filter (420 nm).

3.4.3.b. 0.15% $CaCl_2$-S

The filtrate collected was fed in Skalar Autoanalyser (Model SA-5100) and sulphur content was estimated by segmented flow analysis. Here the sample was diluted with $BaCl_2$ solution. The principle was, the sulphate in the filtrate reacted with the barium and got precipitated. The excess barium was dialysed against a colour reagent. The decrease in colour intensity of the reagent was measured at 630 nm which was inversely proportional to the sulphur concentration. (For $BaCl_2$ reagent, $BaCl_2$ (0.5 g), citric acid (19 g) and disodium orthophosphate (4 g) were dissolved in distilled water and volume was made up to one litre. For colour reagent, Sulfanzo III (0.007 g), citric acid (19 g) and disodium orthophosphate (4 g) were dissolved in distilled water and volume was made up to 1 litre). The filtrate was fed along with $BaCl_2$ and colour reagent and sulphur content was estimated.

3.5. Method of calculation

The following calculations were done to obtain the values on soil and plant analysis.

3.5.1. Response

Yield of treated plot - Yield of control plot

3.5.2. Plant uptake : kg ha^{-1}

$$\frac{\text{Per cent nutrient in grain} \times \text{Grain yield}}{100} + \frac{\text{Per cent nutrient in stover} \times \text{Stover yield}}{100}$$

3.6. Targetted yield approach parameters

3.6.1. Nutrient requirements of grain (NR) Kgq^{-1}

$$NR = \frac{\text{Total uptake of nutrient (kg ha}^{-1}\text{)}}{\text{Grain yield (q ha}^{-1}\text{)}}$$

3.6.2. Per cent contribution from soil (Cs)

$$Cs = \frac{\text{Total uptake of nutrient in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value of nutrient in control plot (kg ha}^{-1}\text{)}} \times 100$$

3.6.3. Per cent contribution form fertilizer (Cf)

$$Cf = \frac{\text{Total uptake from treated plot} - \text{Soil test value of treated plot} \times \text{Av.Cs}}{\text{Fertilizer dose}} \times 100$$

3.6.4. Fertilizer nutrient required for a particular yield target (T)

$$F = T \times \frac{NR}{Cf/100} - \frac{Cs}{Cf} \times \text{Soil test value}$$

3.7. Statistical analysis

The data regarding the yield of grain and stover, nutrients uptake and soil analysis methods were subjected to statistical analysis to determine the effects due to treatments. Simultaneous equations were employed for predicting the yield, using soil available nutrients and uptake (Alger, 1969; Bin-Swanger 1975). The experimental data were processed for working out correlation and fitting up of various regression equations by following procedure outlined by Snedecor and Cochran (1973).

RESULTS

CHAPTER IV

RESULTS

The results obtained from the fertilizer gradient experiment with fodder maize followed by the experiment on sunflower are presented. Based on the response of sunflower to fertilizers, optimization of the fertilizer doses in adjustment with initial soil test values in Irugur soil series of Lower Bhavani ayacut area of Tamil Nadu State, India were formulated and presented in this Chapter.

4.1. Description of the experimental soil (Fig.1)

The soil of the experimental site belonged to Irugur series which occupies 64 per cent of the ayacut in Lower Bhavani Project Command area in Periyar district of Tamil Nadu. The soil is dark reddish brown to dark red, deep, sandy clay loam, moderately well drained and developed over granite gneiss.

The results of analysis of the experimental soil are given in Table 6. The soil is sandy clay loam in texture, registering a pH of 6.9 and CEC of 16.5 C mol $(p^+)kg^{-1}$. The nitrogen and organic carbon status were low, sulphur and phosphorus status were medium and potassium status was high.

Table 6. Analytical data of initial soil

Sl.No.	Soil property	Value
I. Physical properties		
1.	Particle size distribution	
	(i) Coarse sand (per cent)	45.64
	(ii) Fine sand (per cent)	25.22
	(iii) Silt (per cent)	4.05
	(iv) Clay (per cent)	24.50
	Texture	Sandy clay loam
2.	Moisture (%)	1.47
II. Chemical properties		
1.	Total nitrogen (%)	0.046
2.	Total phosphorus (%)	0.015
3.	Total potassium (%)	0.242
4.	Total sulphur (%)	0.170
5.	Total calcium (%)	0.672
6.	Total magnesium (%)	0.145
7.	Sesquioxide (%)	10.09
8.	Iron oxide (%)	6.28
9.	Alumina (%)	3.81
10.	$KMnO_4$-N (kg ha^{-1})	170.00
11.	Organic carbon (%)	0.400
12.	Olsen-P (kg ha^{-1})	18.0

13.	Bray-p (kg ha^{-1})	28.0
14.	Morgans reagent-S (kg ha^{-1})	20.0
15.	$CaCl_2$-S (kg ha^{-1})	32.0
16.	NH_4OA_c-K (kg ha^{-1})	286.0
17.	Available calcium (%)	0.94
18.	Available magnesium (%)	0.15
III.	**Physico chemical properties**	
1.	Soil reaction (pH)	6.9
2.	Electrical conductivity (dSm^{-1})	0.2
3.	Cation exchange capacity (C mol (p+) kg^{-1})	16.5
4.	P fixing capacity (kg ha^{-1})	138

4.2. Fertility gradient experiment (Table 7,8 and 9)

Fertility gradient was created according to the procedure outlined in the Chapter "Experimental details".

Field soils do not possess sufficient range of nutrient levels such that crop response models can not be applied for optimizing fertilizer schedules but this can be overcome by creating fertility gradients in one and the same field by the application of fertilizers. Therefore, a fertility gradient experiment was conducted adopting the methodology 'proposed by Ramamoorthy (1968). Creation of sufficient range of nutrient levels can be observed by comparing the response of gradient crop, interms of yield and nutrient uptake and soil test values of pre sowing and post-harvest soil samples.

4.2.1. Initial soil analysis (Table 7; Fig.3)

The resutls of 16 samples collected before raising the gradient crop showed that the $KMnO_4$-N ranged from 155 to 185 kg ha^{-1} with mean values of 165, 168, 176 and 170 kg ha^{-1} respectively for Strips I to IV. The Olsen-P values varied from 16.8 to 21.5 kg ha^{-1} with a mean value of 19.0 kg ha^{-1} in Strip I, 19.5 kg ha^{-1} in Strip II, 19.7 kg ha^{-1} in Strip III and 18.3 kg ha^{-1} in strip IV. The values of Morgan's reagent-S extended from 17.0 kg to 24.0 kg ha^{-1} with mean values of 21.5, 20.0, 20.7, 21.0 kg ha^{-1} in Strip I,II,III and IV respectively.

Table 7. Available nutrient status of pre sowing and post-harvest soil of gradient experiment

(Maize-Co 1)

Strip	Gradient			Pre sowing analysis (kg ha^{-1})			Post-harvest analysis (kg ha^{-1})		
	N	P	S	$KMnO_4$-N	Olsen-P	Morgan's reagent-S	$KMnO_4$-N	Olsen-P	Morgan's reagent-S
I	N_0	P_0	S_0	167	16.8	21.0	158	15.0	20.5
				166	17.7	20.5	150	17.5	18.8
				155	21.5	22.0	161	20.5	23.0
				172	20.0	22.6	155	21.0	21.5
		Mean		165	19.0	21.5	156	18.5	20.9
II	$N_{1/2}$	$P_{1/2}$	$S_{1/2}$	173	18.8	22.5	220	28.0	24.5
				159	17.9	24.0	204	25.0	23.5
				164	20.5	17.0	199	23.0	25.4
				177	20.8	16.5	193	25.8	21.0
		Mean		168	19.5	20.0	204	25.5	23.6
III	N_1	P_1	S_1	181	21.5	22.0	217	29.0	31.0
				170	18.2	19.8	221	32.0	26.2
				168	18.6	23.0	234	30.5	28.9
				185	20.5	18.0	240	26.0	29.0
		Mean		176	19.7	20.7	228	29.4	28.7
	N_2	P_2	S_2	183	18.8	22.0	236	36.0	31.5
				159	20.5	19.8	221	30.5	30.4
				164	17.1	22.5	202	29.5	33.0
				174	16.8	19.7	225	38.0	35.5
		Mean		170	18.3	21.0	221	33.5	32.6

The range and mean values of alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S estimated after the harvest of gradient crop clearly indicated that there was significant built up in fertility gradient among the strips.

4.2.2. Post-harvest soil analysis

4.2.2.1. Available nitrogen (Table 7 and 8; Fig.3)

The alkaline $KMnO_4$-N level varied from 150 to 240 kg ha^{-1}, the mean values of alkaline $KMnO_4$-N were 156, 204, 228, 221 kg ha^{-1} respectively. The levels of N applied significantly influenced the availability of soil N after the harvest of gradient crop.

4.2.2.2. Available phosphorus (Table 7 and 8; Fig.3)

The Olsen-P ranged from 15.0 to 38.0 kg ha^{-1}. The mean Olsen-P values were 18.5, 25.5, 29.4, 33.5 kg ha^{-1} in Strip I, Strip II, Strip III and Strip IV. The levels of fertilizers also significantly influenced the P availability in the soil after the harvest of gradient crop of maize.

4.2.2.3. Available sulphur (Table 7 and 8; Fig.3)

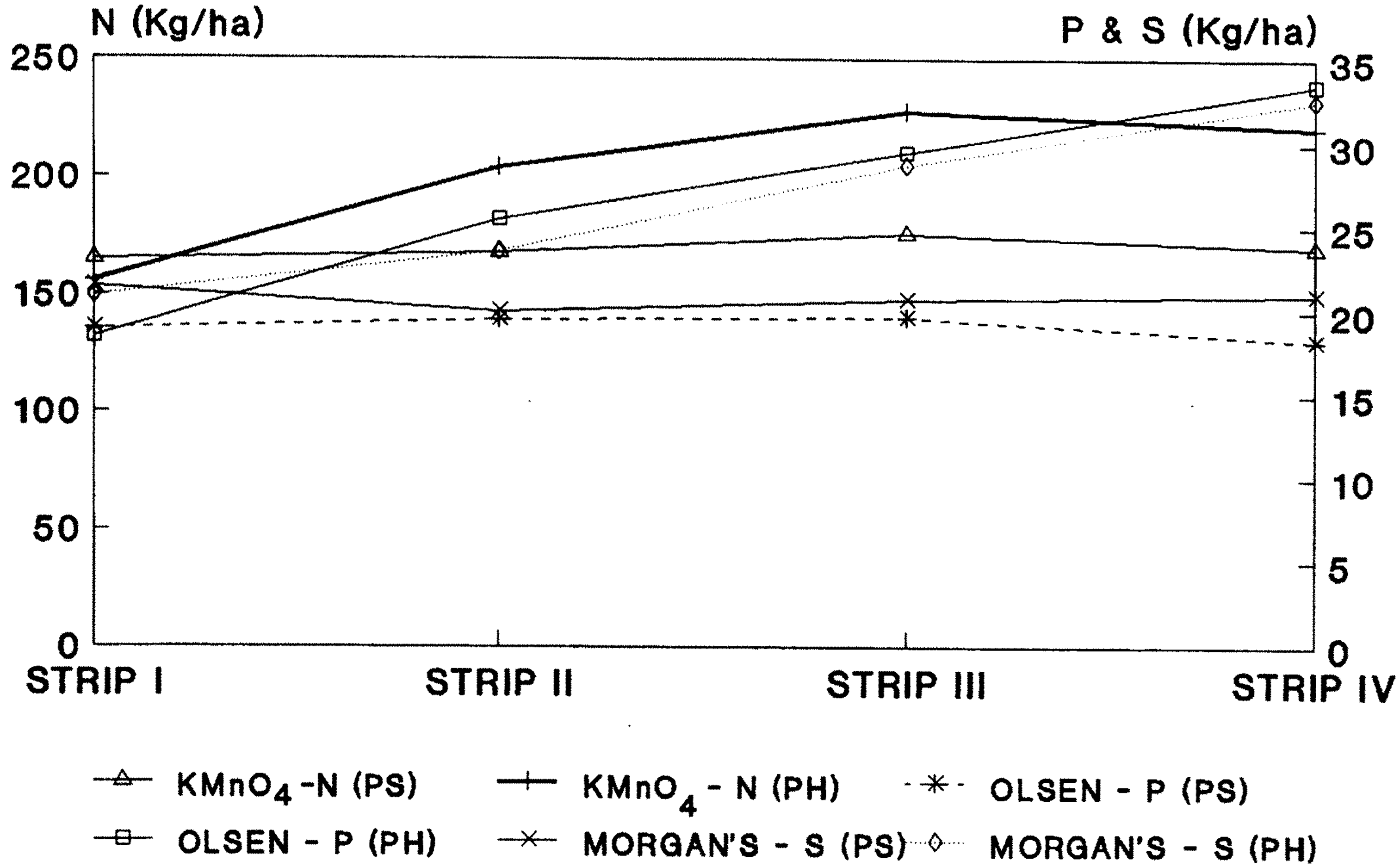
The ranges in Morgan's reagent-S in the soil after the harvest of gradient crop of maize were 18.8 to 35.5 kg ha^{-1} with mean values of 20.9, 23. 6, 28.7, 32.6 kg ha^{-1} in Strip I, Strip II, Strip III and Strip IV.

Table 8. Soil available nutrients levels as affected by amounts of fertilizers applied to different fertility gradient strips

Strip	Fertilizer dose kg ha^{-1}			Available nitrogen		Available phosphorus		Available sulphur	
	N	P	S	Alkaline $KMnO_4$-N (kg ha^{-1})	Organic carbon (%)	Olsen-P (kg ha^{-1})	Bray-P (kg ha^{-1})	Morgan's reagent-S (kg ha^{-1})	$CaCl_2$-S (kg ha^{-1})
I	0	0	0	156	0.36	18.5	36.0	20.9	31.0
II	45	69	25	204	0.40	25.5	40.1	23.6	41.5
III	90	138	50	228	0.43	29.4	49.2	28.7	45.8
IV	180	276	100	221	0.44	33.5	57.0	32.6	51.2
'F' test				181.68**	5.439**	33.069**	28.312**	17.79**	21.25**
SEd				3.403	0.022	1.57	2.50	1.75	2.632
CD at 5%				7.699	0.049	3.55	5.65	3.96	5.95
CV%				2.38	7.56	8.31	7.76	9.36	8.81

** Significant at P = 0.01

Fig.3 PRE SOWING AND POST HARVEST SOIL AVAILABLE NUTRIENTS



The sulphur availability indices in the soil of these gradients were also significantly influenced by the amounts of fertilizer S applied.

4.2.3. Fodder, drymatter yield and nutrient uptake of gradient crop-maize (Table 9; Fig.4 and 5)

The results revealed that the fodder yield and nutrient uptake in maize increased with increase in amounts of fertilizer addition.

4.2.3.1. Fodder yield of gradient crop - maize

The fodder yield of maize in Strip I where no fertilizer was added was poor (9.03 t ha^{-1}). In Strip II, ($N_{1/2}$ $P_{1/2}$ $S_{1/2}$), the fodder yield was comparatively higher (11.24 t ha^{-1}). The fodder yield in Strip III ($N_1P_1S_1$) was higher when compared to the $N_0P_0S_0$ plots (12.33 t ha^{-1}). In the Strip IV ($N_2P_2S_2$) the fodder yield was significantly higher (19.22 t ha^{-1}). The results of statistical analysis also indicated that each strip was significantly different from the other with respect to the fodder yield of maize.

