

**SOIL TEST CROP RESPONSE STUDIES ON WHEAT UNDER  
INTEGRATED PLANT NUTRITION SYSTEM IN ALFISOLS**

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## **CERTIFICATE**

This is to certify that the thesis entitled “**SOIL TEST CROP RESPONSE STUDIES ON WHEAT UNDER INTEGRATED PLANT NUTRITION SYSTEM IN AIFISOLS**” submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in AGRICULTURE** to the **TAMIL NADU AGRICULTURAL UNIVERSITY, COIMBATORE** is a record of Bonafide Research Work carried out by **VANDANA L.JAYAN** under my Supervision and Guidance and no part of this thesis has been submitted for the award of any degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any Scientific or Popular Journal or Magazine.

Place : Coimbatore

Date :

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## **ABSTRACT**

### **SOIL TEST CROP RESPONSE STUDIES ON WHEAT UNDER INTEGRATED PLANT NUTRITION SYSTEM IN ALFISOLS**

By

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**Degree : M.Sc (Agriculture) in Soil Science and  
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Increasing agricultural production is absolutely essential to meet the growing population of 1.25 billion by the year 2020 AD. The projected wheat demand of the country is 109 million tonnes and this calls for an additional 37 million tonnes of wheat production by 2020 AD.

With the escalating cost of chemical fertilizers and deteriorating ecosystem, it is essential to adopt a strategy of Integrated Plant Nutrition System (IPNS) for wheat production by using judicious combinations of chemical fertilizers, organic manures and bio-fertilizers. To increase the production potentials of wheat and for the sustenance of soil fertility through balanced fertilization, the soil testing research should be directed to calibrate soil test values for recommending manures, chemical and biofertilizers for desired yield targets. Hence, the present investigation was envisaged with the objectives to make soil test calibrations and to formulate fertilizer recommendations under IPNS for wheat by targeted yield approach, to evaluate the extent of saving of fertilizer inputs under IPNS and to select suitable soil testing procedures for assessing the available N, P and K for wheat.

Two field experiments viz., gradient crop experiment with an exhaustive crop of potato variety Giriraja and test crop experiment with wheat variety HW2044 were

conducted in red non calcareous sandy clay loam Ultic Hapludalf of Ooty series in the IARI, Wheat Research Station, Wellington, Coonoor. After creation of fertility gradient, the test crop experiment was conducted in four strips with 28 treatment combinations of 5 levels of nitrogen, 4 levels of phosphorous and 4 levels of potassium randomized in each strip. For the IPNS treatments, vermicompost @ 5 t ha<sup>-1</sup> and *Azospirillum* @ 2 kg ha<sup>-1</sup> were super imposed across the strips. The experiment was carried out in a Fractional Factorial Randomised Block Design.

The initial and the post harvest soil samples of wheat were analysed for the available nutrient status and the grain yield and dry matter were recorded. The plant samples were analysed for N, P and K content and the nutrient uptake was calculated. From the soil test and crop response data, the basic parameters viz., nutrient requirement (NR), soil efficiency (Cs), fertiliser efficiency (Cf) and organic efficiency (Co) were computed. Based on these basic parameters equations were developed under IPNS.

#### **NPK with Vermicompost plus *Azospirillum***

$$FN = 7.6 T - 0.55 SN - 1.5 ON$$

$$FP_2O_5 = 3.59 T - 0.26 SP - 0.95 OP$$

$$FK_2O = 3.88 T - 0.45 SK - 1.2 OK$$

The fertilizer estimates under IPNS clearly brought forth the yield increase (5468 kg ha<sup>-1</sup> in NPK with vermicompost and *Azospirillum* treatments) and efficient nutrient use in terms of response ratio. When Vermicompost alone was applied @ 5 t ha<sup>-1</sup>, a contribution of 36,11 and 20 kg of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O respectively could be achieved. Inclusion of *Azospirillum* @ 2 kg ha<sup>-1</sup> resulted in a saving of 10 kg ha<sup>-1</sup> of fertiliser nitrogen. Hence under IPNS, these quantities of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O fertilizers could be reduced from the recommended dose of nutrients resulting in economy of fertilizer use other than maintenance of soil fertility.

The Fertiliser Prescription Equations (FPE) developed in the present study can be advocated to the related soil series after validation. The soil test based balanced fertiliser recommendations under STCR- IPNS for wheat not only helped in achieving higher yield targets but also in the sustenance of soil fertility.

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## **CHAPTER I**

### **INTRODUCTION**

Cereals contribute to the most important group of food grains of man kind and wheat is usually accorded the pride of place for providing the people with high quality nutritive food. Wheat is the world's most widely cultivated crop and one of the earliest known crops. Cultivation of wheat dates back to prehistoric times of settled agriculture. India is the second largest producer of wheat in the world. At present India produces more than 75.67 million tones of wheat and is the second most important staple food crop next to rice. Wheat became one of the vanguards of green revolution and it has been recognized as an essential component of diet even in South India. The total area under wheat cultivation in India is 22.43 million ha. Productivity is almost equal to that of global level. About 91 per cent of Indian wheat is produced in Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan and Bihar. Uttar Pradesh, with 25.6 million tones (mt) in 2003-2004 contributes to be the highest producer of wheat followed by Punjab (14.5 mt) and Haryana (9.1mt).

In Tamil Nadu, even though wheat cultivation is found to be suitable in Coimbatore, Dharmapuri, Vellore, Erode (Sathyamangalam), Dindugal (Palani) and Theni districts, it is being grown in a lesser area compared to other states. The advantage is that the crop is not water intensive as that of rice. The IARI Wheat Regional Research Station, Wellington, Conoor has developed wheat varieties suitable for cultivation in the state. The crucial fact about wheat crop in Tamil Nadu is that it can be harvested in 90 days, while in the North the duration is about 140 days. Flour mills in Tamil Nadu also would benefit since, at present wheat has to be transported from North.

In Tamil Nadu, although wheat responds to manuring, precise information on the manurial practices in different regions is meagre and the information on the relative response of wheat to fertilization under specific conditions is necessary. Consequently fertilizer recommendations have to be determined for the maximum yield. Hence, it is considered necessary to study the effect of different levels of fertilizers on growth and yield and to fix an economic optimum fertilizer dose for wheat.

Soil test based application of plant nutrients help to realize higher response ratio and benefit: cost ratio as the nutrients are applied in proportion to the magnitude of

deficiency of a particular nutrient and the correction of nutrient imbalances in soil helps to harness the synergistic effects to sustain soil fertility and crop yields. In the present context, Soil Test Crop Response (STCR) correlation studies under Integrated Plant Nutrient System (IPNS) will be an imperative feature for achieving continuous advances in biological productivity of crops in an ecologically and economically sound manner. Further it could form an important component of precision farming for maximizing the productivity of crops. Since 1967, soil test crop response correlation studies have been carried out and fertilizer prescription equations are developed for a variety of crops in different agro climatic zones of Tamil Nadu (Selvakumari *et al.*, 2000 a). However, Soil Test Crop Response correlation studies have not been carried out for wheat. The balanced fertilization through STCR must be based on the concept of Integrated Plant Nutrition System, as this is the only viable strategy advocating accelerated and enhanced use of fertilizer with adoptions of organic manures and biofertilizers, so that productivity is maintained for sustainable agriculture.

The fertilizer recommendations based on STCR correlation studies are more quantitative and precise. It provides the scientific basis for balanced fertilization which in turn gives a real balance between applied nutrients and the available nutrients already present in the soil. Once the fertilizer prescription equations are developed for wheat, site-specific soil test based fertilizer recommendation for desired target yields of wheat can be arrived according to the grower's resources and management options. Hence, the present study was undertaken with the following objectives:

- To establish relationship between soil test values and response of wheat to fertilizers in order to provide a soil test calibration for fertilizer recommendations,
- to evaluate various soil test methods for their suitability to develop soil test based fertilizer recommendations,
- to derive a basis for making fertilizer recommendations for targeted yields of wheat and
- to evaluate the extent to which fertilizer requirement of wheat can be reduced under IPNS.

## **CHAPTER II**

### **REVIEW OF LITERATURE**

Soil test based fertilizer recommendation plays a vital role in ensuring balanced nutrition to crops and fertilizer schedules. The production potential of the crop is much higher than the average production of the crop in the state. One of the reasons for lower production is imbalanced fertilization of nutrients, and decline in organic matter of the soil. Based on All India coordinated Soil Test Crop Response Correlation Project, an experiment was conducted aims at developing fertilizer schedule based on soil test values and the magnitude of crop response to applied nutrients at different soil fertility levels. Hence, there is a scope to increase the production of wheat by balanced N, P and K fertilizers through soil testing. The present investigation was carried out with a view to develop the fertilizer prescription equation for wheat under Integrated Plant Nutrition System.