4.2.3.2. Drymatter yield

The drymatter yield of fodder also increased with increasing amounts of fertilizer additions. The average drymatter yield was 1.81, 2.05, 2.28 and 3.84 t ha^{-1} for Strip I, Strip II, Strip III and Strip IV respectively. The results of statistical analysis indicated that each strip

Table 9. Fodder, drymatter yield and nutrient uptake of maize under differnt fertility gradient

Strip	Fertilizer dose kg ha^{-1}			Fodder yield t ha^{-1}	Dry matter yield t ha^{-1}	Uptake kg ha^{-1}		
	N	P	S			N	P	S
I	0	0	0	9.03	1.81	21.72	4.72	3.98
II	45	69	25	11.24	2.05	28.63	6.15	5.73
III	90	138	50	12.33	2.28	36.48	11.20	8.10
IV	180	276	100	19.22	3.84	76.80	15.36	12.22
'F'test				1086.28**	3991.00**	11558.8**	3911.25**	4436.933**
SEd				0.047	0.005	0.081	0.028	0.019
CD (5%)				0.107	0.012	0.184	0.062	0.043
CV (%)				2.059	1.163	1.122	1.665	1.426

** Significant at P = 0.01

FIG.4 FODDER AND DRYMATTER YIELD OF MAIZE UNDER DIFFERENT FERTILITY GRADIENTS

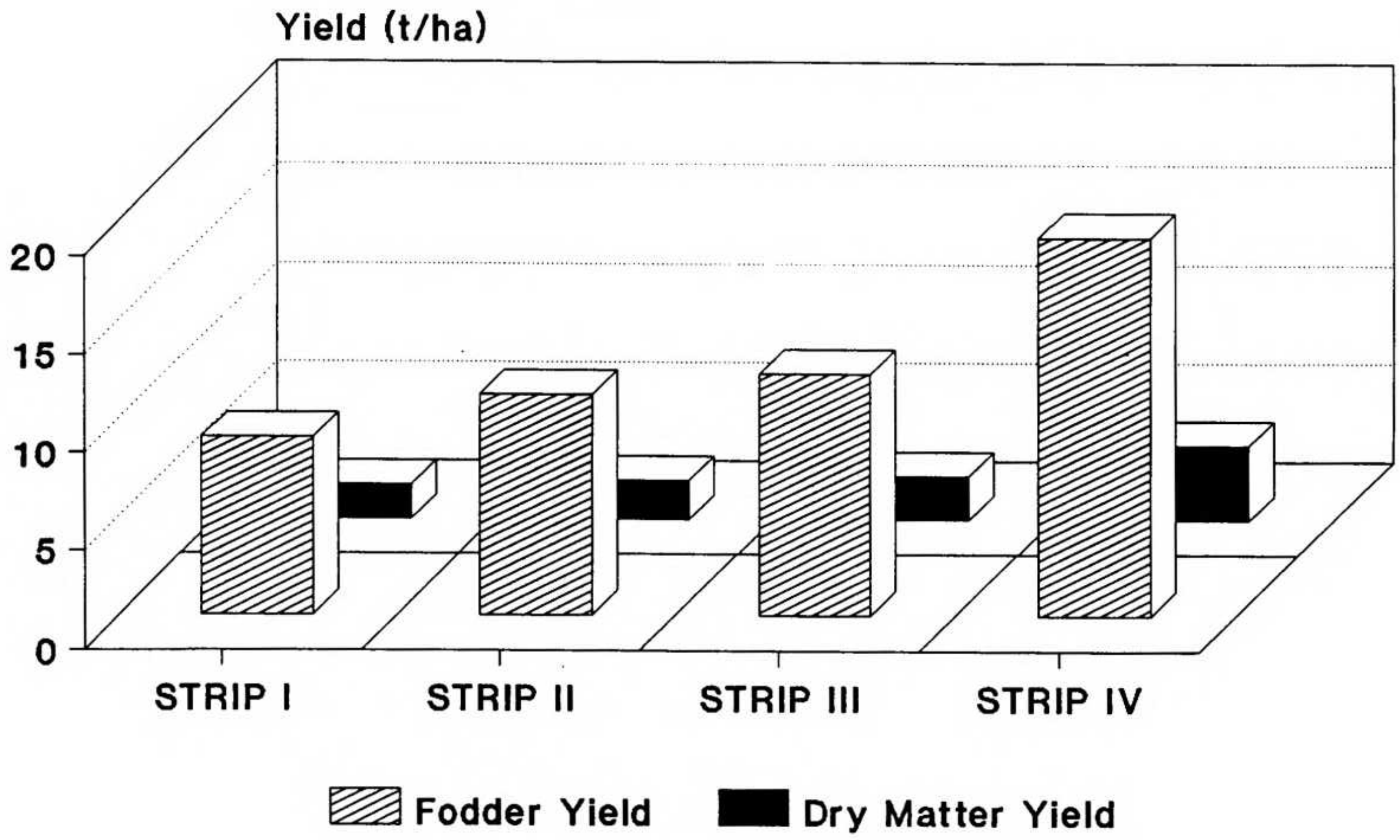
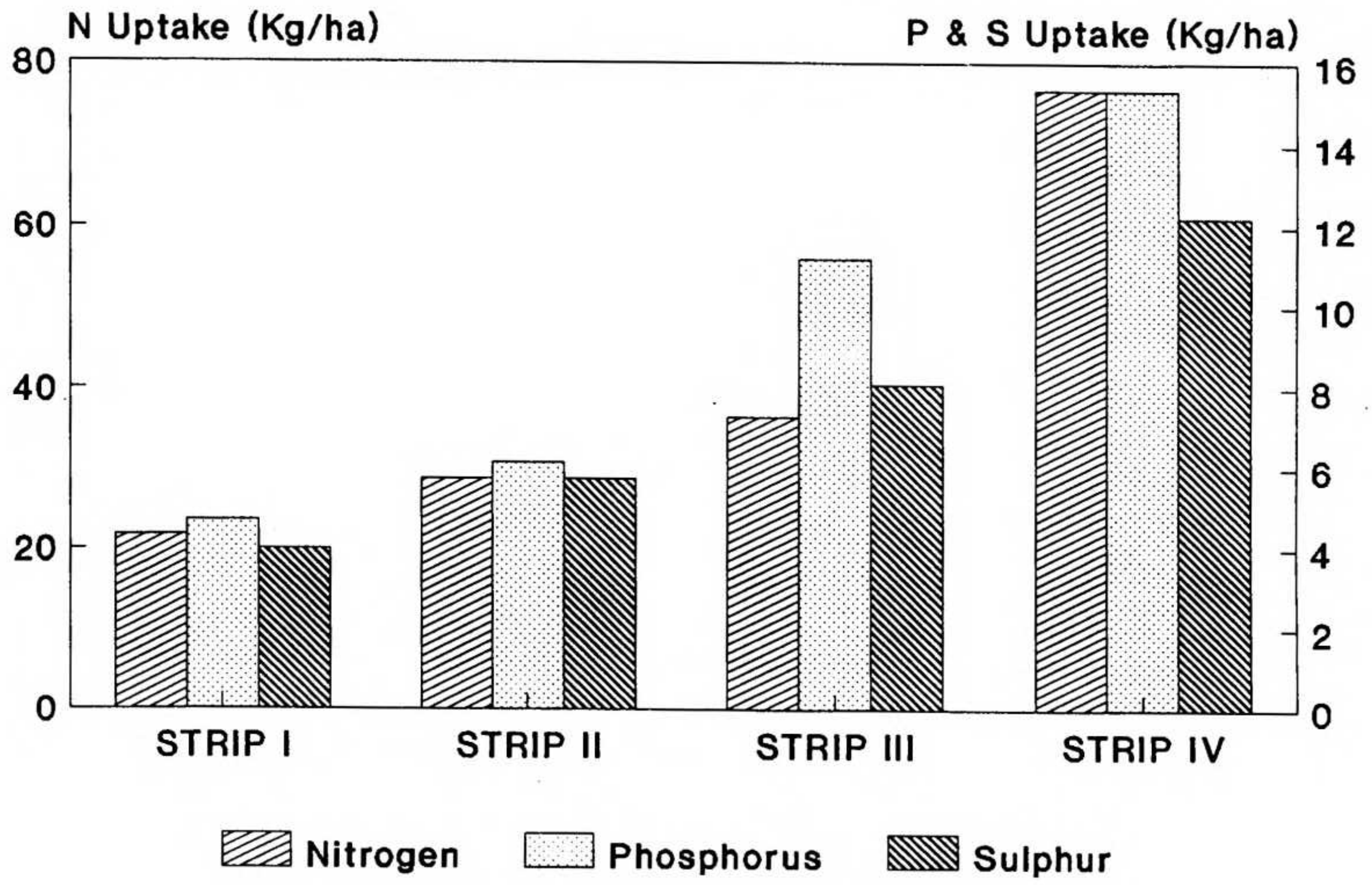


FIG.5 NUTRIENT UPTAKE OF MAIZE UNDER DIFFERENT FERTILITY GRADIENTS



was significantly different from each other with respect to drymatter yield.

4.2.3.3. Nutrient uptake

The N, P and S uptake progressively increased with increase in levels of fertilizer addition. The nitrogen uptake values increased progressively from Strip I to IV (Mean values : 21.72, 28.63, 36.48 and 76.8 kg N ha^{-1}).

The phosphorus uptake values were also significantly differ within the gradient strips (mean values : 4.72, 6.15, 11.20 and 15.36 kg P ha^{-1} in Strips I, II, III and IV respectively). Sulphur uptake was 3.98 kg ha^{-1} in Strip I, 5.73 kg ha^{-1} in Strip II, 8.10 kg ha^{-1} in Strip III and 12.22 kg ha^{-1} in Strip IV. The results of the statistical analysis of N, P and S uptake revealed that each strip was significantly different from the others with respect to the uptake of N, P and S.

4.3. Test crop experiment

4.3.1. Range and mean values of available nutrients, yield, nutrient uptake and protein content (Table 10 to 13)

4.3.1.1. Range and mean values of available nutrients

The range and mean values of pre-sowing soil test values showed that the $KMnO_4$-N increased from 107 kg ha^{-1} in Strip I to 274 kg ha^{-1} in Strip III with the mean values of 166, 212, 235 and 226 kg ha^{-1} respectively in Strips I, II, III and IV. Organic carbon ranged from 0.30 to 0.49 per cent

Table 10. Range and mean values of available nutrients, yield and nutrient uptake by sunflower in Strip I

Parameters	Range		Mean
	Minimum	Maximum	
$KMnO_4$-N (kg ha^{-1})	107.0	209.0	166.0
Organic carbon (%)	0.30	0.42	0.36
Olsen-P (kg ha^{-1})	16.1	22.4	18.14
Bray-P (kg ha^{-1})	30.8	44.2	36.8
Morgan's reagent-S (kg ha^{-1})	18.0	25.5	21.1
$CaCl_2$-S (kg ha^{-1})	29.4	32.3	31.3
Grain yield (kg ha^{-1})	814.0	2100.0	1464.0
Oil yield (kg ha^{-1})	307.0	819.0	565.0
N uptake (kg ha^{-1})	24.0	82.0	50.65
P uptake (kg ha^{-1})	12.5	46.0	28.5
S uptake (kg ha^{-1})	11.67	33.0	22.0
Protein content (%)	10.63	16.25	12.36

Table 11. Range and mean values of available nutrients, yield and nutrient uptake by sunflower in Strip II

Parameters	Range		Mean
	Minimum	Maximum	
$KMnO_4$-N (kg ha^{-1})	163.0	256.0	212.0
Organic carbon (%)	0.35	0.47	0.40
Olsen-P (kg ha^{-1})	22.0	29.0	25.3
Bray-P (kg ha^{-1})	34.2	48.2	40.1
Morgan's reagent-S (kg ha^{-1})	20.6	26.7	24.0
$CaCl_2$-S (kg ha^{-1})	39.0	44.0	41.5
Grain yield (kg ha^{-1})	924.0	2365.0	1657.0
Oil yield (kg ha^{-1})	344.0	919.0	631.0
N uptake (kg ha^{-1})	28.1	90.0	58.5
P uptake (kg ha^{-1})	16.0	51.4	32.4
S uptake (kg ha^{-1})	9.65	40.1	22.5
Protein content (%)	10.63	16.25	12.62

Table 12. Range and mean values of available nutrients, yield and nutrient uptake by sunflower in Strip III

Parameters	Range		Mean
	Minimum	Maximum	
$KMnO_4$-N (kg ha^{-1})	186.0	274.0	235.0
Organic carbon (%)	0.36	0.49	0.43
Olsen-P (kg ha^{-1})	25.2	32.4	29.3
Bray-P (kg ha^{-1})	36.2	59.4	49.7
Morgan's reagent-S (kg ha^{-1})	28.0	30.0	28.8
$CaCl_2$-S (kg ha^{-1})	44.5	46.9	45.8
Grain yield (kg ha^{-1})	1185.0	2598.0	1907.0
Oil yield (kg ha^{-1})	419.0	1016.0	728.1
N uptake (kg ha^{-1})	36.4	103.2	70.0
P uptake (kg ha^{-1})	20.2	53.6	36.1
S uptake (kg ha^{-1})	12.7	34.2	23.0
Protein content (%)	10.8	16.5	13.0

Table 13. Range and mean values of available nutrients, yield and nutrient uptake by sunflower in Strip IV

Parameters	Range		Mean
	Minimum	Maximum	
$KMnO_4$-N (kg ha^{-1})	195.0	264.0	226.0
Organic carbon (%)	0.36	0.48	0.44
Olsen-P (kg ha^{-1})	30.5	36.0	33.8
Bray-P (kg ha^{-1})	48.2	62.4	57.4
Morgan's reagent-S (kg ha^{-1})	30.8	35.7	32.9
$CaCl_2$-S (kg ha^{-1})	50.0	52.6	51.2
Grain yield (kg ha^{-1})	1235.0	2728.0	1992.0
Oil yield (kg ha^{-1})	463.0	1093.0	759.0
N uptake (kg ha^{-1})	39.7	107.5	69.8
P uptake (kg ha^{-1})	21.4	55.4	38.33
S uptake (kg ha^{-1})	13.3	35.0	23.9
Protein content (%)	11.31	16.25	12.5

with the mean values of 0.36, 0.40 , 0.43 and 0.44 respectively in strip I, II,III and IV. The Olsen-P varied from 16.1 to 36.0 kg ha^{-1} with the mean values of 18.14, 25.3, 29.3 and 33.8 kg ha^{-1} in Strip I, II, III and IV respectively. The Bray-P registered higher values compared to Olsen P. The mean values of Bray-P in Strip I, II III and IV were 36.8, 40.1, 49.7 and 57.4 kg ha^{-1} respectively. With regard to the sulphur availability indices, the Morgan's reagent-S varied from 18.0 to 35.7 with mean values of 21.1, 24.0, 28.8 and 32.9 kg ha^{-1} in strips I, II, III and IV respectively and the mean values of 0.15% $CaCl_2$-S recorded in the corresponding strips were 31.3, 41.5, 45.8 and 51.2 kg ha^{-1}.

4.3.1.2. Grain yield

The sunflower grain yield ranged from 814 to 2728 kg ha^{-1} with mean values of 1464, 1657, 1907 and 1992 kg ha^{-1} in Strip I, II,III and IV respectively. The oil yield registered also ranged from 307 to 1093 kg ha^{-1} with the mean values of 565, 631, 728 and 759 kg ha^{-1} in the respective strips.

4.3.1.3. Uptake of nutrients

The nitrogen uptake extended from 24.0 to 107.5 kg ha^{-1} with mean values of 50.65, 58.50, 70.00 and 69.80 kg ha^{-1} in strips I, II, III and IV respectively. Variation in the uptake values of P and S were also observed. The phosphorus uptake ranged from 12.5 to 55.4 kg ha^{-1} and S uptake varied from 11.67 to 35.0 kg ha^{-1}. The mean values were 28.5, 32.4, 36.1 and 38.33 for P and 22.0, 22.5, 23.0 and 23.9 kg ha^{-1} for S in strips I, II, III and IV respectively.

4.3.1.4. Protein content

The protein content ranged from 10.63 to 16.5 per cent with the mean values of 12.36, 12.62, 13.0 and 12.5 per cent in strip I, II, III and IV respectively.

4.3.2. Range and mean values of available nutrients, yield, nutrient uptake and protein content in overall gradient (Tale 14)

THe $KMnO_4$-N values ranged from 107 to 274 kg ha^{-1} with mean of 210 kg ha^{-1}. Organic carbon extended from 0.30 to 0.49 with mean value of 0.41 per cent. With regard to the two P availability indices, the values for Olsen-P varied from 16.1 to 36.0 kg ha^{-1} with mean value of 26.7 kg ha^{-1}. The mean value of Morgan's reagent-S and $CaCl_2$-S were 26.7 and 41.9 kg ha^{-1} respectively.

The sunflower grain yield ranged from 814 to 2728 kg ha^{-1} with mean value of 1755 kg ha^{-1}. The oil yield ranged between the values of 307 to 1093 kg ha^{-1} with mean value of 670 kg ha^{-1}. The nitrogen uptake varied from 24.9 to 107.5 kg ha^{-1},while the P uptake ranged from 12.5 to 55.4

Table 14. Range and mean values of available nutrients, yield and nutrient uptake by sunflower in over all gradients

Parameters	Range		Mean
	Minimum	Maximum	
$KMnO_4$-N (kg ha^{-1})	107.0	274.0	210.0
Organic carbon (%)	0.30	0.49	0.41
Olsen-P (kg ha^{-1})	16.1	36.0	26.7
Bray-P (kg ha^{-1})	30.8	62.0	46.0
Morgan's reagent-S (kg ha^{-1})	18.0	35.7	26.7
$CaCl_2$-S (kg ha^{-1})	19.42	52.6	41.9
Grain yield (kg ha^{-1})	814.0	2728.0	1755.0
Oil yield (kg ha^{-1})	307.0	1093.0	670.0
N uptake (kg ha^{-1})	24.9	107.5	62.3
P uptake (kg ha^{-1})	12.5	55.4	33.8
S uptake (kg ha^{-1})	9.6	40.1	22.7
Protein content (%)	10.63	16.5	12.62

kg ha^{-1} and the S uptake recorded from 9.6 to 40.1 kg ha^{-1}. The mean values were 62.3 for N, 33.8 for P and 22.7 for S uptake. The protein content varied from 10.63 to 16.5 per cent with mean value of 12.62 per cent.

4.3.3. Range and mean values of available nutrients, yield, nutrient uptake and protein content in control plots (Table 15)

The range and mean values of soil nutrients before sowing of sunflower indicated that alkaline $KMnO_4$-N varied from 154 to 230 kg ha^{-1} with mean value of 200. The per cent of organic carbon oscillated between the values of 0.35 to 0.52 with mean of 0.42. The Olsen-P ranged from 20.6 to 33.0 kg ha^{-1} with mean of 27.4. The mean values for Bray-P, Morgan's reagent-S and $CaCl_2$-S were 41.2, 25.2 and 41.3 kg ha^{-1}. The grain yield ranged from 728 to 1314 kg ha^{-1} and oil yield varied from 265 to 490 kg ha^{-1} with mean values of 1024 and 380 kg ha^{-1} respectively. The nitrogen uptake varied from 26.6 to 49.3 kg ha^{-1}, while the phosphorus uptake extended from 15.7 to 28.4 kg ha^{-1} and the sulphur uptake ranged from 10.5 to 17.4 kg ha^{-1} with mean values of 38.3, 22.3 and 14.8 kg ha^{-1} for N, P and S. The protein content varied from 12.5 to 14.4 per cent with mean of 13.5 per cent.