Literature pertaining to different approaches in the formulation of fertilizer recommendations and fertility evaluation, various soil test methods followed for the estimation of soil available nutrients, response models in predicting fertilizer requirement of crops and soil test based fertilizer recommendations, role of IPNS on crop yield and soil fertility maintenance and response of wheat to the applied nutrients are reviewed below.

#### **1. Soil fertility evaluation -Approaches**

The main objective of soil fertility evaluation is to economize the fertilizer application through balanced fertilization coupled with an emphasis on the maintenance of soil fertility, ultimately aimed to increase the crop yield to obtain rich dividends. Soil scientists have put forth several approaches of soil fertility evaluation and the concepts and the salient features of those approaches are discussed below.

##### **1.1. Soil analysis**

The approach of soil fertility evaluation involves determination of available nutrients by standard analytical procedures and rating the soils as low, medium and high nutrient levels (Muhr *et al.*, 1965; Perur *et al.*, 1973). The fertilizer recommendations are given in an adhoc basis and the quantity of fertilizer doses recommended on the basis of soil rating is arbitrary and therefore, this method needs further refinement in the recent innovations of scientific research.

## 1.2. Plant analysis

This approach involves the application of plant analysis as a diagnostic tool, where, the plant itself is considered as an agent for extracting the nutrient elements. This approach was established more than twenty five years ago in France (Malavolta *et al.*, 1960). The foliar analysis has been successful for long duration crops like sugarcane, banana and perennial trees like rubber, coconut *etc.* However, its applicability to short duration crops still remains to be of limited significance. Environmental factors such as drought, strong wind, and excessive rainfall as well as incidence of pests and diseases limit the use of this approach for fertilizer recommendations (Ranganathan *et al.*, 1969). Trehan and Grewal (1994) estimated the optimum dose of K to be side dressed for potato at the time of earthing up based on leaf tissue analysis.

## 1.3. Nutrient indexing system

Nutrient indexing system was developed by Parker *et al.* (1951) and this concept is very useful in formulating area-wise fertilizer recommendations and in comparing fertility status of different areas. Nutrient index is calculated by giving weightage to number of samples falling in low, medium and high soil fertility classes. In this concept, weightage 1 is given for the samples with low fertility class, 2 for medium fertility class and 3 for high fertility class.

The nutrient index is arrived by multiplying the number of samples in each class by the respective weightage of that class. Totalling the sum of three classes thus arrived and dividing it by the number of samples analyzed the nutrient index is obtained.

$$\text{Nutrient index} = \frac{(\text{Nl} \times 1) + (\text{Nm} \times 2) + (\text{Nh} \times 3)}{\text{Total number of samples}}$$

Where, Nl, Nm and Nh were the number of samples falling in low, medium and high category of nutrient status respectively.

Separate indices are calculated for different nutrients like N, P and K. The index value of less than 1.67 and more than 2.33 indicates low and high fertility class respectively. Nutrient index value ranging from 1.67 to 2.33 indicates medium fertility class.

#### 1.4. Agronomic approach

The influence of fertilizers on the yield of different crops has been studied by different workers and based on the crop response to applied fertilizer; the optimum fertilizer dose is worked out. However, these data are not directly related, either to soil fertility status or to the nutrient requirement of crops (Basker, 1990).

#### 1.5. Mitscherlich – Bray approach

The most useful concept for guiding the fertilizer recommendation was first developed by Mitscherlich (1909). Later, Bray (1954) modified this equation by incorporating the efficiency factor for soil nutrient level also. This modified Mitscherlich-Bray equation is being used universally for prescribing fertilizer recommendations. The equation takes the form as,

$$\ln(A-Y) = \ln A - C_1b - Cx$$

Where,

A - Maximum yield

Y - Yield produced

b - Soil nutrient level

x - Fertilizer nutrient level and

C<sub>1</sub>- Efficiency co-efficient for soil nutrients

C - Efficiency co-efficient for fertilizer nutrients.

For predicting yield responses and fertilizer requirements based on soil test values this method was used by several scientists (Ranganathan *et al.*, 1969; Venu Reddy *et al.*, 1979; Dhanapalan Mosi *et al.*, 1979; Mooddy *et al.*, 1990). Though this method was useful, the neglect of the nutrient interaction and the lack of standard procedures for assessing the maximum yield of crops limit its accessibility. To overcome these Ranganathan *et al.* (1969) suggested a suitable method for calculating the maximum possible yield. This approach is being followed by the Department of Agriculture, Tamil Nadu for giving fertilizer recommendations based on soil test values. Shete and Sonar (1993) reported that this concept could be successfully employed for making fertilizer recommendations for *kharif* sorghum. Babhulkar and Sonar(1996) determined requirements of fertilizer N, P and K of wheat based on Mitscherlich – Bray concept. Bangar (1998)

used the modified Mitcherlich-Bray equation for achieving 75 per cent of maximum yield of sorghum and fertilizer recommendation schedule has been worked out.

### **1.6. Critical level approach**

This procedure was given by Cate and Nelson (1965) with a scatter diagram involving soil test values, the percentage yield and an overlay for partitioning to fix up the critical value. In 1971, the same authors refined this technique through computer programme.

Agboola and Ayodele (1987) observed that the critical nutrient level and calibration obtained with Cate and Nelson's technique for soil P in maize crop was better than the quadratic and Mitscherlich functions. The main drawback of this approach is that it can only provide information on the profitability of response and not the actual yield and hence the utility of this approach for individual situations is limited.

Hariprakasa Rao *et al.* (1992) made an attempt to find out the critical levels of available N, P and K for nine vegetable crops. The available soil nutrients were significantly correlated with yield of all the vegetable crops except for tomato and cabbage.

### **1.7 Fertility Capability Classification**

The Fertility Capability Classification (FCC) concept was first developed by Buol (1972). Later different category and descriptions of FCC system were formulated by Buol *et al.* (1975) and modified by Sanchez *et al.* (1982). This system consists of three categories *viz.*, type, substrata type and modifiers. Type and substrata type considers the soil texture in the upper 20 cm and 20-50 cm depth respectively. Modifiers account for the physical and chemical properties of the plough layer and decide the specific fertility limitations. FCC system helps the fertility scientists to group experimental sites that are expected to respond similarly to soil fertility management practices and extrapolate their findings to soils that can be expected to behave in a similar manner.

For studying the response to fertilizer application for different crops, Lin (1984, 1985) and Denton *et al.* (1987) used the FCC system. Shinde (1987) stated that this system was successful for managing fertility of rice soils in India. Mathan *et al.* (1994) used the FCC system for identifying major fertility constraints of Kamarajar district in Tamil Nadu.

### **1.8. Diagnosis and Recommendation Integrated System (DRIS)**

A variation of the multiple regression approach developed is the Diagnosis and Recommendation Integrated System (DRIS) developed by Beaufils. Many yield determining factors of quantitative or qualitative expression are considered simultaneously in making a diagnosis, and recommendations are made from that diagnosis. These factors include not only soil and plant analysis data but also information pertaining to climate, insects, diseases, varieties, etc. This approach overcomes the limitations in using the nutrient ratios and critical level of nutrient elements in plant tissues. The advantage of this approach are its ability to,

- a) Make a diagnosis at any stage of crop growth,
- b) List the nutrient elements in the order of limiting importance on yield and
- c) Identify not only the most limiting nutrient but also the order in which the other nutrients are likely to limit the yield.

Compared to critical level approach, the DRIS method for various crops with the same set of data is able to make meaningful diagnosis over a wide range of plant ages to classify the order in which nutrients limit the yield (Sumner, 1979). The superiority of the DRIS over critical level approach is revealed from its use for various crops like sunflower (Grave and Sumner, 1982) and Letzsch and Sumner (1984) for maize. Raghupathi and Bhargawa (1998) developed DRIS norms for pomegranate, Sharma (1991) for potato, Hundal and Arora (2001) for kinnow fruit and cauliflower (Hundal *et al.*, 2003). Raghupathi *et al.* (2004) developed DRIS norms for mango from high yielding population, while diagnosis of nutrient imbalance was made in low yielding plants.