Table 15. Range and mean values of available nutrients, yield and nutrient uptake by sunflower in control plots

Parameters	Range		Mean
	Minimum	Maximum	
$KMnO_4$-N (kg ha^{-1})	154.0	230.0	200.0
Organic carbon (%)	0.35	0.52	0.42
Olsen-P (kg ha^{-1})	20.6	33.0	27.4
Bray-P (kg ha^{-1})	26.2	56.0	41.2
Morgan's reagent-S (kg ha^{-1})	19.8	31.4	25.2
$CaCl_2$-S (kg ha^{-1})	31.0	50.2	41.3
Grain yield (kg ha^{-1})	728.0	1314.0	1024.0
Oil yield (kg ha^{-1})	265.0	490.0	380.0
N uptake (kg ha^{-1})	26.6	49.3	38.3
P uptake (kg ha^{-1})	15.7	28.4	22.3
S uptake (kg ha^{-1})	10.5	17.4	14.8
Protein content (%)	12.5	14.4	13.5

4.4. Effect of applied nutrients on nutrient response (Table 16)

4.4.1. N-response

The response for N was increased with increased levels of N application. The nutrient responses expressed as grain yield increase per unit quantity of N applied have been worked out and it decreased from 7.65 to 6.87 kg of grain per kg of N for 120 kg N ha^{-1}.

4.4.2. P-response

Progressive increase in response for the increased levels of P was observed in the present investigation. The highest unit response is for addition of 60 kg P ha^{-1}. The nutrient response expressed interms of quantity of nutrient applied, worked out to 11.93 kg of seed per kg of P for 60 kg P ha^{-1}.

4.4.3. S-response

The added S behaved differently with application of 25 kg S ha^{-1}. The response is 2.08 kg of seed per kg of S and increasing the level of S (50 kg ha^{-1}) has decreased the response ratio to 1.98.

4.5. Selection of suitable soil testing procedure (Table 17 to 19)

The suitability of different soil testing procedures were assessed through simple correlation and multiple regression studies.

Table 16. Effect of applied nutrients on response

	Level of fertilizers kg ha^{-1}	Mean response	Response
N	40	187 (40)	4.68
	80	612 (24)	7.65
	120	824 (8)	6.87
P	20	54 (34)	2.72
	40	261 (12)	6.51
	60	716 (4)	11.93
S	25	52 (37)	2.08
	50	99 (8)	1.98

( ) - No. of observations

4.5.1. Correlation studies (Table 17)

The simple correlation studies revealed that the available N assessment through $KMnO_4$-N method appeared as a good index as it exhibited significant positive correlation with grain yield (0.8057^{**}), oil yield (0.689^{**}) and nitrogen uptake (0.7853^{**}). Organic carbon also showed a positive significant correlation with the above mentioned response variables viz., 0.6506^{**}, 0.525^{**} and 0.6504^{**}, respectively.

The Olsen-P correlated significantly and positively with grain yield (0.4567^{**}), oil yield (0.4440^{**}) and P uptake (0.3639^{**}). Similar trend was established by Bray-P with grain yield (0.6203^{**}), oil yield (0.2610^{**}) and P uptake (0.5326^{**})

The Morgan's reagent-S showed a significant positive correlation with grain yield (0.5166^{**}), oil yield (0.483^{**}) and uptake (0.2447^{*}). In the case of $CaCl_2$-S it showed positive significant correlation with grain yield (0.3653^{**}) and non-significant correlation with oil yield and uptake.In control plots, $KMnO_4$-N,organic carbon, Olsen-P, Bray-P, Morgan's reagent-S, $CaCl_2$-S showed positive and significant correlation with all the response variables **viz.**, grain yield, oil yield and uptake.

Table 17. Correlation of soil test values with response variables in sunflower (r-values)

Variables correlated	Alkaline $KMnO_4$-N	Organic carbon	Olsen-P	Bray-P	Morgan's reagent-S	$CaCl_2$-S
(1) Grain yield						
Treated plots	0.8057**	0.6506**	0.4567**	0.6203**	0.5166**	0.3653**
Control plots	0.9015**	0.7576**	0.9840**	0.9739**	0.9744**	0.8110**
(2) Oil yield						
Treated plots	0.6890**	0.5250**	0.4440**	0.261**	0.483**	0.155
Control plots	0.8990**	0.7660**	0.9860**	0.972**	0.975**	0.993**
(3) Uptake						
Treated plots	0.7853**	0.6504**	0.3639**	0.5326**	0.2447*	0.1130
Control plots	0.9170**	0.8571**	0.9705**	0.9480**	0.8430**	0.816**

** Significant at P = 0.01

* Significant at P = 0.05

4.5.2. Multiple regression analysis (Table 18 and 19)

Strengthening the results of simple correlation studies, the multiple regression equations were worked out to relate the crop response variables with soil test values of all the three nutrients **viz.**, nitrogen, phosphorus and sulphur in all the eight possible combinations of soil test methods (2 for nitrogen x 2 for phosphorus x 2 for sulphur) and fertilizer nutrients. The multiple regression equations were also worked out to relate the yield with soil test methods for all the eight combinations with control plots. In the case of treated plots, the results obtained with R^2 values for relating the grain yield with soil test values and fertilizer nutrient amount indicated that 6 combinations predicted 92 per cent **viz.**, organic carbon, Olsen P, Morgan's reagent-S; Organic carbon, Bray P, Morgan's reagent-S; $KMnO_4$-N, Bray-P, $CaCl_2$-S; Organic carbon, Bray-P, $CaCl_2$-S; $KMnO_4$-N, Olsen P, $CaCl_2$-S and organic carbon, Olsen P, $CaCl_2$-S and 2 combinations predicted 94 per cent ($KMnO_4$-N, Olsen P, Morgan's reagent-S and $KMnO_4$-N, Bray P Morgan's reagent-S) when the yields were correlated.

The results obtained from the control plots were also highly significant and the predictability was 98 per cent in the combinations **viz.**, $KMnO_4$-N, Olsen P, Morgan's reagent-S, Organic carbon, Olsen-P, Morgan's reagent-S; Organic carbon, Bray, Morgan's reagent-S; $KMnO_4$-N, Bray P,

Table 18. Multiple co-efficient of determination (R^2) of function relating response variable (grain yield) in sunflower with soil test methods of different combinations

Particulars	$KMnO_4$-N Olsen-P Morgan's reagent-S	Organic carbon Olsen-P Morgan's reagent-S	$KMnO_4$-N Bray-P Morgan's reagent-S	Organic carbon Bray-P Morgan's reagent-S	$KMnO_4$-N Bray-P $CaCl_2$-S	Organic carbon Bray-P $CaCl_2$-S	$KMnO_4$-N Olsen-P $CaCl_2$-S	Organic carbon Olsen-P $CaCl_2$-S
(a) Treated plots	0.9445**	0.9241**	0.9401**	0.9221**	0.9184**	0.9211**	0.9245**	0.9210**
(b) Control plots	0.9899**	0.9819**	0.9791**	0.9832**	0.9883**	0.9918**	0.9903**	0.9842**

** Significant at P = 0.01

Table 19. Multiple co-efficients of determination (R^2) of function relating nutrient uptake with soil test methods

Soil test methods	Nutrient uptake
Alkaline $KMnO_4$-N	0.8792**
Organic carbon	0.8497**
Olsen-P	0.8267**
Bray-P	0.7967**
Morgan's reagent-S	0.4544
$CaCl_2$-S	0.4251

** Significant at P = 0.01

$CaCl_2$-S and organic carbon, Olsen-P, $CaCl_2$-S. Predictability of 99 per cent was seen in other combinations.

The results obtained with R^2 values relating the uptake of nutrients with soil test methods indicated that $KMnO_4$-N predicted higher values (0.8792^{**}) than organic carbon (0.8497^{**}) for nitrogen uptake.

In the case of P uptake, the Olsen-P predicted higher R^2 value (0.8267^{**}) than Bray-P (0.7967^{**}). For the S uptake, the prediction by Morgan's extractant was 0.4544 and for $CaCl^2$ method it was 0.4251.

4.6. Fertilizer doses for specific yield targets based on relationship of nutrient removal by crop with soil and fertilizer nutrients

4.6.1. The approach

Optimum dose of fertilizers may prove superior based on economic considerations in giving higher yields as well as profits with relatively lower dose of fertilizers. But viewing from the angle of maintaining the fertility of the soil, it has been suggested that the targetted yield approach is preferable since it ensures both higher yields and maintenance of soil fertility for sustainable crop production (Ramamoorthy **et al.**, 1967, 1971). With this in view, Ramamoorthy **et al.** (1967) have established reliable relationships between the nutrient uptake and grain yield and have proposed the concept of fertilizing the crop for specific yield targets based on balanced nutrition taking into consideration both efficiency and economy in the use of fertilizers.

4.6.2. Theoretical concept involved in fertilizer prescription for desired yield targets

Considering the nutrient uptake (U) by the crop as function of soil (S) and fertilizer (F) nutrients which is stated mathematically as

$$U = f(S,F) \tag{1}$$

Then the mathematical form of this function is written as

$$U = Cs\ S + Cf\ F \tag{2}$$

where Cs is the soil nutrient efficiency and Cf is the fertilizer nutrient efficiency.

Equation (1) is used for predicting the fertilizer amounts for specific yield targets and soil available nutrient level as described below :

First, the nutrient requirement (NR) of the crop is computed using the response data as

$$NR = \frac{U}{Y} \tag{3}$$

where, U is the nutrient uptake in kg ha^{-1} and Y is the yield in q ha^{-1}. The mean of all the experimental plots were taken as the nutrient requirement (NR) of that crop and expressed in the units of kg q-1. Secondly, the soil nutrient efficiency (Cs) is estimated as

$$Cs = \frac{Uo}{So} \quad (4)$$

where, Uo and So are respectively, the uptake of the nutrient by the crop (kg ha^{-1}) and the soil available nutrient level (kg ha^{-1}) in situation where fertilizer has not been applied. The mean of the control plots is taken as soil nutrient efficiency.

Thirdly, the fertilizer nutrient efficiency (Cf) is estimated as

$$Cf = \frac{UF - Uo}{F} \quad (5)$$

where, UF is the uptake of the nutrient in situation where fertilizer has been applied.

For easy computation, equation (5) can be written as

$$Cf = \frac{UF - (CF \times STV)}{F} \quad (6)$$

where STV is the soil available nutrient level in situation, where fertilizer has been applied because equation implies

$$Uo = Cs\ So \quad (7)$$

and for all practical purpose So = STV

Finally, substituting equation (2) in (3), we get

$$NR = \frac{Cs\ S + Cf\ F}{Y} \qquad (8)$$

solving equation (8) for F, we get

$$F = \frac{1}{Cf} \quad (NR\ Y - Cs\ S) \qquad (9)$$

Equation (9) serves for the purpose of predicting fertilizer amounts for specific yield targets and soil nutrient levels.

4.6.3. Methods for the calculation of efficiencies of soil and fertilizer nutrients

Over the year, the STCR correlation project co-ordinating cell has developed different methods for calculating the basic data. They are (1) the whole field (2) the yield maximum (3) the yield response.

In general, the value of efficiencies of soil and fertilizer should fall within 0 to 1. Sometimes variations in efficiencies caused due to the empirical nature of the soil test procedure (Mombiela **et al.**, 1981) or a priming effect (Maruthisankar **et al.**, 1983). The efficiencies of soil and fertilizer nutrients calculated from different methods are given below.

4.6.3.1. Whole field method

In the whole field method, all the treatment combinations are taken for working out the basic parameters for calculating the fertilizer prescription equations.

4.6.3.2. Yield maximum method

In the yield maximum method, the treatments which recorded the highest yield in each level of nutrient in all the four strips are taken for working out the basic parameters for calculating the fertilizer prescription equations.

4.6.3.3. Yield response method

In the yield response method, the treatments which give higher and positive response in each nutrient level in all the strips are taken for the calculation of basic parameters for working out the fertilizer prescription equations.

4.6.4. Employing the targetted yield equation for fertilizer prescription with different procedures (Table 20; Fig.6, 7 and 8)

Using the soil test crop response data of the present investigation by different methods the nutrient requirement (NR), the soil efficiency (Cs) and fertilizer efficiency (Cf) were calculated.

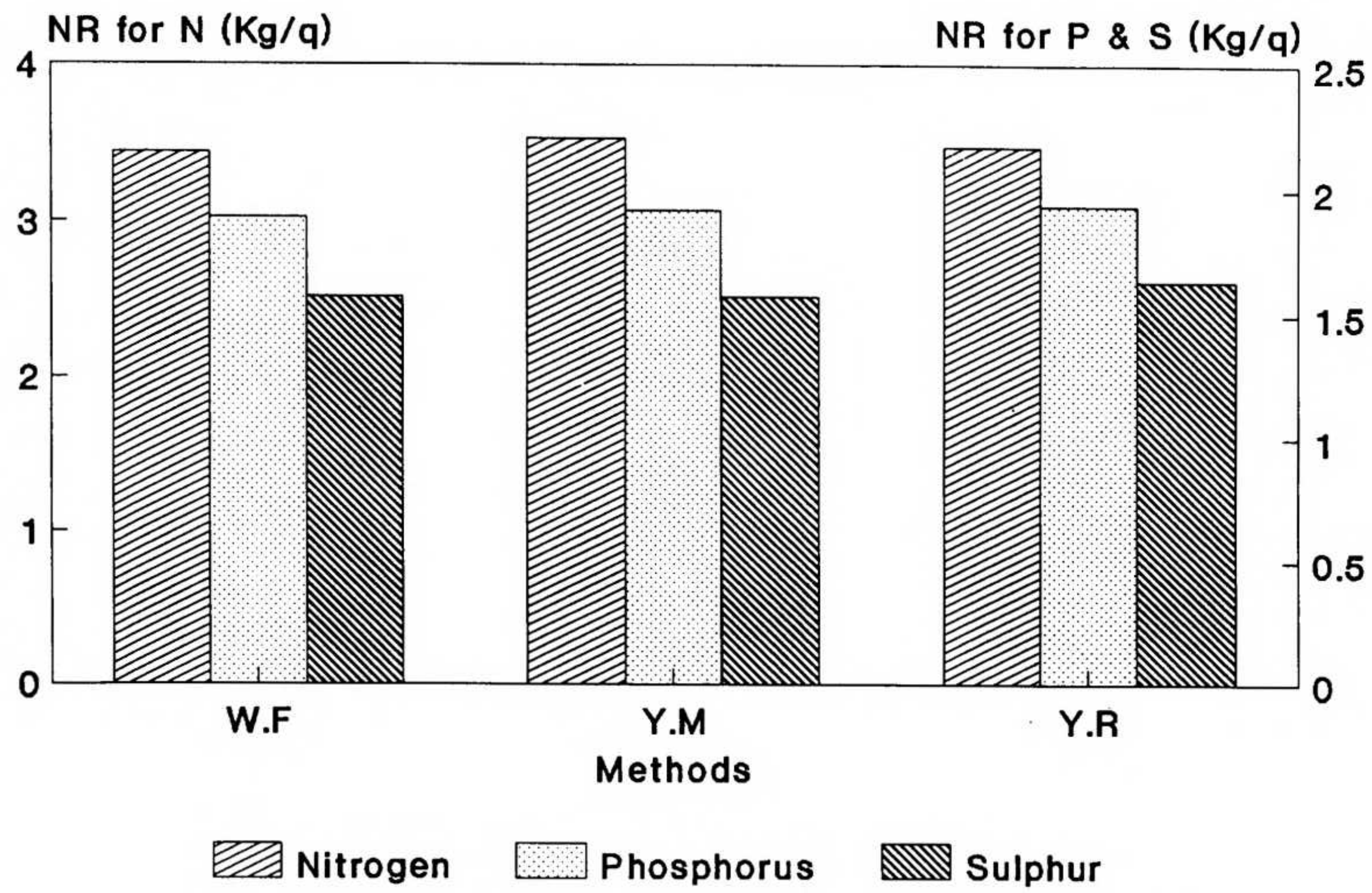
4.6.4.1. Whole field method

The results of whole field method indicated that sunflower required 3.4 kg of N, 1.89 kg of P and 1.57 kg of S for producing 1 q of sunflower. The soil nitrogen efficiency (Cs) was 0.1843 and the fertilizer nitrogen

Table 20. Nutrient requirement and estimates of Cs and Cf by different procedure for sunflower

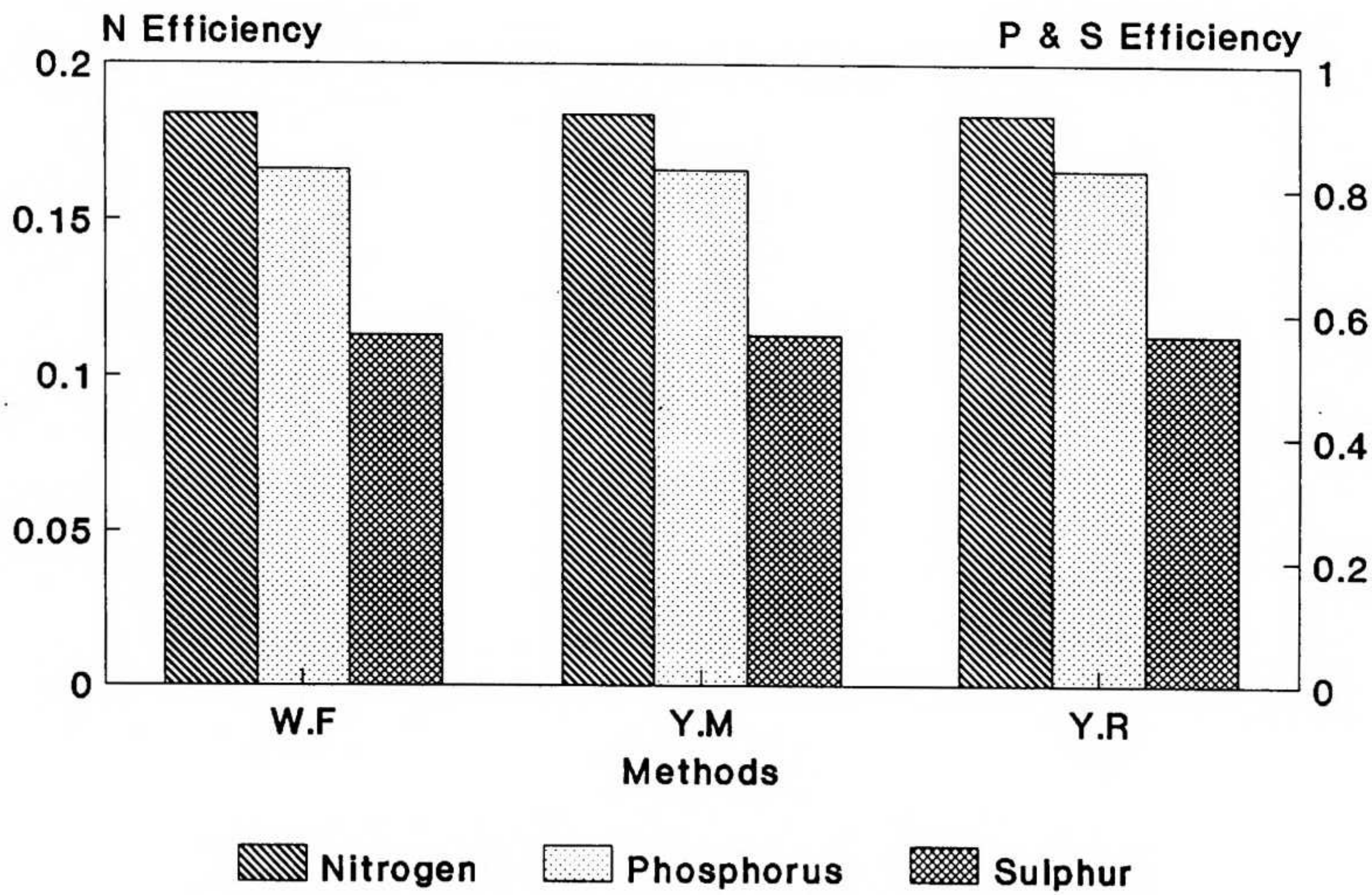
Nutrient	Whole field method			Yield maximum method			Yield response method		
	NR	Cs	Cf	NR	Cs	Cf	NR	Cs	Cf
Nitrogen	3.4446	0.1843	0.1941	3.536	0.1843	0.2629	3.477	0.1843	0.2018
Phosphorus	1.89	0.8306	0.9032	1.92	0.8306	0.8231	1.94	0.8306	0.6560
Sulphur	1.5741	0.5653	0.4093	1.573	0.5653	0.334	1.635	0.5653	0.333
Response yardstick (kg/kg)		3.79			4.25			3.40	

FIG.6 NUTRIENT REQUIREMENT FOR SUNFLOWER UNDER DIFFERENT METHODS



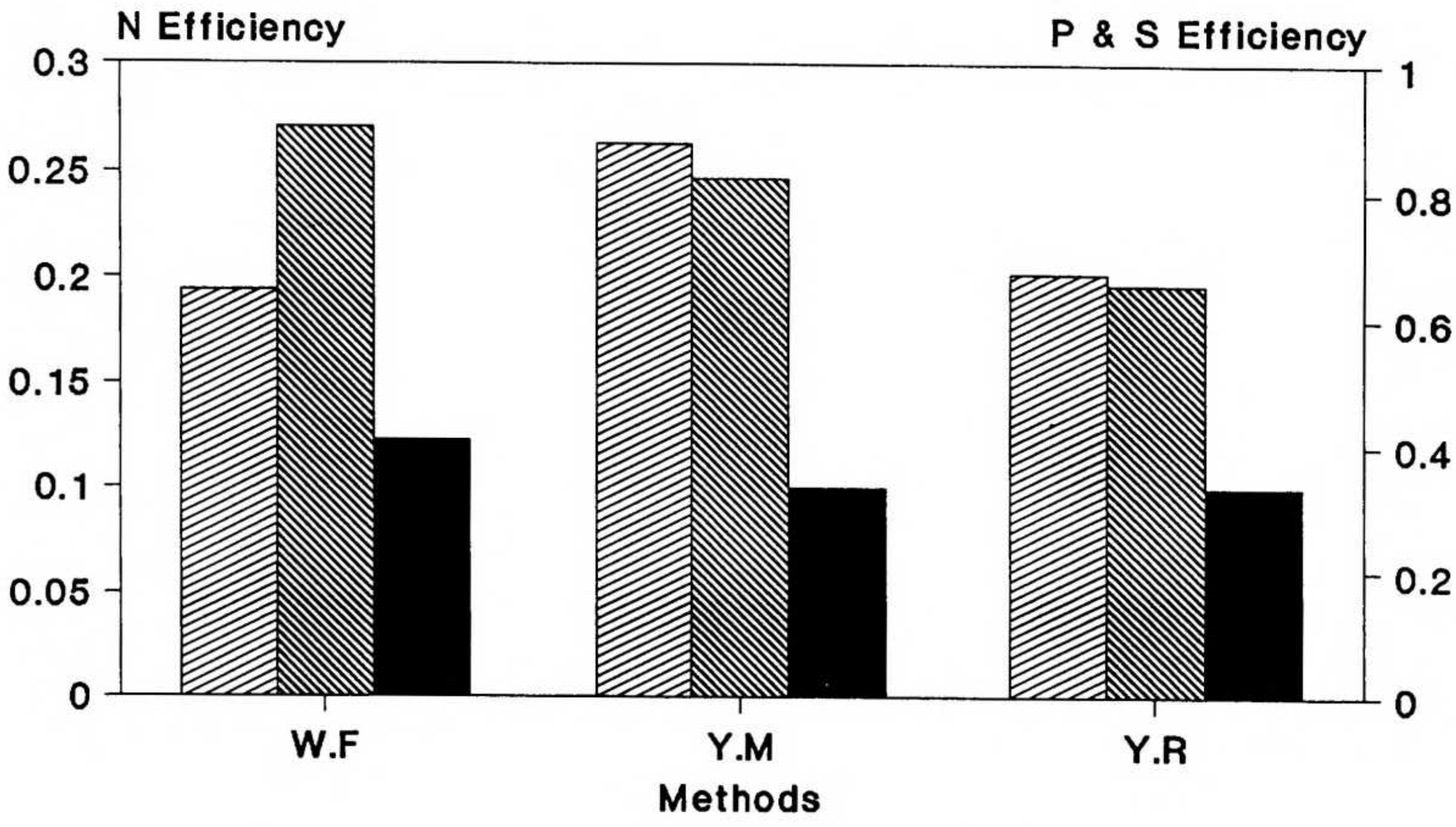
W.F-Whole Field, Y.M-Yield Maximum, Y.R-Yield Response

FIG.7 SOIL EFFICIENCY OF N, P & S
FOR SUNFLOWER UNDER DIFFERENT METHODS



W.F-Whole Field, Y.M-Yield Maximum, Y.R-Yield Response

FIG.8 FERTILIZER EFFICIENCY OF N, P & S FOR SUNFLOWER UNDER DIFFERENT METHODS



W.F-Whole Field, Y.M-Yield Maximum, Y.R-Yield Response

efficiency (Cf) was 0.1941. The efficiencies of both soil and fertilizer ranges from zero to one.

The soil phosphorus efficiency was 0.8306 and the fertilizer phosphorus efficiency was 0.9032. In the case of S, the soil efficiency (Cs) and fertilizer efficiency (Cf) was 0.5653 and 0.4093 respectively. The response yardstick was 3.79 kg kg^{-1}.

4.6.4.2. Yield maximum method

In the yield maximum method, the nutrient requirement was 3.5 kg of N, 1.92 kg P and 1.57 kg of S for producing one quintal of sunflower grain. The soil efficiency of N, P and S will be the same for three methods. The per cent fertilizer efficiency was 26.29, 82.31 and 33.4 for nitrogen, P and S respectively. The response yardstick for yield maximum method was 4.25 (kg kg^{-1}).

4.6.4.3. Yield response method

In the case of yield response method the nutrient requirements were 3.47, 1.94 and 1.63 respectively for N, P and S. The per cent fertilizer nitrogen efficiency was 20.18, the per cent fertilizer P efficiency was 65.60 and the per cent fertilizer S efficiency was 33.30. The response yardstick was 3.40 (kg/kg).

Among the different methods, the higher response yardstick (kg/kg) may be employed for judging the best method.

Among the different methods, yield maximum method registered higher response yardstick of 4.25 (kg/kg). So, the targetted yield equation was worked out using the basic parameters obtained from yield maximum method.

4.6.5. Targetted yield equation using yield maximum method

The targetted yield equations formed using the nutrient requirement (NR), soil efficiency (Cs) and the fertilizer efficiency (Cf) estimated by the yield maximum method are presented below,

$$FN = 13.45\ T - 0.70\ SN$$

$$F\ P_2O_5 = 5.36\ T - 2.31\ SP$$

$$F\ SO_4 = 4.71\ T - 5.07\ SS$$

where FN, FP, FS respectively are fertilizer nitrogen, phosphorus and sulphur in kg ha^{-1}, T is the grain yield target in quintal ha^{-1} and SN, SP and SS respectively are alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S in kg ha^{-1}.

A soil test calibration and fertilizer prediction using the above equation for an yield target of 20 q of sunflower grain ha^{-1} and for ranges of soil test values are presented in Table 21.

The results indicated that the fertilizer N requirement would be 199 kg ha^{-1} when the $KMnO_4$-N was 100 kg ha^{-1} and if the soil alkaline $KMnO_4$-N level was

Table 21. Fertilizer amounts for an yield target of 20 quintals ha^{-1} of sunflower grain under yield maximum method

Soil test $KMnO_4$-N kg ha^{-1}	Nitrogen amounts in kg N ha^{-1}	Soil test Olsen-P kg ha^{-1}	Phosphorus amounts in kg P_2O_5 ha^{-1}	Soil test Morgan's reagent-S kg ha^{-1}	Sulphur amounts in kg SO_4 ha^{-1}
100	199	5	95	10	44
125	181	10	84	15	18
150	164	15	73	20	-
175	146	20	61	25	-
200	129	25	49	30	-
225	111	30	38	35	-
250	94	35	26	-	-
275	76	40	15	-	-
300	59	45	3	-	-
325	41	50	-	-	-
350	24	-	-	-	-
375	6.5	-	-	-	-
400	-	-	-	-	-

375 kg ha^{-1}, the fertilizer requirement was only 6.5 kg ha^{-1} to achieve an yield target of 20 q ha^{-1}.

The fertilizer phosphorus requirement would be 95 kg P_2O_5 ha^{-1} for the lowest level of Olsen-P (5 kg ha^{-1}) and for highest level of Olsen-P (45 kg ha^{-1}) the fertilizer phosphorus requirement would be 3 kg P_2O_5 ha^{-1}.

In the case of sulphur, 44 kg SO_4 ha^{-1} would be the fertilizer S requirement to achieve an yield target of 20 quintal ha^{-1}, when the Morgan's reagent-S level in the soil was 10 kg ha^{-1}. For 15 kg of Morgan's reagent-S ha^{-1} level in soil, the fertilizer sulphur requirement would be 18 kg SO_4 ha^{-1}.

A soil test calibration and fertilizer prediction using the equation obtained from yield maximum method for an yield target of 25 q of sunflower grain ha^{-1} for different soil test values of N, P and S are presented in Table 22 (Fig.9, 10 and 11).

The fertilizer nitrogen requirement would be 266 kg ha^{-1} when the $KMnO_4$-N was 100 kg ha^{-1} and when the alkaline $KMnO_4$-N level was 375 kg ha^{-1}, the fertilizer N requirement was only 71 kg ha^{-1}.

In the case of phosphorus, 122 kg ha^{-1} would be the fertilizer P requirement to achieve an yield target of

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Table 22. Fertilizer amounts for an yield target of 25 quintals ha^{-1} of sunflower grain under yield maximum method

Soil test $KMnO_4$-N kg ha^{-1}	Nitrogen amounts in kg N ha^{-1}	Soil test Olsen-P kg ha^{-1}	Phosphorus amounts in kg P_2O_5 ha^{-1}	Soil test Morgan's reagent-S kg ha^{-1}	Sulphur amounts in kg SO_4 ha^{-1}
100	266	5	122	10	67
125	249	10	111	15	41
150	231	15	99	20	16
175	214	20	87	25	-
200	196	25	76	30	-
225	179	30	64	35	-
250	161	35	53	-	-
275	144	40	41	-	-
300	126	45	30	-	-
325	109	50	18	-	-
350	91	55	6	-	-
375	71	60	-	-	-
400	56	-	-	-	-
425	39	-	-	-	-
450	21	-	-	-	-
475	4	-	-	-	-
500	-	-	-	-	-