### **1.9. Deductive approach**

This approach was developed by Colwell (1968) which involves the conduct of multi location trials scattered over a large area and the experimental data are pooled and utilized for the establishment of soil test crop response correlations. Based on the regression of the yield with fertilizer doses and their interaction, the fertilizer doses are adjusted in accordance with the soil test values. In the All India Co-ordinated Research Project on Soil Test Crop Response, correlation studies were conducted based on this approach in farmer's fields. This approach was not very successful in deriving soil test based calibrations in India (Velayutham *et al.*, 1985).

### 1.10. Inductive approach

The concept of Inductive approach was developed by Ramamoorthy *et al.* (1967) to get a large variation possible in soil test values in the same field in a given locality, where artificial fertility variations are created by applying graded doses of fertilizers and growing a gradient crop. The real relationship between the yield and the level of soil fertility is evaluated without interference from other factors affecting crop yield. This method is being followed in the All India Co-ordinated Research Project on Soil Test Crop Response Correlation Studies.

### 1.11. Targeted yield approach

This approach for prescribing fertilizer recommendations for different yield targets, soils and climatic conditions was outlined by Truog (1960) and evoked considerable interest (Ramamoorthy *et al.*, 1967). Among the various methods of formulating fertilizer recommendations, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve, if good agronomy is followed in raising the crop Velayutham (1979). (Dohary *et al.*, 1997) revealed that the target oriented fertilizer schedule helps in rationalising the use of phosphatic fertilizers. Sharma and Singh (2000) concluded that fertilizer recommendation based on targeted yield approach were more balanced, profitable and helpful in checking nutrient mining which is essential for sustainable crop production as compared to fertilizer recommendation for economic yield based on regression approach.

This procedure takes into account the nutrient requirement (NR) of a crop for production of unit quantity of economic produce, the per cent contribution of nutrient from soil (Cs) by a given soil test and the per cent contribution of nutrient from the added fertilizer (Cf). These three parameters are used to relate yield target (T) with soil nutrients (S) and fertilizer nutrients (F).

$$F = \frac{NR}{Cf/100} T - \frac{Cs}{Cf} S TV$$

Fertilizer adjustment equations for desired yield target of rice (Singh and Sharma, 1978; Srinivas *et al.*, 2001), cotton, sorghum, groundnut and soybean (Rani Perumal *et al.*, 1982) have been developed. Similar studies have also been made by Murugappan (1985)

on sugarcane, Kadam *et al.* (1985) on groundnut, Murugesu Boopathi (1988) on blackgram, Natarajan (1991) on rice-groundnut-blackgram cropping sequence, Shanmugam (1992) on cotton-maize cropping sequence, Murugesu Boopathi (1995) on rice-rice-pulse sequence, Santhi (1995) on rice-rice-pulse sequence in Inceptisols and Kausadikar *et al.* (2003) on soybean.

Fertilizer prescription equations were also developed for horticultural crops like bhendi (Andi, 1998), chilli and tapioca (Selvakumari *et al.*, 2001), onion (Santhi *et al.*, 2002a), potato (Gayathri, 2003), cabbage (Smitha John 2004), cauliflower (Kasthuri Thilagam 2004) and turmeric (Anonymous, 2004f), carrot (Umadevi, 2005).

## **2. Soil test methods for available soil nutrients**

Soil testing is a scientific technique used for assessing external nutrient requirement of crops to achieve profitable response under specific soil crop conditions. Intensive efforts are being made from time to time and again to invent procedures that would extract nutrients in about the same proportion as growing plants would extract them. Several extractants have been proved to be excellent under specific conditions. The ability to extract proportional amount of available nutrient, dependability and rapidity are universal principles for a successful soil test. The soil testing procedures attempted for the estimation of available NPK are reviewed below.

### **2.1. Available Nitrogen**

For the estimation of available N, the most common methods followed in India are the estimation of organic carbon by wet digestion (Walkley and Black, 1934) and alkaline potassium permanganate method (Subbiah and Asija, 1956). Organic carbon had also proved to be a good index of N availability. Significant positive correlation between organic carbon and alkaline  $\text{KMnO}_4\text{-N}$  was reported by Kalbande (1964). According to Srivastava (1975), it was found that alkaline  $\text{KMnO}_4\text{-N}$  was highly correlated with amino- sugar N, hydrolysable-N and aminoacid-N. According to Rani Perumal and Velayutham (1977), organic carbon method accounted for 75 per cent of various N fractions, while alkaline  $\text{KMnO}_4$  method accounted only for 64 per cent.

Sidhu *et al.* (1983), Ramanathan *et al.* (1984) and Murugappan (1985) established the usefulness of this method for rice, wheat, soybean and sugarcane respectively. Several workers have indicated the superiority of alkaline  $\text{KMnO}_4\text{-N}$  as an index of N availability (Sumam, 1988; Natarajan, 1991; Shanmugam, 1992;

Murugesu Boopathi, 1995). Prasad (1994) established the superiority of alkaline  $\text{KMnO}_4\text{-N}$  over organic carbon and  $\text{NH}_4\text{-N}$  method as a measure of available N for rice and maize in Inceptisols of Bihar. According to Gayathri (2003), alkaline  $\text{KMnO}_4\text{-N}$  correlated significantly with the tuber yield and N uptake by potato while organic carbon did not correlate with any of the response variables in acidic soils of Ooty. The similar trend was reported by Kasthuri Thilagam (2004) in cauliflower, Smitha John (2004) in cabbage in Irugur soil series and Umadevi (2005) in carrot for Ooty soil series.

## 2.2. Available Phosphorus

Soil tests for available P has been under investigation for a considerable period of time and several methods have been recommended though none of the methods have been universally accepted. Some of the important extractants used for the estimation of available P are 0.001 N sulphuric acid with ammonium sulphate (Truog, 1930), 0.5 N acetic acid with 0.75 N sodium acetate (Morgan, 1937), 0.03 N ammonium fluoride and 0.025 N hydrochloric acid (Bray and Kurtz, 1945), 0.5 M sodium bicarbonate (Olsen *et al.*, 1954), and water (Van Diest, 1963). Extensively used extractants are 0.5 M  $\text{NaHCO}_3$  and 0.03 N  $\text{NH}_4\text{F}$  and 0.025 N HCl of Bray I.

The Olsen extractant mainly extracts Ca-P (Sharma *et al.*, 1979). Kumaraswamy (1980) observed that Olsen and Bray I methods extracted P mainly from the Al-P and Fe-P, whereas Truog, Mehlich and Morgan methods extracted P mainly from Al-P and Ca-P. Further, Olsen and Bray I methods consistently gave higher significant correlation with yield and uptake of P in rice.

Olsen-P was reported to be superior for crops *viz.* blackgram (Lakshminarashiman, 1982), wheat (Sidhu *et al.*, 1983; Palwe and Sonar, 1989), sugarcane (Murugappan, 1985), greengram (Dhillon *et al.*, 1988), sorghum (Selvaraj, 1988), groundnut (Prasanthi, 1989) and cotton (Shanmugam, 1992). Debnath and Mandal (1982) and Ramanathan *et al.* (1984) reported that Bray I was found to be the best extractant of P for soybean and rice crops. 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).

Ray *et al.* (1986) evaluated the soil test methods for available P in jute growing soils and among the five chemical extractants *viz.*, 0.5 M  $\text{NaHCO}_3$  (pH adjusted to 8.5), 0.03 N  $\text{NH}_4\text{F}$  + 0.025 N HCl, 0.05 N  $\text{Na}_2\text{C}_2\text{O}_4$ , 0.002 N  $\text{H}_2\text{SO}_4$  +  $(\text{NH}_4)_2\text{SO}_4$  (pH adjusted to 3.0) and also

by 'A' value using radio active tracers and concluded that Olsen's method is the most promising one for assessing available P. Patel and Savani (1987) established a positive correlation for Olsen's extractant with dry matter yield in groundnut in Typic Ustrochrepts. Murugesu Boopathi (1988) compared five P methods (Olsen-P, Bray I, Truog, Morgan and water extractable P) through multiple regression analysis on black calcareous soil and found that all the five methods were on par in assessing the availability of P in soil.