FIG.9. FERTILIZER N REQUIREMENT FOR AN YEILD TARGET OF 25 q/ha

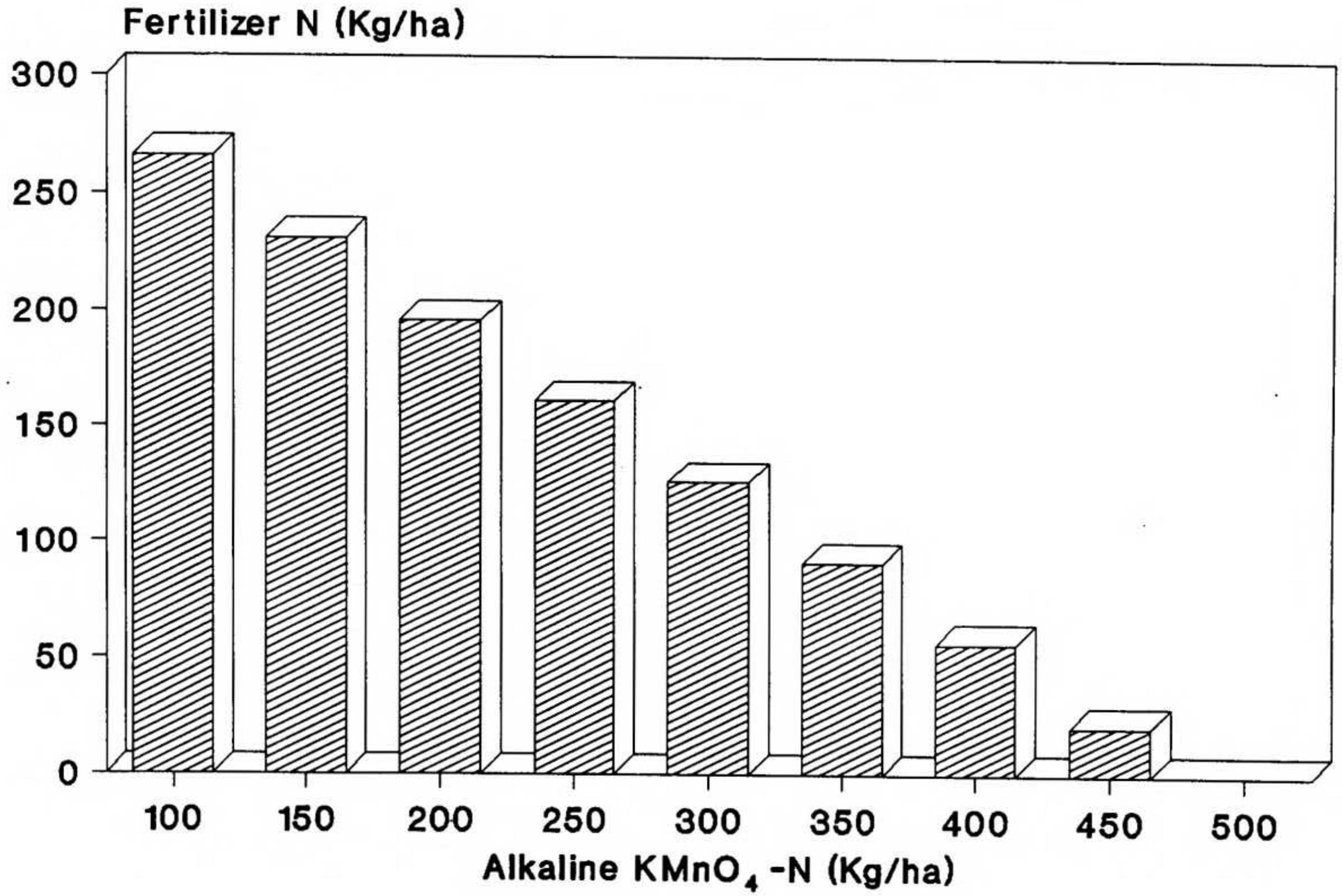


FIG.10 FERTILIZER P_2O_5 REQUIREMENT FOR AN YEILD TARGET OF 25 q/ha

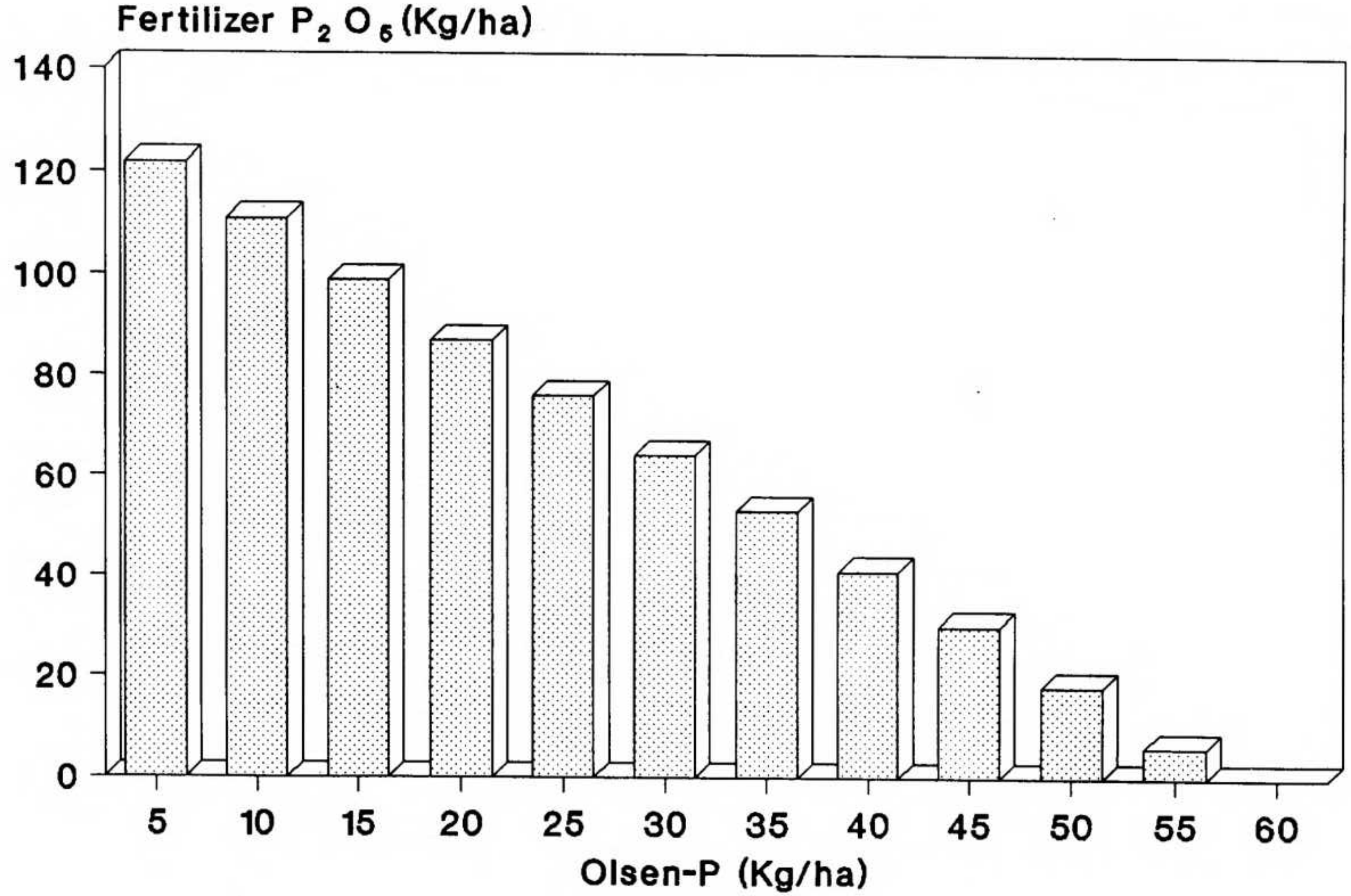
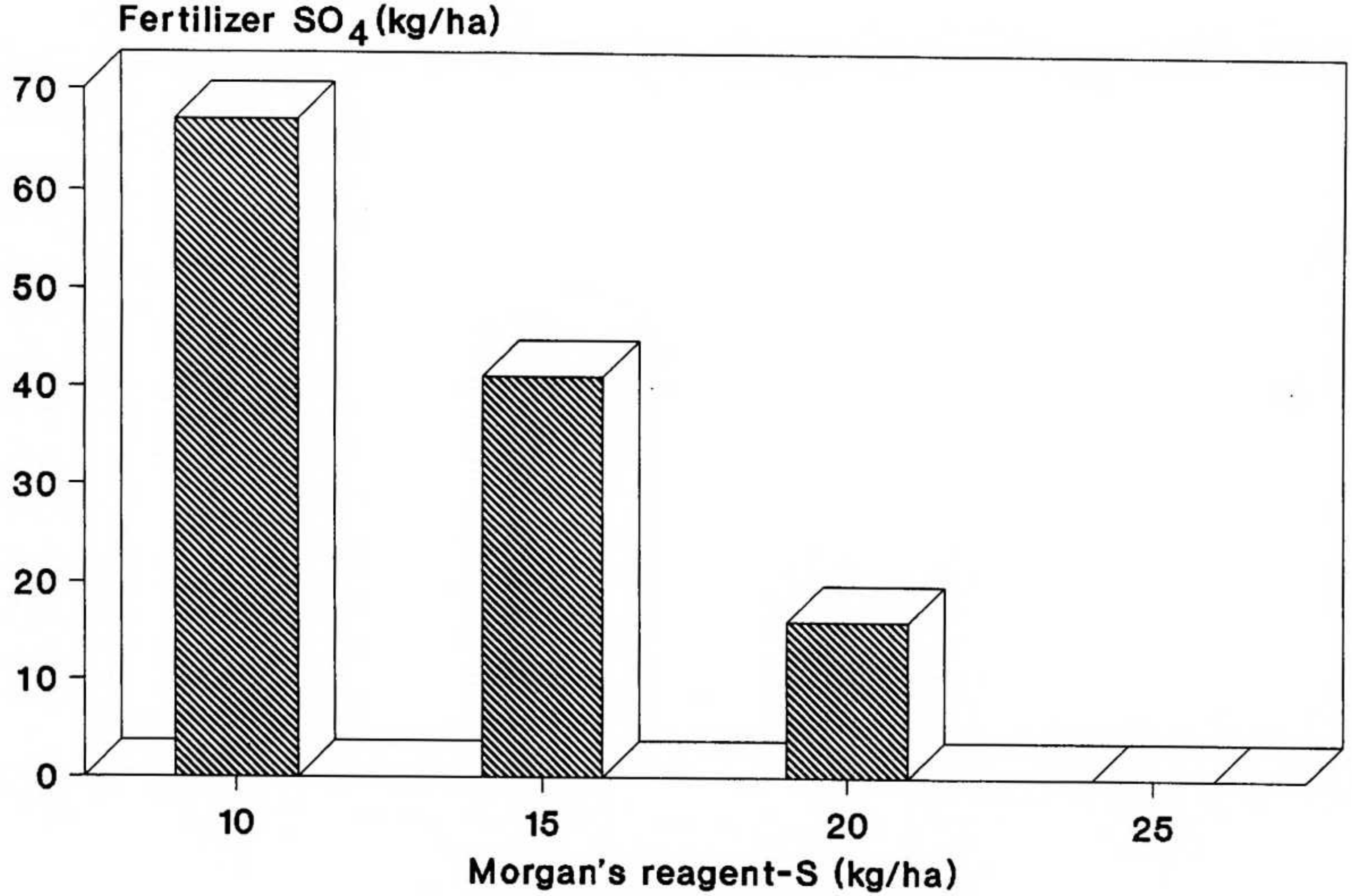


FIG.11 FERTILIZER SULPHATE REQUIREMENT FOR AN YEILD TARGET OF 25 q/ha



25 q ha^{-1} when the phosphorus level was low (5 kg ha^{-1}). For 55 kg of Olsen-P ha^{-1} in soil, the fertilizer P requirement would be 6 kg P_2O_5 ha^{-1}.

The results indicated that the fertilizer S requirement would be 67 kg SO_4 ha^{-1} when the Morgan's reagent-S level was 10 kg ha^{-1}. For 20 kg Morgan's reagent-S ha^{-1} level in the soil, the fertilizer S requirement would be 16 kg SO_4 ha^{-1}.

4.7. Effect of nutrients on sunflower crop

Generally oil seed crops requires more amount of N,P and S. All the three nutrients had positive and significant influence on grain, oil yield and protein content. For this purpose, certain treatment combinations were selected based on different levels of N, P and S and analysis of variance was worked out for assessing the superiority of the individual level combination. The treatment combinations are as follows

T_1 - $N_0P_OS_0$

T_2 - $N_{40}P_0S_0$

T_3 - $N_{40}P_{20}S_0$

T_4 - $N_{80}P_0S_0$

T_5 - $N_{80}P_{20}S_0$

T_6 - $N_{80}P_{20}S_{25}$

T_7 - $N_{80}P_{40}S_{50}$

T_8 - $N_{120}P_0S_0$

T_9 - $N_{120}P_{20}S_{25}$

T_{10} - $N_{120}P_{40}S_{50}$

T_{11} - $N_{120}P_{60}S_{25}$

T_{12} - $N_{120}P_{60}S_{50}$

T_{13} - $N_{160}P_{40}S_{50}$

T_{14} - $N_{160}P_{60}S_{50}$

4.7.1. Grain yield (Table 23; Fig.12)

The results clearly indicates that the combined application of 120 kg of N, 60 kg of P and 50 kg S ha^{-1} registered the highest grain yield of 2420 kg ha^{-1}. However, application of 120 kg N, 40 kg P and 50 kg S ha^{-1}, 160 kg N, 60 kg P, 50 kg S ha^{-1}, 120 kg N, 60 kg P, 25 kg S ha^{-1} and 160 kg N, 40 kg P and 50 kg S ha^{-1} registered on par yield with the above yield and were significantly higher than the other combinations. Hence, it can be concluded that the application of 120, 60, 50 kg N, P and S ha^{-1} can be recommended for getting yield of (2420 kg ha^{-1}).

4.7.2. Oil yield (Table 23; Fig.13)

Similar to that of grain yield, the oil yield was also increased by the application of 120 kg N, 60 kg P and 50 kg S ha^{-1} followed by the application of 120, 40.50 kg of N, P and S ha^{-1} respectively. Eventhough these two levels were statistically on par which were significantly higher than the other levels.

Table 23. Effect of fertilizer application on grain, oil yield and protein content of sunflower

Sl.No.	Fertilizer amounts (kg ha^{-1}) N	P	S	Grain yield kg ha^{-1}	Oil yield kg ha^{-1}	Protein content (%)
1.	0	0	0	1027	373	10.38
2.	40	0	0	1044	389	10.82
3.	40	20	0	1142	433	10.85
4.	80	0	0	1305	499	11.08
5.	80	20	0	1339	511	11.19
6.	80	20	25	1385	532	11.33
7.	80	40	50	1519	597	11.64
8.	120	0	0	1596	611	11.67
9.	120	20	25	1801	685	12.68
10.	120	40	50	2347	919	13.51
11.	120	60	25	2330	907	14.46
12.	120	60	50	2420	960	14.91
13.	160	40	50	2312	860	14.69
14.	160	60	50	2346	876	16.29
	CD (P=0.05)			101.42	42.91	0.536