Stewart, Morgan and 0.15 M  $\text{NH}_4\text{HCO}_3$  methods were better correlated with yield and P uptake than Olsen, modified Olsen, 0.02 N Ca - lactate - 0.02 N HCl, and Bray extractable soil P methods in a sandy loam to clay loam soil having a pH of 7.8 - 9.0 (Raghubir Singh *et al.*, 1993). Chandra Sekhara Rao and Bajaj (1994) observed that the amount of soil P extraction increased with increase in soil solution ratio (1: 40) and also with shaking time. However, shaking time had less effect on the amount of P extracted as compared to soil solution ratio. Olsen's P with 4 hours shaking had the highest correlation with wheat grain yield when compared with other extractants like citric acid, acetic acid, Bray-I, Bray-II and Egner for sodic soils of Punjab (Milap Chand and Dhillon, 1994). Prasad (1994) concluded that Olsen's method was superior over Bray's method for estimating available P for rice and maize in Inceptisols of Bihar.

Balwinder Singh and Bishnoi (1994) observed a significant and positive correlation between soil P extracted by Olsen's and AB - DTPA methods in Udic Ustrochrepts soils of Punjab for soybean. Gill and Dhillon (1995) estimated the superiority of Olsen's method to Datta and Kamath P and Morgan P for prediction of P availability to berseem. According to Gayathri (2003), Bray I-P (1:50 ratio and one minute shaking) was found to be the best method for the extraction of available P in acid soils of Ooty and was found to correlate significantly with tuber yield and uptake by potato. Kasthuri Thilagam (2004) and Smitha John (2004) found that Olsen method was best for extraction of P in red non calcareous soils compared to Bray I method. They also found that the curd yield of cauliflower and head yield of cabbage was significantly correlated with Olsen P method. According to Umadevi (2005) Bray I -P 1:50 is found to be best correlated with carrot yield, while Bray-P 1:10 did not show any significant correlation either with yield or with uptake.

### **2.3. Available Potassium**

Potassium is present in soil in different forms viz., water soluble, exchangeable, non-exchangeable and lattice potassium confers complexity to its availability. Numerous

chemical and biological methods have been advocated from time to time for measuring the available potassium status of soils under different situations. Among the different extractants used Ammonium acetate extractant (Hanway and Heidal, 1952) is widely employed to measure the available potassium but its utility for universal adoption still remains unsolved (Kanwar, 1971). Several other extractants like 0.01M Calcium chloride, Morgan's extractant, boiling 1N nitric acid are commonly employed.

Perur and Nithyantha, (1976) in their review on the methods of measuring available potassium in soils suggested the need for standardizing a suitable method for each soil or crop in view of the conflicting views existing. Ramanathan (1977) observed that the extractant 0.1N HNO<sub>3</sub> was found to be effective based on rice response and this was confirmed by Balasundram (1978) and Ramanathan *et al.*, (1984) in soybean, Altaf Ahmed (1985) in sorghum, and Murugappan (1985) in sugarcane. Grewal and Sharma (1980) and Pati Ram and Prasad (1983) observed that 1N NH<sub>4</sub>OAc extractable K gave the highest correlation with dry matter yield of potato. The extractant, neutral normal ammonium acetate has been reported to be effective for wheat (Bhadoria *et al.*, 1986; Chandra Prakash and Vinay Singh, 1986), rice (Durairaj Muthiah, 1986), sorghum-blackgram-cotton cropping sequence (Jaiswal, 1989), groundnut (Prasanthi, 1989), rice-groundnut-blackgram cropping sequence (Natarajan, 1991), cotton-maize sequence (Shanmugam, 1992), potato (Gayathri, 2003), cabbage (Smitha John, 2004) and cauliflower (Kasthuri Thilagam 2004). Regarding the methods for available K, NH<sub>4</sub>OAc-K correlated significantly with yield and K uptake when compared to 0.1 N HNO<sub>3</sub>-K methods (Umadevi, 2005).

Among different reagents *viz.*, 3 N HCl, 1 N HNO<sub>3</sub>, 6 N H<sub>2</sub>SO<sub>4</sub>, N N NH<sub>4</sub>OAc, 0.75 N HCl, 0.5 N NaHCO<sub>3</sub>, 0.01 M CaCl<sub>2</sub> and distilled water, N N NH<sub>4</sub>OAc gave the highest correlation with K uptake as well as relative yield of wheat (Chandra Prakash and Vinay Singh, 1986). Krishnakumari and Khera (1989) and Vinay Singh *et al.* (1992) observed that 1N boiling nitric acid extracted comparatively large amounts of potassium than the other extractants.

Prasad (1994) established the superiority of N N NH<sub>4</sub>OAc-K over HNO<sub>3</sub> - K as a measure of available K for rice and maize in Inceptisols of Bihar. Tiwari *et al.* (1995) evaluated the relative efficiency of soil test methods and established the best extraction capacity for boiling HNO<sub>3</sub> and lowest for 0.01M CaCl<sub>2</sub> in wheat. Srinivasa Rao and

Takkar (1997) estimated that among the different extractants *viz.*, water, dilute salt solutions, dilute organic acids, multi nutrient extractants, mineral acids and various fractions of electro ultra filtration in smectitic soils using sorghum as a test crop and neutral normal  $\text{NH}_4\text{OAc-K}$  showed a higher degree of correlation with sorghum shoot, root and relative yield. Bedi *et al.* (2002) studied a suitable extractant for available K for sub tropical soils of Jammu and Kashmir region and found that neutral normal  $\text{NH}_4\text{OAc}$  was found to be the best extractant. The efficiency of six chemical extractants ( $\text{NH}_4\text{OAc}$ ,  $\text{HNO}_3$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{NaCl}$ , AB-DTPA and Mechlich-III) for predicting K response to sorghum grown on smectitic soils were evaluated and reported that  $\text{NH}_4\text{OAc-K}$  gave the best correlation with K removal in sorghum plants grown for 20 days (Pasricha, 2004).

### **3. Role of response models in predicting fertilizer requirements of crops**

A 'response model' has a characteristic shape and is defined by a mathematical expression of a particular form with suitably restricted co-efficient (Wimble, 1980). Statistical models are developed to predict a crop yield for varying levels of fertilizers and to optimise fertilizer doses for attaining either maximum yield or economic yield.

Rapid advances have been made in the development and application of quantitative and mechanistic crop models that allow a simultaneous evaluation of complex physical, chemical, and biological processes related to nutrient acquisition and dry matter production. Models also provide a means to simulate nutrient uptake by crops grown in rotations and mixed cropping systems, once basic parameters (nutrient supplying capacity of soil, root morphology, nutrient absorption kinetics, *etc.*) have been adequately defined. Models enable us to determine how far root and soil characteristics limit nutrient acquisition. This in turn is useful in developing site-specific nutrient recommendations.

#### **3.1 Linear model**

Linear model is developed based on the Liebig's law of minimum *i.e.*, the crop responses to fertilizer additions have the form of linear segments or straight line function of applied nutrient. The linear model is represented by  $Y = a + bx$  where, Y is yield, a is the Y intercept with no nutrient, b is coefficient and x is the fertilizer nutrient. This type of linear response is expected if the nutrient is mobile and it will be incorrect for immobile nutrients (Bray, 1954).

### 3.2. Linear response and plateau model

Swanson (1963) developed a model by modifying Liebig's law of minimum, which postulates a linear response to the principal limiting element. When the limitation is corrected, it halted abruptly.

### 3.3. Linear plateau models

Linear plateau models were suggested by Anderson and Nelson (1975) for a multinutrient experiment with number of levels of each nutrient in a complete factorial experiment and are considered to be the best for estimating optimal nutrient levels. However, Maruthi Sankar (1992) did not accept this model for optimization of fertilizer doses for varying levels of available nutrients.

### 3.4. Curvilinear models

Linear model is found to be inadequate when the increase in yield with successive addition of nutrients becomes less. So to interpret fertilizer responses, curvilinear models are used where the addition of fertilizer resulted in steady and smaller responses. Quadratic and square root models are some curvilinear models. These models state that yield increase with fertilizing up to a maximum beyond which any additional application decreases production. These two models have been compared by a number of workers who found that the quadratic model tends to give greater estimate of the optima (Boyd *et al.*, 1976).

### 3.5. Mitscherlich model

According to the model developed by Mitscherlich (1909), "the increase in yield per unit of added nutrient is proportional to the difference between the maximum attainable yield and actual yield". It is expressed as

$$dy / dx = C (A-Y)$$

Where, y is yield, A is maximum yield and C is fertilizer efficiency factor.

### 3.6. Mitscherlich – Bray model

Bray (1948), modified the Mitscherlich model and he gave the equation as

$$\log (A-Y) = \log A - (C_1b)-Cx$$

Where, A = 100, which is the percentage yield of crops with all nutrients at adequate levels.