FIG.12 EFFECT OF FERTILIZER ON SUNFLOWER GRAIN YIELD

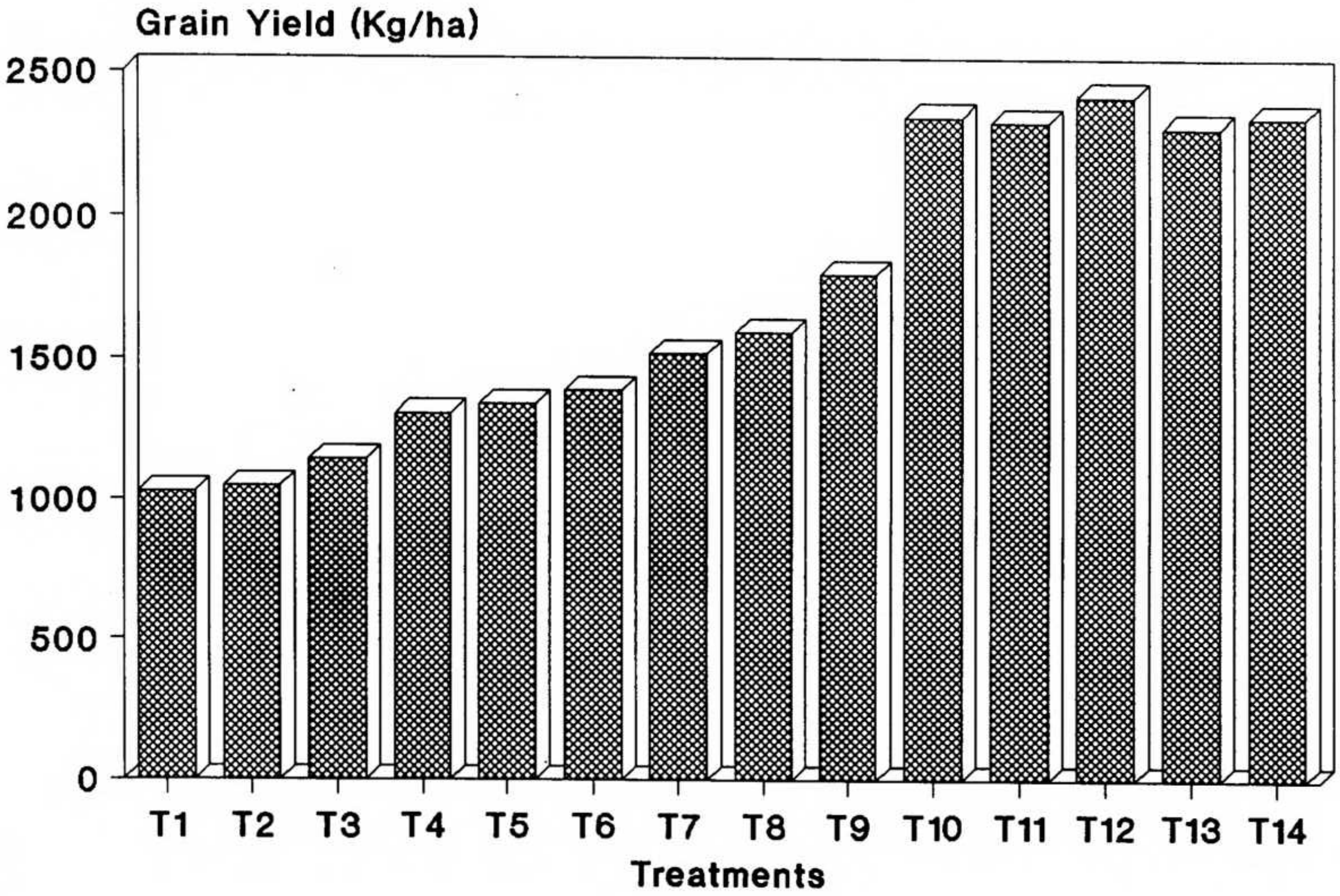


FIG.13. EFFECT OF FERTILIZER ON SUNFLOWER OIL YIELD

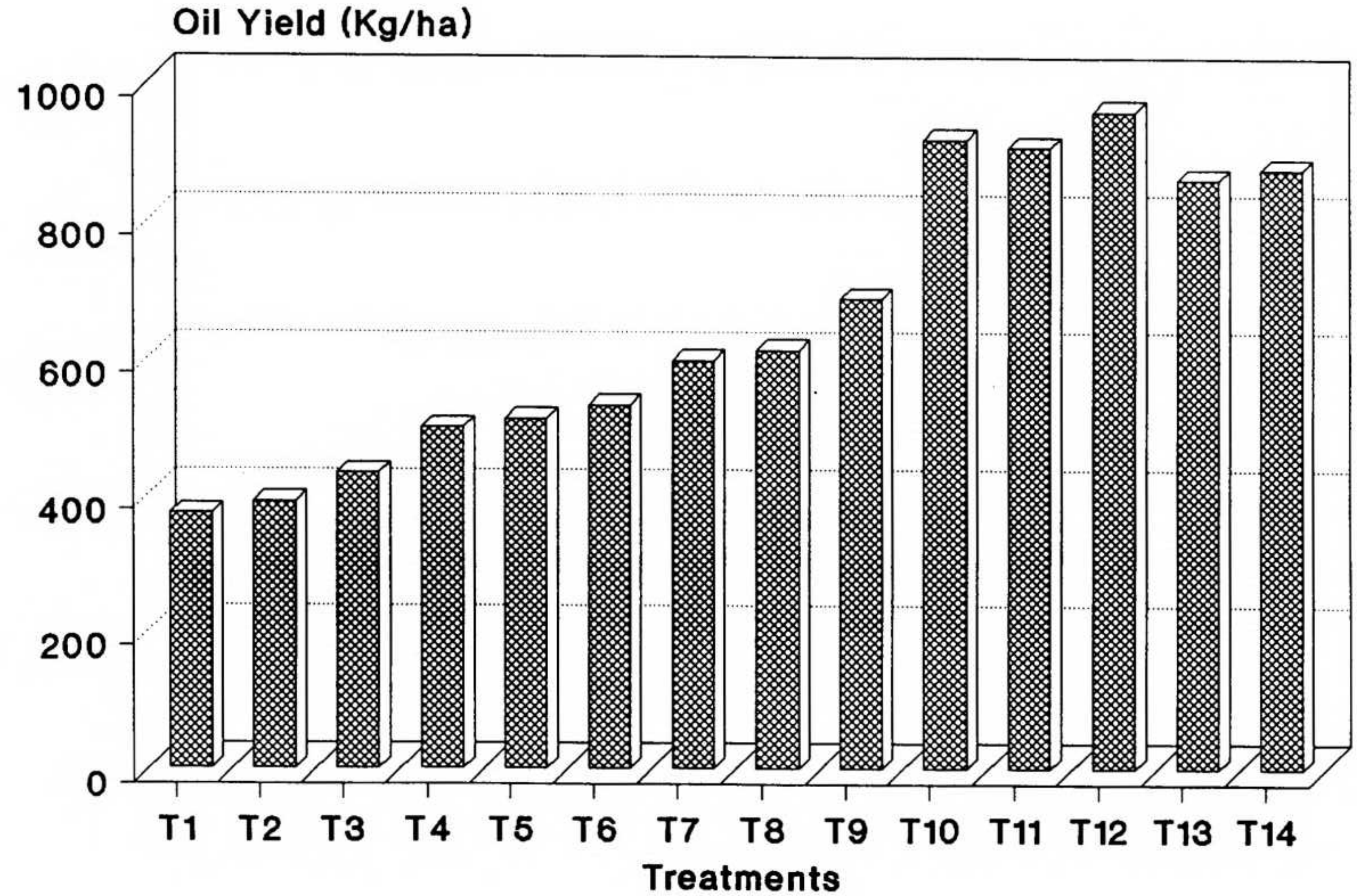
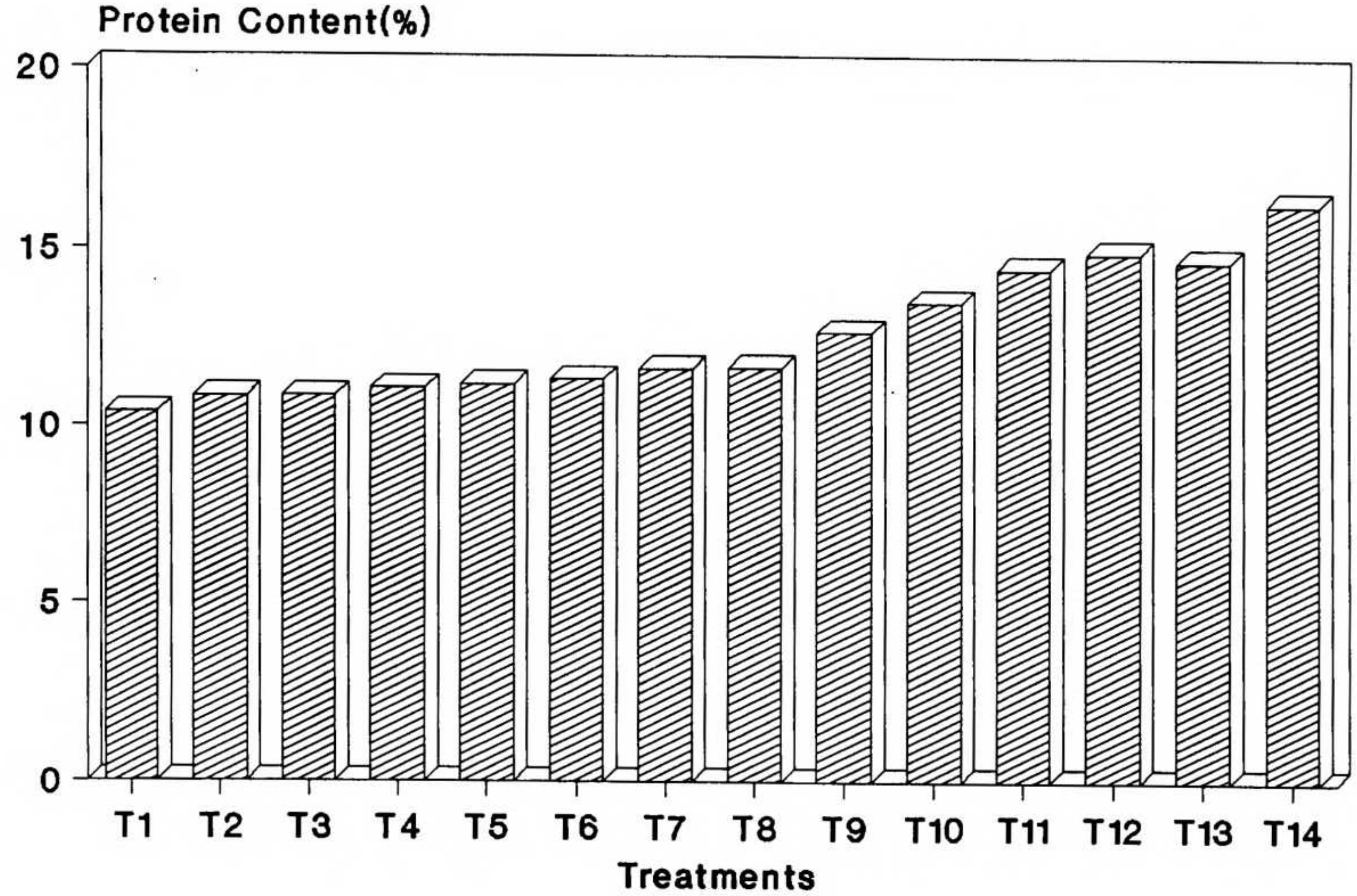


FIG.14 EFFECT OF FERTILIZER ON PROTEIN CONTENT



4.7.3. Protein content (Table 23; Fig.14)

Application of 160 kg N, 60 kg P and 50 kg S ha^{-1} registered significantly higher protein content of 16.29 per cent. This result implies that higher the N, P and S application higher will be the protein content.

4.8. Predictability of post-harvest soil test values for available nutrients

Predicting the post-harvest soil test values from the associated parameters like the initial soil test value, fertilizer dose and yield/nutrient uptake will be a useful approach for making fertilizer recommendations for the whole sequence at the beginning itself. This approach helps to overcome the handicap faced in going for a soil test for each crop in the sequence because of the limited time gap between the crops. Among the methods employed in predicting post harvest soil test, the linear polynomial model is generally used.

4.8.1. Predicting post-harvest soil test value based on linear polynomial model (Table 24)

Inorder to predict the post-harvest soil test values, linear polynomial equations were fitted relating the post-harvest soil test values (collected after the harvest of crop) with the pre-sowing soil test values (collected before planting of crop), the fertilizer doses and

Table 24. Relationship between post-harvest and presowing soil test values, applied fertilizer nutrients and grain yield/uptake

Soil test methods	Regression equation	R^2 value
Grain yield		
Y PH $KMnO_4$-N	4.38 + 0.17** FN + 0.88** IS $KMnO_4$-N -0.025 Grain yield	0.9698**
Y PH Olsen-P	-3.097 + 0.23** FP + 0.622** IS Olsen-P -0.004 Grain yield	0.9137**
Y PH Morgan's reagent-S	-5.15 + 0.18** FS + 0.77** IS Morgan's reagent-S -0.005 Grain yield	0.7077**
Uptake		
Y PH $KMnO_4$-N	-3.52 + 0.19** FN + 0.89** IS $KMnO_4$-N -0.605** N-uptake	0.9849**
Y PH Olsen-P	-2.39 + 0.23** FP + 0.58** IS Olsen-P -0.2 P uptake	0.9287**
Y PH Morgan's reagent-S	-0.56 + 0.12** FS + 0.47** IS Morgan's reagent-S -0.15 S uptake	0.6674**

** Significant at P = 0.01

IS Initial soil test
PH Post harvest soil test

yield/uptake, by assuming the following functional relationship

$$YPHS = f\ (F,\ IS,\ \text{yield/nutrient uptake}) \qquad (1)$$

where, YPHS is the post harvest soil test value, F is the applied fertilizer nutrient and IS is the initial soil test value of the respective nutrient. The equation (1) will take the mathematical form,

$$YPHS = a + b1\ F + b2\ IS + b3\ \text{yield/nutrient uptake} \qquad (2)$$

where 'a' is the absolute constant and bs are the respective regression coefficient. Using this approach, the linear polynomial equations were developed for predicting the post-harvest soil test values.

The linear polynomial equations (along with concerned R^2 values) used for predicting the post-harvest soil test values after the harvest of sunflower were presented in Table 24. The predictability of $KMnO_4$-N with yield and uptake was 0.9698^{**} and 0.9849^{**} respectively. With respect to Olsen-P, the predictability was 91 per cent with yield and 92 per cent with uptake. The predictability in the case of Morgan's reagent-S was 70 per cent with yield and 66 per cent with uptake.

4.8.2. Application of the models to the field data

The post-harvest soil test values of alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S after the harvest of crop was predicted for five experimental plots in each strip which received the treatments $N_0P_0S_0$, $N_1P_1S_1$, $N_2P_2S_2$, $N_3P_3S_2$ and $N_4P_3S_2$ by making these predictions, the linear polynomial equations in order to compare such predicted values with the actuals. In making these predictions, the linear polynomial equations involving the yield parameter were only considered because of their practical value and in most cases the predictability for these equations was higher as those of the equations involving the nutrient uptake. The predicted and observed soil test values are presented in Table 25, 26 and 27.

In order to assess whether there was depletion or built up of soil fertility the initial nutrients status were compared with that of post-harvest one for different yield targets of 20 and 25 q ha^{-1} using linear polynomial equation and the results are presented in Table 28. The results showed that there was depletion of alkaline $KMnO_4$-N from 200 kg to 152 kg ha^{-1} for 20 q and 151 kg for 25 q when the initial N was 200 kg ha^{-1}. For 20 kg Olsen-P ha^{-1} it depleted to 15.37 kg ha^{-1} for 20 q and 19.59 kg ha^{-1} for 25 q.

In the case of Morgan's regent-S it decreased to 6.1 kg ha^{-1} when the initial Morgan's reagent-S was 20 kg ha^{-1} for 20 q and 4.1 kg ha^{-1} for 25 q.

Table 25. Observed and predicted soil nitrogen ($KMnO_4$-N kg ha^{-1}) at values of grain yield and uptake of sunflower crop by linear polynomial model

Strip No.	Treatments	Observed	Predicted	
			Grain yield	Uptake
I	N_0 P_0 S_0	120	126	121
	N_1 P_1 S_1	136	140	141
	N_2 P_2 S_2	141	132	134
	N_3 P_3 S_2	142	141	142
	N_4 P_3 S_2	150	154	154
II	N_0 P_0 S_0	154	154	152
	N_1 P_1 S_1	170	172	174
	N_2 P_2 S_2	185	181	185
	N_3 P_3 S_2	189	186	189
	N_4 P_3 S_2	201	200	201
III	N_0 P_0 S_0	154	159	157
	N_1 P_1 S_1	178	175	173
	N_2 P_2 S_2	184	177	182
	N_3 P_3 S_2	189	188	188
	N_4 P_3 S_2	205	212	209
IV	N_0 P_0 S_0	173	173	173
	N_1 P_1 S_1	180	178	179
	N_2 P_2 S_2	183	180	184
	N_3 P_3 S_2	185	185	186
	N_4 P_3 S_2	198	201	197

Table 26. Observed and predicted soil phosphorus (Olsen-P kg ha^{-1}) at values of grain yield and uptake of sunflower crop by linear polynomial model

Strip No.	Treatments	Observed	Predicted	
			Grain yield	Uptake
I	N_0 P_0 S_0	5.34	7.15	6.71
	N_1 P_1 S_1	15.20	11.96	12.57
	N_2 P_2 S_2	19.70	18.54	18.98
	N_3 P_3 S_2	20.20	22.62	22.37
	N_4 P_3 S_2	21.20	21.15	20.66
II	N_0 P_0 S_0	7.40	10.53	10.14
	N_1 P_1 S_1	17.40	17.18	16.94
	N_2 P_2 S_2	20.00	22.22	22.75
	N_3 P_3 S_2	22.30	24.13	23.76
	N_4 P_3 S_2	23.20	25.82	24.64
III	N_0 P_0 S_0	8.10	5.55	5.98
	N_1 P_1 S_1	19.20	16.65	16.66
	N_2 P_2 S_2	23.00	22.30	22.77
	N_3 P_3 S_2	26.40	26.71	26.59
	N_4 P_3 S_2	27.20	27.24	26.16
IV	N_0 P_0 S_0	10.60	13.93	13.67
	N_1 P_1 S_1	21.70	20.14	19.98
	N_2 P_2 S_2	26.80	24.46	24.49
	N_3 P_3 S_2	29.20	26.83	30.53
	N_4 P_3 S_2	30.10	29.14	27.87

Table 27. Observed and predicted soil sulphur (Morgan's reagent-S kg ha^{-1}) at values of grain yield and uptake of sunflower crop by linear polynomial model

Strip No.	Treatments	Observed	Predicted	
			Grain yield	Uptake
	N_0 P_0 S_0	5.10	6.86	7.34
	N_1 P_1 S_1	9.30	8.39	9.01
I	N_2 P_2 S_2	10.80	13.02	12.12
	N_3 P_3 S_2	11.20	13.37	13.00
	N_4 P_3 S_2	10.40	13.05	12.79
	N_0 P_0 S_0	6.50	8.04	8.06
	N_1 P_1 S_1	14.20	9.69	9.77
II	N_2 P_2 S_2	12.10	12.39	12.67
	N_3 P_3 S_2	13.32	12.60	13.62
	N_4 P_3 S_2	10.50	12.24	12.97
	N_0 P_0 S_0	12.50	12.09	11.41
	N_1 P_1 S_1	14.60	11.92	12.09
III	N_2 P_2 S_2	16.20	18.50	16.78
	N_3 P_3 S_2	17.10	14.58	15.32
	N_4 P_3 S_2	16.10	14.78	14.60
	N_0 P_0 S_0	9.20	10.96	10.92
	N_1 P_1 S_1	15.20	14.01	13.63
IV	N_2 P_2 S_2	18.40	15.65	14.75
	N_3 P_3 S_2	16.30	17.27	19.91
	N_4 P_3 S_2	19.00	18.63	17.37

Table 28. Fertilizer requirement for maintenance of soil fertility after the harvest of the crop (ISTV $KMnO_4$-N-200 kg ha^{-1}, Olsen-P 20 kg ha^{-1}, Morgan's-S 20 kg ha^{-1}

Yield target q ha^{-1}	Sunflower crop						Post harvest soil test value kg ha^{-1}		
	Crop removal			Fertilizer dose kg ha^{-1}					
	N	P	S	N	P_2O_5	SO_4	N	P	S
15	53.00	29.00	24.00	62.00	34.00	0.00	153.40	11.16	8.10
20	70.00	38.00	31.00	129.00	61.00	0.00	152.00	15.37	6.10
25	88.00	48.00	39.00	196.00	88.00	16.35	151.00	19.59	4.10

DISCUSSION

CHAPTER V

DISCUSSION

The prime objective of an intensive agricultural system is to achieve the highest yield per unit urea. The crop production has to be increased through the efficient and economic use of fertilizers apart from the use of high/yielding strains. Soils are heterogeneous in nature and their physical, chemical and biological properties affect the availability of native and added nutrients to the crops. In soil, mechanisms like nutrient fixation and release, nutrient mobility, their mineralisation and immobilizations are influenced by these soil properties. Hence, there is an absolute need to make fertilizer predictions for crops based on soil properties or, in taxonomical terms soil types (Goswami, 1986).

Fertilization programmes are to be based on soil properties, especially on its inherent capacity to supply nutrients to the crops in a balanced proportion and crop uptake. The real balance for maximum yield is "not that between the applied nutrients but that after taking into account the relative availability from soil and fertilizer" (Ramamoorthy, 1993). The emphasis on soil test based balanced fertilization has become much more relevant in the present scenario of high fertilizer costs and yield maximisation programmes.

Recommendations based on fertilizer needs of crop can not be developed for each piece of land because such exercises are not only laborious but also expensive and time consuming. Instead, experiments for a crop can be conducted on a soil which represents a larger area in a particular region and the results of such experiments could be extrapolated profitably to other areas with similar soils.

The effect of N, P and S on the growth and yield of sunflower crop has been studied extensively in earlier times. However, the interaction effect of all the above three nutrients and the balanced fertilizer recommendation have not been studied so far. Keeping all the above aspects in mind, the present field investigation was carried out on a red noncalcareous soil (Irugur soil series) viz., Inceptisols of Agricultural Research Station, Bhavanisagar using sunflower test crop. The study included the selection and characterisation of the soil of the experimental site, raising gradient crop maize Co 1 and test crop with sunflower MSFH-8, screening suitable soil test methods for estimating available N,P and S. It also includes the evaluation of crop yield response with soil test values for optimising the fertilizer requirements and prediction of post-harvest soil test values based on initial soil test values. The salient findings of the experimental results are discussed in this Chapter.

5.1. Characterisation of the experimental soil

The soil which was red noncalcareous belonged to Irugur series. It was dark red to dark reddish brown, moderately deep, fine loamy and well drained with neutral reaction (pH 6.9). The soil was free from salinity and sodicity hazards with EC of 0.2 dSm^{-1}. The available N, P and K status were low, medium and high respectively. The CEC was 16.5 C mol (p+) kg^{-1} and dominant clay mineral is kaolinitic type.

There is significant increase in clay content in B_1 and B_2 horizons, but the increase is not sufficient enough to qualify for an argillic horizon. Further there was no signs of clay illuviation as evident from the absence of clay films. The subsurface, therefore qualifies for cambic horizon.

The soil has been grouped under the order Inceptisol (Soil Survey Staff, 1975). The soil moisture regime is ustic and the temperature regime is isohyperthermic. Hence the suborder is ustropepts. The great group is Udic Ustropept as there was no accumulation of secondary lime nodules in the solum. The soil family name is fine loamy, mixed, isohyperthermic Udic Ustropepts which is the central concept of Irugur series.

The irrigability class of Irugur soil series is 3St, *viz.*, lands with severe limitations due to moderate solum depth and gently sloping topography. This implies that leaching loss of nutrients are likely to occur when the soils belonging to Irugur soil series (Dhanapalan Mosi **et al.**, 1978). The crop suitability classification made by the same authors revealed that Irugur series is poorly suited for paddy, highly suited for groundnut and sunflower and moderately suited for pulses. This was also confirmed in the present investigation. A maximum yield of 2.7 tonnes ha^{-1} of sunflower seed was obtained.