Y = Percentage yield of crops with all nutrients except for nutrient being studied.

C<sub>1</sub> = Proportionality constant

b = Soil test value of the nutrient for the control plot.

x = Fertilizer nutrient level and

C = Efficiency co-efficient for fertilizer nutrients

On account of its applicability to only single nutrient studies, the Mitscherlich model is seldom used for optimization of fertilizer in multinutrient studies. Sidhu *et al.* (1984) has found out the fertilizer P requirement of wheat for pre determined yield levels using Mitscherlich and Baule equation and found that wheat responded significantly to applied P in soils testing low and medium in available P.

### 3.7. Targeted yield model

Fertilizer prescription based on this model was advocated by Truog (1960) and later refined by Ramamoorthy *et al.* (1967). This model is the scientific basis for balanced fertilization and proved balance between applied nutrients and soil available nutrients. As per this model, a linear relationship exists between nutrients absorbed by the plant and the yield obtained. This would imply that for obtaining a specific yield of grain or any other economic produce, a definite quantity of nutrient must be taken up by the crop.

Three basic parameters are required for developing a targeted model. They are.

- i. Nutrient requirement (NR in kg q<sup>-1</sup> of yield)
- ii. Per cent contribution from soil (Cs)
- iii. Per cent contribution from applied fertilizer (Cf)

$$\text{Fertilizer dose} = \frac{\text{NR}}{\text{Cf}} \times 100 \text{ T} - \frac{\text{Cs}}{\text{Cf}} \times \text{STV}$$

This model is useful for computing optimal fertilizer doses for varying soil test values for obtaining desired yield targets.

Fertilizer doses based on soil analysis and crop needs for 50 q/ha yield target increased wheat yield by 12q /ha over farmers practice Tandon (1976). Dev and Dhilon (1979) developed fertilizer prescription equation for wheat for obtaining economic yields with each nutrients based on soil test crop response correlation studies. The results revealed that wheat responded significantly to added nutrients and to level of nutrients present in the soil. Subha Rao and Sanjay (2000) showed that in the follow up trials a target of 45q ha<sup>-1</sup> is obtained on wheat on fertilizer prescription equation developed based

on STCR approach. Sharma and Singh (2000) reported that targeted yield approach was more balanced, profitable and helpful in checking soil nutrient mining as compared to fertilizer recommendations for economic yield based on regression approach.

Based on the targeted yield model the fertilizer prescription equation was developed for tomato (Anonymous 2003a), cauliflower (Anonymous 2003b), potato (Anonymous 2004a), cabbage (Anonymous 2004a), pea (Anonymous 2004b), ginger (Anonymous 2004c), banana (Anonymous 2004c), wheat (Anonymous 2004d) bhendi (Anonymous 2004e), turmeric Anonymous (2004f) and carrot Anonymous (2005).

### 3.8. Multiple regression model

Multiple regression model is the proper statistical tool to assess the contribution of nutrients in the soil to yield. For prescribing fertilizer doses based on soil test values for attaining either maximum yield or maximum profit this model is used. This model was suggested by Ramamoorthy (1968). The regression equation is as follows

$$Y = A \pm b_1 SN \pm b_2 SN^2 \pm b_3 SP \pm b_4 SP^2 \pm b_5 SK \pm b_6 SK^2 \pm b_7 FN \pm b_8 FN^2 \pm b_9 FP \pm b_{10} FP^2 \pm b_{11} FK \pm b_{12} FK^2 \pm b_{13} FN SN \pm b_{14} FP SP \pm b_{15} FK SK$$

Where, Y = crop yield (kg ha<sup>-1</sup>), A = intercept (kg ha<sup>-1</sup>), b<sub>1</sub> to b<sub>15</sub> = regression co-efficient; SN, SP and SK are soil available N, P and K (kg ha<sup>-1</sup>) respectively and FN, FP and FK are fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O (kg ha<sup>-1</sup>) respectively.

The responses are estimated based on R<sup>2</sup> value. The R<sup>2</sup> value of more than 0.66, between 0.45 to 0.66 and less than 0.45 represents good, moderate and poor fit of the data respectively. Based on the multiple regression equation models, fertilizer adjustment equations for obtaining economic yields of wheat, paddy, bajra, maize and groundnut were developed by Dev and Dhillon (1979).

### 3.9 Orthogonal polynomial model

Colwell (1968) proposed orthogonal polynomial model for calibrating yield - fertilizer trend relationship for a given crop in a given location. The polynomials are easy to compute and are flexible and accommodate different fertilizer interaction effects. It is also possible to perform different types of analysis of variance for orthogonal polynomial models of yield and fertilizer data. Linear, quadratic, cubic and quartic of any n<sup>th</sup> order polynomial could be fitted, depending on its suitability and significance of variables. The n<sup>th</sup> order polynomial is of the form

$$Y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \dots\dots + a_n x^n$$

Where,  $a_0, a_1, a_2, \dots, a_n$  are polynomial co-efficients.

Although orthogonal polynomials are suited for calibrating the yield and fertilizer trend relationships, the model often fails to take care of available soil fertility levels and the fertilizer recommendations, calibrated independent of soil test values.

### **3.10 Use of Decision Support Systems for fertilizer recommendations**

The Decision Support System for Agro Technology Transfer (DSSAT) of IBSNAT, was designed for users to easily create 'experiments' to simulate on computers, outcome of complex interactions between various agricultural practices, soil and weather conditions and suggest appropriate solutions to site specific problems (Jones, 1986 and Uehara, 1989). Selvamani (2003) calibrated the DSSAT-CROPGRO Peanut growth model using the field observations in Inceptisols of Tamil Nadu.

The model QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) developed by Janssen *et al.* (1990) calculates the yields of crops as a function of availability of soil and fertilizer N, P and K. Smaling (1993) calibrated the model based on fertilizer trials conducted in Kenya and made some modifications and validated the model. This model could be one of the tools in IPNS and is being used by IRRI scientists.

A computer software DSSIFER (Decision Support System for Integrated Fertilizer Recommendation) was developed to generate crop, site and situation specific balanced fertilizer prescriptions in Tamil Nadu (Murugappan *et al.*, 2004). This software utilizes the crop and location specific fertilizer prescription equations based on targeted yield model developed by the AICRP-STCR scheme, Department of Soil Science and Agricultural Chemistry, TNAU and Mitscherlich and Bray percentage sufficiency recommendation equations developed by soil testing wing of the Department of Agriculture, Tamil Nadu.

Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) is the model developed by Janssen *et al.* (1990). The model calculates the yields of crops as a function of availability of soil and fertilizer N, P and K. Smaling (1993) calibrated the model based on fertilizer trials conducted in Kenya and made some modifications. This model could be one of the tools in research programmes in INM.

#### **4.0 Soil test based fertilizer recommendation for crops**

Soil testing is a scientific tool to evaluate soil fertility by predicting probability of getting profitable crop response to recommended fertilizer application under specific soil-crop condition. It is essentially a simple and rapid chemical analysis of soils with the objectives of recommending fertilizer and liming practices.

Meelu (1979) on his experiment showed clearly the superiority of soil test based fertilizer recommendation for economic returns in wheat. The response of fertilizer is greatly influenced by soil type. There was selective response of nutrients in various soil associates and the responsiveness varied with soil development and maturity of soil. (Tamboli and Sonar, 1998) showed that the economics of fertilizer use based on soil test for achieving maximum yield indicated additional benefit over farmers practice. (Ray *et al.*, 2000) revealed that fertilizer prescription based on testing of soils was found profitable as compared to adhoc recommendation for Jute, Rice and Wheat.

The results of thirty frontline demonstrations on farmer's field in Punjab with rice and twenty-six trials with wheat revealed that in majority of the cases the yield targets of rice and wheat were achieved with in +/- 10 per cent variation. In both the crops the farmer practice of fertilizer application was inferior to soil test based fertilizer recommendation. (Subba Rao and Sanjay, 2001). Soil test based fertilizer recommendation plays a vital role in ensuring balanced nutrition to crops and also in preventing wasteful expenditure on the use of costly mineral fertilizers (Biswas, 2002).

Santhi *et al.*, (2002a) stated that more than 90 per cent the targeted bulb yield of onion was achieved in soil test based fertilizer recommendation compared to blanket and farmer's practice. The STCR treatments recorded relatively higher response ratio and benefit cost ratio. Sharma (2005) on a soil test based fertilizer use experiment in wheat found that lower response yardstick and benefit cost ratio were obtained with normal recommendation when compared to soil test based fertilizer recommendations for economic yield.

#### **5.0 Integrated Plant Nutrition System (IPNS) and optimizing fertilizer doses for targeted yield of crops.**

As the mineral fertilizer alone cannot meet the requirements of crops and cropping systems because of high cost and also environmental related risks involved in its application and usage, complementary use of organics and biofertilizers with inorganic fertilizers is desired. Further, in high intensive cropping systems, neither the mineral

fertilizers alone nor the organic sources exclusively can achieve the production sustainability. Application of mineral fertilizers alone might supply a few nutrients only but conjoint use of macro and micronutrients and organic manures is required to provide all the essential nutrients and provide balanced nutrition. So development of prescription involving integrated use of organics, fertilizer and bioculture for different crops and cropping systems in different agroecoregions is an urgent need for the country. The STCR Project has to invariably generate integrated nutrient supply system recommendations for crops and cropping systems in different regions of the country. Hence, a combination of mineral fertilizers with locally-available organic sources of plant nutrients is recommended. Such mixed applications are also complementary because organic material benefits the soil beyond its nutrient content, including improved soil physical conditions, improved water retention, enhanced nutrient retention capacity and biological activity. Integrated Plant Nutrition is an approach which adapts plant nutrition to a specific farming system particular yield targets, the physical resource base, locally available and accessible nutrient sources of both organic and mineral origin and the socio-economic background. Integrated Plant Nutrition aims to ensure sustainable agricultural and rural development with special attention to developing environmentally sound and economically beneficial plant nutrition technologies. The integrated plant nutrition approach aims at ensuring a sustainable supply of plant nutrients to increase future yields without harming the environment and soil productivity.

### **5.1 IPNS on crop yield**

A study on vermicompost and phosphobacteria in combination with two inorganic – P sources namely single super phosphate (SSP) and Tunisia rock phosphate (TRP) were verified in a calcareous black soil for their effect on the yield parameters of blackgram (CO 5) and cotton (LRA 5166) mix (Thiyageshwari and Rani Perumal 1998). The application of TRP (100%) with vermicompost and phosphobacteria in blackgram recorded the highest grain and haulm yield. In cotton LRA 5166, the effect off SSP and TRP on the kappas yield and stover yield were on par. The soil available Olsen's P and the PUE was increased in the blackgram -cotton mix due to the integrated nutrient supply of TRP with vermicompost and phosphobacteria.

Field experiment was conducted on Inceptisol at Agricultural Research Station, Bhavanisagar, Tamil Nadu with turmeric to find out the effect of combined application of fertilizers, organic manures (industrial wastes), micronutrients and Azospirillum on yield,

nutrition and soil fertility in turmeric by Selvakumari and Baskar (1998). Integration of organics such as pressmud, composted coirpith, FYM with fertilizers increased the nutrient uptake, yield of fresh rhizome of turmeric and nutrient availability significantly over the application of NPK as fertilizers. The results have clearly indicated that IPNS is the most appropriate strategy for increasing the yield of turmeric and for the sustenance of soil fertility.

Sumam Susan Varghese and Rani Perumal (1998) estimated the fertilizer requirements of rabi maize in Alfisols based on yield targeting and found that by the application of FYM @ 6 t and 12 t ha<sup>-1</sup>, the fertilizer requirement can be reduced to the extent of 20,14,18 and 40, 29 and 36 kg ha<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O respectively. Selvakumari *et al.*, (1999) reported that recommending 50 per cent of NPK prescribed as per targeted yield concept for rainfed sorghum is the best practice in terms of efficient fertilizer use, higher yield and net profit.

Higher use efficiency of fertilizers especially N in the presence of organic manures is well established. Substitution of 50% of mineral fertilizer N by either FYM or green manure – N in different agro-eco regions of tropical India in kharif component of rice – wheat, rice – rice, pearl millet – wheat cropping systems sustain their productivity (Yadav and Kumar, 1999). (Nayak and Gupta, 2000) found that application of organic matter at all levels of P increased the grain and straw yield of wheat.

A study was conducted on the effect of P, S and bio-fertiliser on yield, nodulation and quality of pea by Mishra and Tiwari (2001). Results of field experiments revealed that the pea cultivars Azad – 1 responded significantly to the application of P, S and rhizobium inoculation. All these factors had positive effect on the uptake of N, P, K, S, nodulation leghaemoglobin and N contents in nodules, protein and S containing amino acids. Rajamani *et al.* (2001) suggested that split application of 50:65:125 kg NPK ha<sup>-1</sup> at 3<sup>rd</sup>, 6<sup>th</sup> and 9<sup>th</sup> month after planting along with *Azospirillum* and Phosphobacteria each @ 2 kg ha<sup>-1</sup> was found to increase the tuber yield of tapioca to 2.9 kg plant<sup>-1</sup> compared to inorganic fertilizer alone (1.08 kg plant<sup>-1</sup>). Subbiah and Thenmozhi Narayanasamy (2001) reported that application of 35 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> as Mussooriphos in association with dual inoculation of VAM and phosphobacterium in black soil enhanced the yield and improved the quality of bhendi.

Duraisami *et al.* (2002) reported that combined use of 90 kg N ha<sup>-1</sup> with composted coir pith and biofertilizers was rated as the best in a mixed black soil for sorghum. Santhi *et al.* (2002a) showed that the yield and NPK uptake were increased when chemical fertilizers were applied in conjunction with FYM and *Azospirillum* for onion in red non-calcareous soils of Tamil Nadu. Venkatesh *et al.* (2002) observed that P uptake by maize grain was maximum (17.08 kg ha<sup>-1</sup>) when P was applied @ 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> along with FYM and lime. Wange and Kale (2003) observed a significant improvement in shoot dry weight, fruit numbers and fruit weight plant<sup>-1</sup> in bitter gourd and okra with 75 kg N ha<sup>-1</sup> + *Azotobacter* + *Azospirillum*.

Santhi *et al.* (2002b) reported that the adoption of soil test based fertilizer recommendation for desired yield targets of rice, cotton, groundnut, sunflower, tapioca, onion and bhendi in different agro-climatic zones of Tamil Nadu increased the productivity and profitability of crops and efficiency of added nutrients due to IPNS over fertilizers alone.

Sushilu and Gajendra Giri (2000) found that application of FYM increased the growth, yield and water use efficiency of wheat. Also biofertilizers, azospirillum and azotobacter proved effective in enhancing growth and yield of wheat. Rakesh Banwasi and Bajpai (2006) found that application of organic manures with inorganic fertilizers were found more effective than inorganics alone. Inorganics substituted through organic manure significantly increased grain and straw yield of wheat and wheat recorded significantly higher gluten percentage. In an experiment conducted by Mandal *et al.*, 2005 showed that Integrated Nutrient Management (100% NPK+ FYM) in conjunction with irrigation maximized the yield of wheat. (Kedar Prasad *et al.*, 2005) showed that maximum up take of N, P and K were recorded in farmyard manure treated plots than control in both grain and straw. Virendra Kumar (2006) found that application of 120 kg N ha<sup>-1</sup> significantly increased wheat yield and also biofertilizer application recorded higher in uptake and net returns over no biofertilizers applied plots. In an experiment conducted by (Ajith *et al.*, 2001) on wheat found that application of organic manures irrespective of source increased the grain and straw yield and photosynthesis of wheat. Kavitha *et al.*, (2000) found that application of vermicompost resulted in higher drymatter production and increased grain yield in comparison to organic manure and chemical fertilizers. Muneshwar Singh and Sammi Reddy (2000) showed that the combined application of organic and inorganic N sustained the productivity of wheat

even at lower level of N application. Results revealed that incorporation of 5 t FYM or 6 t GM saved 70-80 kg N ha<sup>-1</sup> yr<sup>-1</sup>. There was an increase in yield due to the application of NPK plus SM, NPK plus *Azospirillum* and NPK with SM plus *Azospirillum* respectively over absolute control (Umadevi, 2005).

## 5.2 IPNS on nutrient availability

The integrated nutrient supply holds great promise in crop production not only for securing high productivity but also against emergence of multiple nutrient deficiencies and deterioration of soil environment.