The soils of the experimental site belonged to 'Ld' group of the fertility capability class of Buol **et al.** (1975), which implies that soil respond to heavier N application and the response to any added nutrient will become pronounced only if sufficient amount of moisture prevails in the soil.

5.2. Fertility gradient experiment

The crop yield (Y) is related to the amount of available soil (S) nutrient and fertilizer (F) nutrients, then,

$$Y = f(S, F)$$

In Soil Test Crop Response studies, it is necessary that the variables S and F should have ranges which are sufficient enough to cover the full range of crop response surface for optimization purposes. It is easier to keep a range with respect to applied fertilizer (F) nutrient levels. The practical limitation is to create such a range with respect to soil nutrient levels. This was done by creating fertility gradient within the experimental field by employing the "inductive field methodology" (Ramamoorthy, 1968). A comparison of the yields and nutrient uptake by the gradient crop of maize as well as the comparison of pre sowing and post-harvest soil samples were useful for the creation of fertility gradient in the experimental site.

5.2.1. Soil fertility status

The soil fertility status with reference to N, P and S was assessed in this experiment by analysing the pre sowing and post-harvest soil samples of the gradient crop. The alkaline $KMnO_4$-N levels in soil after the harvest of fodder maize ranged from 156 to 228 kg ha^{-1}, which indicates the significant built up of soil N as compared to initial one. Among the strips, alkaline $KMnO_4$-N increased with dose of applied fertilizer N. However, the fourth strip recorded a mild reduction in the built up of available N.

The result of analysis of variance also confirmed that each strip was significantly different from other strips with respect to alkaline $KMnO_4$-N. The experimental soil was sandy clay loam in texture with medium cation exchange capacity and the gradient crop being maize, a gardenland crop, leaching losses would have been less resulting in the built up of N status in the soil. Sumam (1988), Saravanapandian (1990) and Natarajan (1991) were also successful in creating soil fertility gradient with respect to available soil nitrogen before raising the test crop.

The mean values of organic carbon were 0.36, 0.40, 0.43 and 0.44 in Strip I to IV respectively. The results of analysis of variance showed that the fertilizer treatments significantly influenced the organic carbon content of the gradient strip. This might be due to high root biomass production in fertilized strips. Similar results were reported by Murugappan (1985) and Natarajan (1991).

Under results among the two nitrogen availability indices that is alkaline $KMnO_4$-N and organic carbon, the former proved to be a better index than the latter and thus the results obtained with organic carbon may not be of much significance in the creation of fertility gradient with respect to soil available N.

Similar to soil N levels, fertility gradient was created with respect to available P also. This was evident from the ranges of Olsen-P, 18.5 to 33.5 kg ha^{-1} and Bray-P 36.0 to 57.0 kg ha^{-1}.

Progressive increase was observed in the mean values of P extracted by these two extractants from Strip I to IV. Available P (Olsen-P and Bray-P) among the four fertility gradient strips, after the harvest of fodder maize indicated such that significant variations have been created. This was possible because a major portion of the applied P would have been retained in the soil which was noncalcareous in varying degrees of solubilities. Further, phosphorous being an immobile nutrient, the loss through leaching was very negligible and so the built up of fertility gradient with regard to soil available P was well pronounced. Balasundaram (1978), Murugappan (1985), Murugesa Boopathi (1988) and Natarajan (1991) have also succeeded in creating fertility gradient with respect to soil available P.

With reference to available S Morgan's reagent-S ranged from 20.9 to 32.6 kg ha^{-1} while 0.15% $CaCl_2$-S ranged between 31.0 and 51.2 kg ha^{-1} indicating significant increase in the availability of S. Progressive and significant increase in available S among the different strips might be due to the addition of graded doses of fertilizer S.

5.2.2. Crop yield and nutrient uptake

The fodder and drymatter yield of maize increased progressively from Strip I (control) to Strip IV (which received twice the amount of N, P and S fertilizers). The mean fodder yield in Strip I to IV was 9.03, 11.24, 12.33 and 19.22 t ha^{-1} and the corresponding dry matter yield was 1.81, 2.05, 2.28 and 3.84 t ha^{-1}. The comparison of yield parameters (fodder and drymatter yield) and the significance of 'F' test clearly indicated that there was significant variation in soil fertility which reflected on the yield. The nutrient uptake is an indication of its relationship with crop yield. Similar to that of fodder and drymatter yield the uptake of N, P and S was also increased with increasing level of fertilizers. The results of variance analysis for the nutrient uptake also revealed that each strip was significantly different from other with respect to soil fertility after the harvest of fodder maize. The comparison of soil test values before and after the gradient experiment, also clearly indicated the creation of significant variations in soil fertility of the experimental field. Similar results were reported by Natarajan (1991) and Shanmugam (1992).

5.3. Effect of applied nutrient on response

5.3.1. N-response

The response for N increased with increased level of N. The nutrient response expressed as grain yield increased per unit quantity of N applied have been worked out and it is 7.65 kg of seed per kg of N for 120 kg N ha^{-1} and it decreased to 6.87 kg for 120 kg N ha^{-1}. The decrease in response showed by the application of increased levels of N might be due to genetic make up of crop. This results corroborates with the findings of Prasanthi (1989).

5.3.2. P-response

The highest unit response is for addition of 60 kg P ha^{-1}. The response increased from 2.72 to 11.98 kg of seed per kg for addition of 60 kg P ha^{-1}. This might be due to medium P status of the soil and high response of this soil to applied P.

5.3.3. S-response

The added S behaved differently with application 25 kg S ha^{-1}. The response decreased from 2.08 to 1.98 kg of seed per kg of S. This might be due to that soil is sandy clay loam in texture wherein the entire dose of S was applied as basal, the leaching losses could have contributed to the decrease in S response.

5.4. Selection of suitable soil testing procedure

Soil tests are the simple and rapid chemical methods that are employed to determine the nutrient supplying ability of the soil. They enable us to arrive at the quantity of fertilizer needs of crops in a given situation. The efficiency of soil testing in determining the fertilizer needs of crops under field condition with different crops have been well established by soil scientists (Dhanapalan Mosi, 1975; Rani Perumal, 1975; Velayutham **et al.**, 1985 and Rhodes, 1988). However, the validity of soil test methods for accurate prediction of such fertilizer needs vary with nature of crop and soil and there is always a search for the best methods for a given situation. Therefore, in the present investigation, an attempt has been made to screen the available soil testing procedures and to select the suitable ones for sunflower grown in a sandy clay loam soil of Irugur series. The selection of appropriate soil testing procedure was made by simple correlation and multiple regression analysis.

5.4.1. Simple correlation studies

The commonly adopted soil testing procedure for the estimation of available soil nutrients **viz.**, alkaline $KMnO_4$ and organic carbon methods for N, Olsen and Bray I methods for P and Morgan's reagent and 0.15% $CaCl_2$ methods for S were employed in the present investigation. Simple correlation of the soil test values by each method were made with sunflower responses for surface soils.

The results of the simple correlation studies revealed that the alkaline $KMnO_4$-N correlated positively and significantly with grain yield, oil yield and nutrient uptake (0.8057^{**}, 0.689^{**} and 0.7853^{**}).

The organic carbon content also correlated positively and significantly with grain yield, oil yield and nutrient uptake (0.6506^{**}, 0.525^{**} and 0.6504^{**}).

The phosphorus indices that is Olsen-P and Bray-P correlated significantly with all the response variables viz., is grain yield, oil yield and nutrient uptake. (0.4567^{**}, 0.4440^{**} and 0.3639^{**} for Olsen-P and 0.6203^{**}, 0.2610^{**} and 0.5326^{**} for Bray-P).

With regard to sulphur Morgan's reagent-S registered significant and positive correlation with grain yield, oil yield and uptake. The values for Morgan's reagent-S were 0.5166^{**} and 0.483^{**} and 0.2447^{*}. In the case of $CaCl_2$-S it showed positive significant correlation with grain yield (0.3653^{**}) and non significant correlation with oil yield and uptake.

Thus in the correlation studies, significant correlation was established with some soil testing procedures while they were weak with some other soil testing procedures. Thus clearcut conclusion on the selection of suitable soil testing procedure could not be drawn with the results of simple correlation studies. Research workers in the past like Datta and Kalbande (1967), Dubey **et al.** (1972). Kanwar and Bhumbla (1967), Murugappan (1985) and Natarajan (1991) too could not achieve much success in correlation studies in selecting suitable soil testing procedures. The low degree of predictability of the correlations was attributed to the curvilinear relationship between the variables correlated.

Ramamoorthy (1968) advocated the use of multiple regression analysis in selecting the most appropriate soil testing procedures for measuring available N, P and K. Therefore, an attempt was made in the present study to relate soil test values with yield and nutrient uptake through multiple regression analysis, as they were expected to show a clear picture.

5.4.2. Multiple regression analysis

In this approach, the magnitude of multiple coefficient of determination (R^2) indicating the degree of fit of the data is usually the chief guiding factor for selecting the most appropriate soil testing procedure. The multiple regression equations relating sunflower response variables, viz., yield and nutrient uptake with soil test values of available soil nutrients in all possible combinations (8) of soil test methods (2 for nitrogen x 2 for phosphorus x 2 for sulphur) and fertilizer nutrients were fitted separately.

In general significant R^2 values were obtained for sunflower with respect to quadratic polynomial function relating yield with soil available and fertilizer nutrients. This indicated the utility of multiple regression analysis with quadratic polynomial function in screening the best combination of soil testing procedure employed in such studies. Similar observations were reported by Murugappan (1985), Natarjan (1991) and Shanmugam (1992).

Considering the highly significant R^2 values in all the cases clearly elucidates that alkaline $KMnO_4$-N and organic carbon method were adequate to describe the changes in available N. Similarly Olsen-P was as good as Bray-P and so also Morgan's reagent-S and $CaCl_2$-S. However, among the eight combinations the R^2 value for $KMnO_4$-N, Olsen-P and Morgan's reagent-S combination gave the highest R^2 value indicating the best fitness when compared to other combinations.

Alkaline $KMnO_4$-N being a direct measure of NH_4 released from the oxidisable organic matter of the soil and organic carbon an indirect measure of soil nitrogen, the former could be expected to contribute more towards uptake and yields of crop than the latter. Alkaline $KMnO_4$-N could have extracted more of aminoacid and hydrolysable NH_4^+ N fraction of the soil (Rani Perumal **et al.**, 1988) than organic carbon method and this might probably have resulted in higher positive and significant values for the alkaline $KMnO_4$-N.

The Olsen reagent 0.5 M $NaHCO_3$ would have more preferential extraction of Ca-P than Fe-P and Al-P (Bray extractant). The crop under study being sunflower an upland crop would have responded better for its preferable fraction of Ca-P rather than others. As a result Olsen-P would have contributed more towards yield than Bray-P and thus the preferential absorption of Olsen-P could be ascribed as cause for higher values of partial regression coefficient for Olsen-P than Bray-P. Similar results were reported by Prasanthi (1989) in groundnut. Several scientists have reported the suitability of Olsen-P for different crops (Pathak **et al.**, 1975; Ekpeta, 1976; Grewal and Sharma, 1979; Baljit Singh, 1977; Ayodele and Agboola, 1981; Sidhu **et al.**, 1983; Patil and Patel 1983; Rao **et al.**, 1984; Selvaraj, 1988 and Sumam, 1988).

For sunflower Morgan's reagent-S and $CaCl_2$-S registered positive values for partial regression coefficient. The capacity to extract S from soils, differed greatly among the extractants used. Kaolinitic type of clay mineral which are predominant in these soils (Irugur series) are known to have high SO_4 adsorption capacity as compared with those dominantly 2:1 type of clay minerals. Sulphate adsorption has been shown to be essentially reversible on kaolinite but almost irrversible on iron and Aluminum oxides. This might be the probable reason for higher correlation with Morgan's reagent than $CaCl_2$ extractant (Ghai **et al.**, 1984).

The results of background research on soil testing the suitability of different soil test methods through multiple regression showed that more than 90 per cent variation in crop yield could be explained by the variation in available N, P and S status. The significance of all the partial regression co-efficient which are positive for SN, SP and SS in the equation indicated that the soil test values determined by alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S significantly affecting the yield of sunflower. The R^2 values showed that the above combinations are best suited for accurately measuring the available nutrients in quantitative proportions as nearly as possible to that of sunflower roots in Udic Ustropepts of Lower Bhavani Project ayacut area established the superiority of alkaline $KMnO_4$, Olsen-P and Morgan's reagent-S combination over others by registering significant values of R^2 more than 0.90^{**}.

5.5. Optimization of fertilizer doses for specific yield targets

The fertilizer use in optimum amounts and proportions mainly depends on the capacity of the soil to supply the native nutrient, the efficiency of applied nutrient and the crop yields (Randhawa and Velayutham, 1982; Velayutham **et al.**, 1985). The concept of fertilizer prescription for specific yield target (Truog, 1960; Ramamoorthy **et al.**, 1967; Aggarwal and Ramamoorthy, 1978; Maruthisankar **et al.**, 1983; Murugappan **et al.**, 1989a and 1989b) not only embraces the above aspects but also ensures both high yields and the maintenance of soil fertility to support a sustained crop production. The theoritical basis involved in this concept of predicting fertilizer needs of crop is well explained under section (4.6.2)

$$F = \frac{1}{B} (NRY - \alpha S)$$

is used as the basis for making such predictions. The calculation procedures of nutrient requirement (NR) and efficiency parameters, α and β , are developed by Ramamoorthy **et al.** (1971). Using the soil test crop response data of the present investigation NR, α and β were estimated by employing this procedure.

The nutrient requirement values indicated that sunflower requires 3.53, 1.92 and 1.57 kg of N, P and S respectively to produce one quintal of sunflower seed. Nutrient requirement is calculated as

$$NR = \frac{U}{Y}$$

On rearrangement of this relationship, it takes the form

$$U = NRY$$

which is a straight line without an intercept. This implies that as long as uptake (U) increases, the yield (Y) also increases. However, in reality this is not the case always.

In the present investigation, the soil and fertilizer efficiencies were determined from whole field, yield maximum and yield response methods developed in the All India Co-ordinated Project on STCR correlation studies (Ramamoorthy **et al.**, 1967, Maruthisankar **et al.**, 1983, 1989). In these methods the Cs is estimated from the values of unfertilized plots and Cf is calculated from treated plots after giving allowance for soil contribution.

As considering the soil and fertilizer efficiency parameters their values fell within the range of zero to one (below 100 per cent) for all the three nutrients in all the three methods employed in the present study. As has been indicated by Maruthisankar **et al.** (1983), these values have got restrictions or otherwise the amounts of nutrients released or added into the soil available pool subsequent to raising of a crop during the growth period through a priming effect as in the case of N and K or by fixation of atmospheric nitrogen by leguminous crops would vitiate the efficiency parameters.

In the whole field method the nutrient requirement for N, P and S is 3.45, 1.89 and 1.57 kg q^{-1} respectively. Whereas in the case of yield response method the above mentioned indices are 3.48, 1.94 and 1.64 kg q^{-1} respectively. In the yield maximum method the values were 3.54, 1.92 and 1.57 kg q^{-1}.

The results clearly showed that there was no marked difference in the estimates of soil efficiency employing all the three methods. However, the soil efficiency of P was more than 80 per cent in all the three methods when compared to N and S.

The fertilizer nitrogen efficiency under whole field method, yield maximum method and yield response method were 19.41, 26.29 and 20.18 per cent respectively.

For the same three methods, the fertilizer P efficiency were 90.32, 82.31 and 65.60 per cent respectively. The sulphur efficiency for the applied fertilizer under above three methods were 40.93; 33.42 and 33.33 per cent respectively. Considering the efficiency of individual nutrients under three methods studied P efficiency was higher than N and S efficiency. This might be due to various losses that are occurred during the mineralisation process of N and S whereas P is not undergoing such losses.

5.5.1. Targetted yield equation

Among the various methods employed for workingout the fertilizer prescription equation, the best method was selected based on the response ratio. Employing the estimates of NR, Cs, Cf obtained from the chosen yield maximum method (response yardstick is 4.25 kg kg^{-1}) the fertilizer doses were optimized for different yield targets. The calibrated fertilizer adjustment equation for sunflower MSFH-8 as follows.

$$FN = 13.45\ T - 0.70\ SN$$

$$FP_2O_5 = 5.36\ T - 2.31\ SP$$

$$FSO_4 = 4.71\ T - 5.07\ SS$$

A soil test calibration and fertilizer prediction for an yield target of 20 and 25 quintals of sunflower grain

ha^{-1} for $KMnO_4$-N, Olsen-P and Morgan's reagent-S were workedout and given as ready reckoner.

The general blanket recommendation for sunflower is 40:20 for N and P respectively. Based on the targetted equation developed, the fertilizer requirement for an yield target of 25 q ha^{-1} was 196 kg for N 87 kg for P and 41 kg for S when the initial soil test values were 200 kg $KMnO_4$-N, 20 kg Olsen-P and 15 kg Morgan's reagent-S. Though the fertilizer requirements determined through specific yield targets were high, it not only increased the yield but also maintains soil fertility.

5.6. Effect of fertilizer application on the yield and protein content

Crop production, intensive or extensive being a complex process is controlled by a large number of exogenous and endogenous factors. In a given set of agroclimatic conditions, the profitability of crop production inturn depends upon the choice of suitable varieties and adoption of improved agronomic practices. Of the agronomic practices, nutrient supply especially N, P and S is by large, the most important single factor that affects the crop yield.

Adequate nitrogen supply increased the amount of cell plasma and chlorophyll which are vital factors for growth, whereas the fertilization of P helps in improving the seed weight and also development of deeper and proliferous root system leading to extraction of water and nutrients from deeper layers of soil profile. Sulphur is essential for oil synthesis. Hence, an attempt was made in the present investigation to study the influence of added fertilizer nutrient on yield and protein content. Selected treatment combinations of N,P and S were subjected to statistical analysis. The results are discussed below.