Farmyard manure one of the components of IPNS which is a good source of carbon and nutrient could contribute considerably to the organic matter status of the soil (Biederdeck *et al.*, 1984). Inclusion of leguminous green manure crops in cropping sequence and incorporation of green manures are found to be beneficial in supplying N to the crop. (Adiningsih, 1988). Benefits of green manuring occur from substitution of chemically fixed nutrients and enhanced biological activity.

As reported by Nambiar and Ghosh (1994) better water retentively and favourable environment for root development were established due to the addition of organic manures. In addition, the improvement in physical and biological conditions on account of addition of organics would have facilitated better absorption of plant nutrients from the soil. The activity of soil microorganisms play a major role in nutrient cycling, organic matter decomposition and turn over. Dudhat *et al.*, 1997 found that application of organics like castor cake and FYM alone or in combination with chemical fertilizers significantly increased the residual status of available N and P in soil. Besides, the use of FYM will generate more employment to farm labour and will change the entire socio-economic status of the community (Gupta and Jagannath, 1998).

In a long term fertilizer experiment continued since 1985 at GKVK, Bangalore effect of 15 t ha<sup>-1</sup> of FYM along with 100 per cent of recommended NPK through the chemical fertilizers was studied on finger millet-maize-cowpea by Sudhir *et al.* (1998). Results obtained on chemical analysis of the soil and yield levels of crops pointed out the beneficial effect of the integrated use of inorganic and organic manures for sustaining the yield levels and improving the soil fertility.

In long term experiments conducted at different locations of India representing various agro-ecological situations indicated that the integrated use of organic manures with mineral fertilizers improved the soil and crop productivity and increased the yield response (Ghosh *et al.*, 1998). IPNS is the most appropriate strategy for increasing the yield of turmeric as well as in the sustenance of soil fertility (Selvakumari and Baskar, 1998).

Integration of flyash @ 20 and 40 t ha<sup>-1</sup> with fertilizer, fertilizer plus compost and fertilizer plus compost plus Azospirillum system resulted in higher quantities of Olsen-P. The NH<sub>4</sub>OAc -K status of the post-harvest soil samples was also increased to the tune of 6.0 & 8.0 kg ha<sup>-1</sup> for the addition flyash @ 20 & 40 t ha<sup>-1</sup>. The increase ranged from 3.0 to 9.0 kg ha<sup>-1</sup> for the integration of flyash with fertilizers, fertilizers plus compost and fertilizers plus compost plus Azospirillum (Selvakumari *et al.*, 1998).

In case of the integrated use of manures and fertilizers, the organic carbon, available P and K were improved in all the cropping sequences. These results indicated that the application of FYM in conjunction with chemical fertilizers will not only increase the productivity of all the cropping sequences but also improve the soil fertility.

A study was conducted by Bhattacharyya and Ghosh (2001) on the effect of P, sulphur and FYM application on yield, and availability of P in brinjal. The maximum beneficial effect in respect to fruit yield of brinjal on dry weight basis was noted in the combined application of 11.90 mg kg<sup>-1</sup> P, 6.82 mg kg<sup>-1</sup> sulphur with FYM. Available P content in soil both at pre-flowering and harvesting stages was increased due to the application of highest levels of P and FYM.

A study was conducted by Pachauri and Vinay Singh (2001) to study the effect of integrated use of chemical fertilizer and FYM on fertility of onion soil. From the result, indiscriminate use of high analysis chemical fertilizer resulted in the deficiency of nutrients that were not applied and caused a decline in organic carbon. However, when manure was applied in conjunction with chemical fertilizers, decline in organic carbon was arrested. Therefore, the use of chemical fertilizer alone may not keep pace with time in maintenance of soil health for sustaining the productivity, continuous application of K in amount less than that removed by the crop led to the decline in available as well as total K.

Muneshwar Singh and Sammi Reddy (2001) observed that the organic matter and total N status decreased with application of fertilizers alone and increased with conjunctive use of fertilizer N and organic manure. The amount of available N in soil increased from 140 to 300 kg ha<sup>-1</sup> in 1997-98 as the dose of FYM increased from 0 to 10 t ha<sup>-1</sup>. The corresponding increase in 1998-99 was from 139 to 300 kg ha<sup>-1</sup>. The N balance due to the use of fertilizer N alone was negative and integration of organic and biological N resulted in positive N balance (Duraisami *et al.*, 2002). Santhi *et al.* (2002b) reported that the post-harvest soil fertility was maintained due to IPNS for onion in Inceptisols of Tamil Nadu. Similar results were obtained by Gayathri (2003) for potato in alfisols, Kasthuri Thilagam (2004) for cauliflower and Smitha John (2004) for cabbage in Inceptisols. Dileep- Kachroo *et al.* (2005) found that integration of nutrient application through inoculation of biofertilizers, FYM and higher nitrogen levels enhanced the total nutrient uptake (N, P, K) and soil status also. Due to the synergistic interaction between sheep manure and *Azospirillum* relatively higher per cent contribution of nutrients would have resulted in the conjoint use of sheep manure plus *Azospirillum* (Umadevi, 2005).

## **6. Response of Wheat to fertilizers**

The experiments conducted over years have clearly indicated that wheat responds well to added nutrients. Being a cereal, the crop requires higher doses of nitrogen than phosphorous and potassium. Application of 120:60:40 NPK kg/ha gave significantly higher yield than the lower levels of fertilizers. Yield of semi dwarf wheat varieties can be enhanced substantially through application of nitrogen at 90-120 kg/ha. Fertilizer doses based on soil analysis and crop needs for 50 q/ha yield target increased wheat yield by 12q /ha over farmers practice. Tandon, (1976). Dev and Dhilon, (1979) developed fertilizer prescription equation for wheat for obtaining economic yields with each nutrients based on soil test crop response correlation studies. The results revealed that wheat responded significantly to added nutrients and to level of nutrients present in the soil. Mehara (1992) in his experiment revealed that nitrogen content in grain and straw of wheat tended to increase with increase in levels of phosphorous. (Singh *et al.*, 1992) found that wheat crop responded significantly up to 60 and 90 kg ha<sup>-1</sup> for grain and straw yields respectively.

In a field experiment conducted to study the effect of nitrogen on winter wheat and the results indicated 22.9 and 43.9 per cent more yield at 40 and 80 kg N ha<sup>-1</sup> than the control on pooled analysis Singh (1997). Nayak *et al.* (1997) found that the percentage content of N and

their uptake in grain and straw were also increased with increasing N levels. An experiment conducted on the effect of management practices on potato –wheat crop sequence by Govindakrishnan (1997) found that progressive delay in harvest of potato and sowing of wheat significantly reduced the wheat yields. Sharma and Acharya (1997) concluded from their experiments that the integration of N upto 120 kg ha<sup>-1</sup> and deep tillage increased the nitrogen uptake and thereby increased the crop yield. (Deor and Patik, 1997) in their experiment found that there is almost 32% increase in the yield when N was increased from 40 to 80 kg ha<sup>-1</sup>. (Sharma *et al.*, 1989) showed that in potato- wheat relay cropping if seed rate is increased to 80 kg ha<sup>-1</sup> and 60 kg N ha<sup>-1</sup> is applied, 4.5 tonnes per hectare of wheat was obtained which is almost the same as that of pure stand of wheat. (Jena and Behera, 1998) found that application of recommended levels of fertilizers (120-60-40) kg ha<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O respectively recorded significantly more grain and straw yield than low levels of fertilizers used by farmers. (Rajiv Singh *et al.*, 1998) reported that K, Mn and Organic matter application significantly increased the grain and n straw yield of wheat. (Sharma *et al.*, 1999) found that phosphorous application up to 80 kg ha<sup>-1</sup> increased the yield of wheat grain by 48 % and straw by 42.6 %. (Karat *et al.*, 1999) studied the role of K in enhancing the wheat growth in saline soils. The increased K application promoted the grain yield. Maximum yield was recorded with 200 kg ha<sup>-1</sup> and it was statistically at par with 50 and 100 kg ha<sup>-1</sup> but significantly higher than control. The application of 200 kg ha<sup>-1</sup> increased the yield by 23 per cent over control. They reported that Manganese uptake by wheat crop increased with increased K application.

Subha Rao and Sanjay (2000) recorded in the follow up trials a targeted yield of 45 q ha<sup>-1</sup> of wheat when the fertilizer prescription equation based on STCR approach was adopted. Balyan and Idani (2000) found that grain yield of wheat was increased owing to higher dose of N 120 kg ha<sup>-1</sup> applied either alone or combined with P<sub>2</sub>O<sub>5</sub>. Among several factors of crop yield, nitrogen plays a key role. (Kundu *et al.*, 2000) showed significant response to application of Urea N up to 120 kg ha<sup>-1</sup>. The grain yield of wheat increased by 22.3, 68.5 and 89 per cent over control due to application of 40, 80 and 120 kg ha<sup>-1</sup> respectively.