5.6.1. Influence of applied fertilizer on grain yield

The influence of applied N,P and S at different levels of application workedout through analysis of variance. The results indicated that grain yield was significantly increased by the application of 120 kg N ha^{-1} along with P and S. Several scientists reported that application of N increased the seed yield (Rao and Reddy, 1982; Sarkar, 1985; Sagare **et al.** 1986; Singh **et al.**, 1987; Sharma and Gaur, 1988; Chaniara **et al.**, 1989; Hirary **et al.**, 1992 and Vivek **et al.**, 1994). Higher seed yield with increased levels of N might be due to favourable effect of N on the diameter of the flower head, number of filled seed per flower head and leaf area which ultimately contributed to the increased seed yield (Mane **et al.**, 1989).

Increased seed yield by the application of P was observed by several authors (Palanivel and Ramanathan, 1981; Maheswarappa **et al.**, 1985; Sagare **et al.**, 1986; Chaniara **et al.**, 1989; Naphade and Naphade 1991 and Ateeque **et al.** 1992). This might be due to the effect of P on seed weight and development of deeper and proliferous root system leading to extraction of water and nutrient from deeper layers of soil profile.

Sulphur application also increased the grain yield (Channel and Balakrishna Rao 1981; Tandon, 1986; Tiwari, 1989; Kene **et al.**, 1990 and Prabhuraj **et al.**, 1993). The increase in seed yield due to application of S levels could be attributed to the increased seed set, head diameter and 100 seed weight (Parameswaran, 1974).

5.6.2. Influence on oil yield

With respect to the influence of applied nutrient on the oil yield, the analysis of variance showed a significant result. The result revealed that application of 160 kg N, 40 kg P and 50 kg S ha^{-1} recorded significant increase in oil yield. Increased dose of N increased the oil yield. This was corroborated with findings of several authors. (Loubser and Grimbeek, 1985; Ujjinaiah **et al.**, 1990; Kene **et al.** 1990 and Manoharan **et al.**, 1991). The reason for increased oil yield might be due to favourable effect of N on oil content and seed yield.

Application of P also increased the oil yield. This was supported by Tarakeswara Rao **et al.**, 1989; Kene **et al.**, 1990; El-Naggar and Allam, 1991 and Hiremath **et al.** 1991. The increased oil yield could be attributed to the increased seed yield.

In the case of sulphur also the increased dose of S increased the oil content and oil yield. It was reported by Revenko (1977), Raut and Ghonsiker (1978), Ajab Singh Yadav and Harishankar (1980), Singh and Sahu (1986), Prabhuraj (1988) and Sagare **et al.** (1990). This might be due to full utilization of carbohydrates in the presence of S for the synthesis of oil in oil seed crops (Yadav and Singh, 1970).

5.6.3. Influence on protein content

The results of analysis of variance with respect to protein content showed a significant influence of the applied N, P and S. Application of 160 kg N along with 60 kg P and 50 kg S ha^{-1} registered higher protein content. Increased dose of N increased the protein content. This was similar with the findings of El-Sayed **et al.** (1984), Loubser and Grimbeek (1985), Tripathi and Shawney (1989) and Manoharan **et al.** 1991. The increased protein content by increased level of N might be due to higher N uptake which favoured the synthesis of protein (Shimanskii, 1961).

Phosphorus nutrient was also found to increase the protein content. This was supported by Srivastava (1978), Maheswarappa **et al.** (1985) and El-Naggar and Allam (1991). This might be due to increased uptake of N by P seed and this N might subsequently be expected to be incorporated in the protein molecule.

In the case of S also increased dose of S increased the protein content. Similar findings were also reported by Ajabsingh Yadav and Harishankar, 1980 and Singh and Sahu, 1986). This may be well explained that in sunflower, protein synthesis from carbohydrate was at a faster rate than oil synthesis.

5.7. Prediction of fertility changes in the soil

In enduring and sustainable agriculture, the basic aim is replenishing back that has been removed by crop. This concept is being exphasised by targetted yield approach. The soil testing is quite ideal way to ascertain the quantity of available nutrients in the soil. In the present day intensive agriculture programmes, where cropping sequences instead of single crops are preferred, testing the soils after each crop is impracticable. Hence, the basis developed by Ramamoorthy **et al.** (1974) to predict the post-harvest soil test values is made use of in the present investigation. An appraisal of experimental evaluation of prediction of fertility changes attempted in this present investigation is given below.

5.7.1. Prediction of post-harvest soil test values

The changes in the soil test values for the major nutrients after the growth of the crop would normally depend on pre-sowing soil test values, the yield levels obtained, the fertilizer doses added, the addition and losses of nutrients that occurred in the soil during the crop growth.

A basis for calculating the nutrient residue after the harvest of crop could be obtained by statistical evaluation of the dependence of post-harvest soil test values on the initial soil test values and other associated parameters like yield, fertilizer dose, etc., has outlined by Ramamoorthy **et al.** (1971) and Singh and Ramamoorthy (1974).

In this present investigation the multiple regression of post harvest soil test values on yield or uptake, fertilizer dose for the nutrient and the initial soil test values were carried out. Highly significant R^2 values of 0.970^{**} for $KMnO_4$-N with yield and 0.985^{**} with N-uptake were recorded. The difference between the calculated soil test values for the treated plots (5 plots in each strip) and the experimental values of the same was found to be very negligible that they both agreed very closely.

Similarly for Olsen-P, highly significant relationship exist with R^2 values of 0.914^{**} with yield and 0.929^{**} with uptake.

Significant relationship was observed for the Morgan's reagent-S with yield (0.708^{**}) and uptake (0.667^{**}).

5.7.2. Soil fertility maintenance targets of sunflower crop

From the regression analysis, the post-harvest soil analysis were predicted for different yield targets of sunflower from the initial soil test values of 200, 20 and 20 kg of $KMnO_4$-N, Olsen-P and Morgan's reagent-S ha^{-1}. In order to assess whether there was depletion or built up of soil fertility, the initial status was compared with that of postharvest one at an yield target of 15, 20 and 25 quintals ha^{-1}. The results indicated that depletion of $KMnO_4$-N, Olsen-P and Morgan's reagent-S in all the three targets. Since the sunflower crop is nutrient exhaustive crop, the built up of nutrients might not have observed.

SUMMARY AND CONCLUSIONS

CHAPTER VI

SUMMARY AND CONCLUSIONS

With a view to study response of sunflower to soil and fertilizer nutrients, field experiments were conducted in Agricultural Research Station, Bhavanisagar, Periyar District, Tamil Nadu. The soil of the experimental site represented Irugur soil series and it is fine loamy, moderately deep, netural, isohyperthermic family of Udic Ustropept. The experimental approach followed was the inductive methodology by which fertility gradients with respect to nitrogen, phosphorus and sulphur were created in the experimental soil by applying different amounts of these nutrients and by growing Co.1 maize. Test crop of sunflower (MSFH-8) was raised and grown under irrigated conditions.

Test crop experiments consisted of measured levels of fertilizer nutrients **viz.**, N,P and S. There were 24 treatment combinations of N,P and S consisting of five levels of N, four levels of P and three levels of S (including zero level) were superimposed over the fertility gradients in order to make predictions on the fertilizer requirements.

Surface soil samples were collected before and after the harvest of test crop and analysed for available nitrogen (alkaline $KMnO_4$-N and organic carbon), phosphorus (Olsen-P and Bray-P) and sulphur (Morgan's reagent-S and $CaCl_2$-S). Plant samples collected and analysed for N, P and S so as to calculate the respective nutrient uptake. The quality parameters such as protein and oil were also assessed.

Relationship between soil test values and yield parameters/nutrient uptake were made by simple correlation studies as well as multiple regression analysis.

For precise estimation of soil and fertilizer nutrient efficiencies, three different methods were employed and compared. Making use of the data generated from the test crop experiments, targetted yield equations were computed using the calculated values of nutrient requirement and soil and fertilizer nutrient efficiencies. An attempt was also made to predict the post-harvest soil test values from the initial soil test values, fertilizer nutrients added to sunflower and the yield/nutrient uptake of sunflower.

The effect of added fertilizers on the grain yield, oil yield and protein content was also determined.

The salient findings and conclusions of the present study are as follows.

6.1. Creation of fertility gradient

In the fertility gradient experiment with fodder maize, it was found that the development of fertility gradient was pronounced significantly in all the cases of nutrients. **viz.**, nitrogen, phosphorus and sulphur.

6.2. Selection of suitable soil testing procedure

Among the eight combinations of soil test methods tested, the combination of alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S was found as ideal and superior for accurately measuring the available soil nutrients based on the correlation studies and multiple regression analysis.

6.3. Optimization of fertilizer doses for specified yield targets

Among the three methods (Whole field, yield maximum and yield response method) tried in this study, they recorded the response ratio of 3.79, 4.25 and 3.40 respectively. The yield maximum method recorded the highest response ratio. Hence, the estimates of soil and fertilizer nutrient efficiencies calculated by this method were used for developing fertilizer prescription equation for sunflower. In the yield maximum method the per cent contribution of soil and fertilizer nutrients for N, P and S were 18, 83, 56 and 26, 82, 33 per cent respectively. Employing these parameters nutrient requirement, fertilizer efficiency and soil efficiency, the following fertilizer prediction equation were derived.

$$FN = 13.45\ T - 0.70\ SN$$

$$F\ P_2O_5 = 5.36\ T - 2.31\ SP$$

$$F\ SO_4 = 4.71\ T - 5.07\ SS$$

Where T - yield target (q ha^{-1}), FN, FP, FS are fertilizer nitrogen, phosphorus and sulphur in kg ha^{-1} respectively and SN, SP, SS are alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S in kg ha^{-1} respectively.

A soil test calibration was evolved using the above equations for an yield target of 20 and 25 q ha^{-1} for sunflower for the range of soil test values existed in the experimental plots. To achieve an yield target of 20 q ha^{-1} for a soil test values of 200, 20 and 15 kg of alkaline $KMnO_4$-N, Olsen-P and Morgan's reagent-S, the fertilizer requirement was calculated. The calculated doses were found to be 129, 61 and 18 kg of N, P_2O_5 and SO_4 per hectare respectively.

6.4. Influence of applied fertilizer on the yield and protein content

A study on the influence of addition of different levels of nitrogen, phosphorus and sulphur on grain yield, oil yield and protein content were also made. The study revealed that application of 120 kg of N, 60 kg P and 50 kg S ha^{-1} recorded significantly higher grain yield of 2420 kg ha^{-1}. The percentage increase was 136 as compared to control.

6.5. Prediction of post-harvest soil test values based on initial soil tests

Prediction of post-harvest soil test values after the harvest of sunflower were made from the relationship of initial soil test values, fertilizer nutrients applied and yield/nutrient uptake based on linear polynomial model as given below.

Grain yield

Y PH $KMnO_4$-N = $4.38 + 0.17^{**} + 0.88^{**}$ IS $KMnO_4$-N -0.025 Grain yield

Y PH Olsen-P = $-3.097 + 0.23^{**}$ FP + 0.622^{**} IS Olsen-P -0.004 Grain yield

Y PH Morgan's reagent = $-5.15 + 0.18^{**}$ FS + 0.77^{**} IS Morgan's reagent-S -0.005 Grain yield

Uptake

Y PH $KMnO_4$-N $= -3.52 + 0.19^{**}$ FN $+ 0.89^{**}$ IS $KMnO_4$-N -0.605^{**} N-uptake

Y PH Olsen-P $= -2.39 + 0.23^{**}$ FP $+ 0.58^{**}$ IS Olsen-P -0.2 P uptake

Y PH Morgan's reagent-S $= -0.56 + 0.12^{**}$ FS $+ 0.47^{**}$ IS Morgan's reagent-S -0.15 S uptake

These relationship could be profitably used in occasions where sufficient time is not left before raising the second crop to go for soil test as this practice would be better than applying fertilizer to the second crop without actually going for soil test.

Thus, it can be concluded that based on the results obtained from this study, balanced fertilization can be recommended for achieving higher yield targets using the targetted yield equation developed from the investigation. This result can be passed on to the farmers for adoption after conducting the test verification trials.

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* Original not seen

Annexure I. Response relationship of sunflower (grain yield) and soil available and fertilizer nutrients

Response function	R^2 value
$Y = -401.27 + 3.14^{*}\ KMnO_4\text{-N} + 13.74\ \text{Olsen-P} + 16.19^{*}\ \text{Morgan's reagent-S} + 7.31^{**}\ FN + 0.014\ FN^2 - 6.06\ FP + 0.17^{**}\ FP^2 - 0.37\ FS + 0.08\ FS^2 - 0.02\ FNSN + 0.146\ FPSP - 0.02\ FSSS$	0.9445^{**}
$Y = -455.88 + 1450\ OCN + 12.78\ \text{Olsen-P} + 19.71^{*}\ \text{Morgan's reagent-S} + 5.07\ FN + 0.007\ FN^2 - 4.44\ FP + 0.17^{**} FP^2 + 1.18\ FS + 0.08\ FS^2 - 1.58\ FNSN + 0.089\ FPSP - 0.068\ FSSS$	0.9241^{**}
$Y = -462.06^{*} + 4.212^{**}\ KMnO_4\text{-N} + 8.13\ \text{Bray-P} + 11.69\ \text{Morgan's reagent-S} + 6.81^{**}\ FN + 0.006\ FN^2 - 2.37\ FP + 0.137^{**}\ FP^2 - 5.61\ FS + 0.09\ FS^2 - 0.015\ FNSN + 0.036\ FPSP + 0.159\ FSSS$	0.9401^{**}
$Y = -417.79 + 1453.35\ OCN + 5.19\ \text{Bray-P} + 2353^{**}\ \text{Morgan's reagent-S} + 3.91\ FN + 0.006\ FN^2 - 3.69\ FP + 0.155^{**}\ FP^2 - 0.403\ FS + 0.065\ FS^2 + 0.49\ FNSN + 0.046\ FPSP + 0.0134\ FSSS$	0.9221^{**}
$Y = -535.83^{**} + 4.52^{**}\ KMnO_4\text{-N} + 10.83^{**}\ \text{Bray-P} + 4.73\ CaCl_2\text{-S} + 8.05^{**}\ FN + 0.008\ FN^2 - 2.24\ FP + 0.145^{**}\ FP^2 - 6.034\ FS + 0.09\ FS^2 - 0.0224\ FNSN + 0.029\ FPSP + 0.107\ FSSS$	0.9184^{**}

$$Y = -606.25^{*} + 1632.42^{*}\ OCN + 6.896\ Bray\text{-}P + 15.297^{**}\ CaCl_2\text{-}S + 6.27\ FN + 0.007\ FN^2 - 3.27\ FP + 0.162^{**}\ FP^2 + 0.056\ FS + 0.082\ FS^2 - 5.162\ FNSN + 0.037\ FPSP - 0.027\ FSSS \qquad 0.9211^{**}$$

$$Y = -485.19^{*} + 3.56^{*}\ KMnO_4\text{-}N + 23.03^{*}\ Olsem\text{-}P + 3.58\ CaCl_2\text{-}S + 8.83^{**}\ FN + 0.012\ FN^2 - 4.22\ FP + 0.164^{**}\ FP^2 - 2.06\ FS + 0.104\ FS^2 - 0.025\ FNSN + 0.089\ FPSP + 0.006\ FSSS \qquad 0.9245^{**}$$

$$Y = -601.92^{*} + 1664.54^{*}\ OCN + 19.060\ Olsen\text{-}P + 9.15\ CaCl_2\text{-}S + 6.92^{*}\ FN + 0.006\ FN^2 - 3.69\ FP + 0.17^{**}\ FP^2 + 2.71\ FS + 0.09\ FS^2 - 5.12\ FNSN + 0.06\ FPSP - 0.092\ FSSS \qquad 0.9210^{**}$$

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* Significant at P = 0.05

** Significant at P = 0.01

Annexure II. Response relationship of sunflower (nutrient uptake) and soil available and fertilizer nutrients

Response function		R^2 value
N uptake	= $56.97^{*} - 0.6287\ SN_1 + 0.2903\ FN + 0.0026^{**}\ SN_1^2 + 0.0013^{**}\ FN^2 - 0.0012\ SN_1\ FN$	0.8792^{**}
	= $67.68 - 291.93\ SN_2 - 0.1928\ FN + 510.04\ SN_2^2 + 0.007\ FN^2 + 0.0018^{**}\ SN_2\ FN$	0.8497^{**}
P uptake	= $17.79 - 0.4589\ SP_1 + 0.0609\ FP + 0.0231\ SP_1^2 + 0.0069^{**}\ FP^2 - 0.0018\ SP_1\ FP$	0.8267^{**}
	= $7.55 + 0.2013\ SP_2 + 0.069\ FP + 0.0035\ SP^2_2 + 0.0061^{**}\ FP^2 - 0.0022\ SP_2\ FP$	0.7967^{**}
S uptake	= $-3.33 + 1.1041\ SS_1 + 0.2653\ FS - 0.0128\ SS_1^2 + 0.0012\ FS^2 - 0.0026\ SS_1\ FS$	0.4544
	= $16.65 - 0.105\ SS_2 + 0.786\ FS + 0.0023\ SS_2^2 + 0.0010\ FS^2 + 0.0051\ SS_2\ FS$	0.4251

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

SN_1 = $KMnO_4$-N SP_1 = Olsen-P SS_1 = Morgan's reagent-S

SN_2 = Organic carbon SP_2 = Bray-P SS_2 - $CaCl_2$-S

PLATE 1. Experimental Field-An Overview

PLATE 2. Experimental Field-Flowering Stage