Sharma and Bapat (2000) found that phosphorous application of 80 kg ha<sup>-1</sup> increased the yield of wheat grain by 48 per cent and straw by 42.6 per cent. Prince Jeya Singh and Singh, (2000) reported that the grain yield of wheat was significantly higher when nitrogen and potassium were applied together than when nitrogen was applied

alone Verma *et al.*, (2000) found that the grain and straw yield of wheat significantly increased with increasing nutrient level. Available nitrogen content increased with applied nitrogen fertilizers up to 100 mg N kg<sup>-1</sup> soil. Dilip Kumar Bastia and Ajay Kumar Rout (2001) and Rawat *et al.* (2000) found that the yield attributing characters of wheat, grain and straw yields significantly increased with increase in fertilizer dose. Saren and Jana (2001) found in a field experiment that nitrogen 100 kg ha<sup>-1</sup> and half of nitrogen top dressed recorded greater grain yield of 40 q/ha than lower level of nitrogen of 50 q/ha. And also 100 kg N ha<sup>-1</sup> enhanced N, P and K uptake compared with 50 kg ha<sup>-1</sup>. In a field experiment conducted by Anilkumar *et al.* (2001) Nitrogen @ 160 kg ha<sup>-1</sup> and P @ 60 kg ha<sup>-1</sup> produced significantly taller plants and more yield. They were more at 120 kg ha<sup>-1</sup> and 160 kg ha<sup>-1</sup> than lower doses of 80 Kg N and 20 kg P. Dilip Kumar Bastia and Ajay Kumar Rout (2001) found that the yield attributes grain and straw yields significantly increased with the increase in fertilizer dose.

(Szentpetyery *et al.*, 2005) found that in cultivation of wheat the economic optimum of nitrogen top dressing was around 80- 100 kg ha<sup>-1</sup>. Mann *et al.* (2005) revealed that wheat responded significantly to both residual fertility and applied nitrogen. Sankar (2005) in his experiment on yield response of wheat to fertilizer levels recorded that application of 100% recommended fertilizer enhanced the straw and grain yield to the tune of 125% and 108% against the control.

Islam *et al.* (2005) suggested that the concentration of P in most of sampling stages of wheat increased when the doses of P increased. It is observed that the application of 80 kg P<sub>2</sub>O<sub>5</sub> along with 5 kg Zn ha<sup>-1</sup> gave the highest yield of both grain and straw. Kulkarni *et al.* (2005) found that in wheat, grain and straw yields were increased with increase in application of potassium up to 120 kg ha<sup>-1</sup>. The results revealed that K content in both grain and straw was significantly influenced by the addition of K in K deficient soils. Thus they concluded that K deficient soils can be enriched by applying K<sub>2</sub>O @ 120 kg ha<sup>-1</sup>. In an experiment conducted at IARI, Pusa with different nitrogen rates, the yield increased up to 180 kg ha<sup>-1</sup> of nitrogen application but significant response was observed only up to 150 kg ha<sup>-1</sup>. Raghuraj *et al.* (2006) concluded that the yield contributing characters in wheat were significantly superior in treatments receiving recommended dose of fertilizer.

## 6.1. Response of wheat to IPNS

Sharma and Singh (2005) on a soil test based fertilizer use experiment in wheat found that lower response yardstick and benefit cost ratio were obtained with normal recommendation when compared to soil test based fertilizer recommendations for economic yield. Ray *et al.* (2000) revealed that fertilizer prescription based on testing of soils was found profitable as compared to adhoc recommendation for jute, rice and wheat. Tamboli and Sonar (1998) showed that the economics of fertilizer use based on soil test for achieving maximum yield indicated additional benefit over farmer's practice.

The maximum yield ( $10.24 \text{ t ha}^{-1}$ ) and high ratio of curd to foliage in cauliflower *var* Snowball-16 were obtained with the application of  $100 \text{ kg N}$  and  $15 \text{ t FYM ha}^{-1}$  along with  $22 \text{ kg}$  and  $42 \text{ kg P}$  and  $\text{K}$  respectively in potato-cauliflower cropping sequence (Kamla Singh and Sharma, 1990). Jeeva Jyothi *et al.* (1993) reported that a nutrient schedule of  $100:125: 25 \text{ kg ha}^{-1}$  along with the application of *Azospirillum* @  $2 \text{ kg ha}^{-1}$  was optimum for cabbage in Tamil Nadu. Rubeiz *et al.* (1993) studied the effect of layer and broiler poultry manure as a source of N fertilizer for cabbage and showed that layer and poultry manure can meet the N requirement of cabbage. Warman and Haward (1996) studied the yield and mineral content of cabbage grown with either composted manure or conventional fertilizers for three years and the data revealed that the significant change occurred only in one year when organically grown cabbage out yielded the conventionally grown. The Zn composition of the edible leaves was also reported to be more in organically grown cabbage. Sharma (2000), found out the influence of integrated nutrient management in broccoli using Green Head variety. The results revealed that integration of organic and inorganic fertilizers significantly increased the head yield over inorganic fertilizers alone and also over control. The treatment  $\text{N}_{175} \text{ P}_{75} \text{ K}_{60} + \text{FYM } 12.5 \text{ t ha}^{-1}$  recorded the maximum yield. Parmar and Vinod Sharma (2001) reported that highest net income of  $\text{Rs.}62,800 \text{ ha}^{-1}$  in cauliflower *var* PSB-1 with the application of 100 per cent recommended NPK and  $30 \text{ t ha}^{-1}$  FYM. Combined application of crop residue, FYM and dual inoculation of *Azotobacter* or *Rhizobium* and VAM produced the yield and plant growth equal to application of 75 per cent of the recommended NPK alone in cauliflower Bhardwaj *et al.* (2002). Gayathri (2003) reported that, the better fertilizer economy, efficient use of fertilizer and soil fertility is maintained under IPNS than compared to inorganic alone in potato. The similar result were obtained by Anonymous (2003b) and Kasthuri Thilagam (2004) in cauliflower, Anonymous (2004a) and Smitha John (2004) in

cabbage, potato Anonymous (2004a), in pea Anonymous (2004b), in ginger Anonymous (2004c), in wheat Anonymous (2004d), Umadevi (2005) in carrot. Experiments conducted on the usefulness of Azospirillum in wheat have shown a positive response Use of Asospirillum resulted in savings of chemical nitrogen fertilizer to the extent of 25 per cent.

The review of literature emphasised the need to generate information on soil test based fertiliser recommendation for wheat. This work provides a basis for fixing the site specific and targeted yield based fertiliser recommendation considering the fertiliser and organic resources available with the farmer. As research results on such aspects for wheat is lacking, the current research will help to develop the fertiliser prescription equation for hill wheat for fertilisers and under IPNS.

# **CHAPTER III**

## **MATERIALS AND METHODS**

The description of the field experiments conducted, analytical methods of soil and plant samples, statistical methods followed are presented in this chapter.

### **3.1 Experimental site**

#### **3.1.1 Location (Fig .1)**

Field experiments were conducted at IARI, Wheat Regional Research Station, Conoor, Nilgiri district, Tamil Nadu. The farm is situated at an altitude of 2134 m above MSL at 11° North latitude and 77° East longitude.

#### **3.1.2 Climate**

The experiments were conducted during July 2004 to March 2005. The normal weather conditions of the study area were as follows: The mean annual rainfall of Ooty is 1560 mm distributed over 65.8 rainy days. The mean maximum and minimum temperatures are 21.5°C and 11.0°C respectively. The mean relative humidity is 85 per cent. The weather parameters prevailed during the cropping period is presented in Table 1 & Fig 2.

#### **3.1.3 Soil characteristics**

The soil of experimental site is Ooty series (Ultic Hapludalf). The soil texture is sandy clay loam with pH of 4.85 and E.C. of 0.02 dSm<sup>-1</sup>. The initial composite soil sample was analyzed for its fertility status and it was found to contain high available N, P and K status. The profile characteristics are furnished in Annexure I.

### **3.2 Field experiments**

Two field experiments namely one fertility gradient experiment with potato (var, Giriraja) and another test crop experiment with wheat (var. HW2044) were conducted in the Wheat Regional Research Station, IARI, Wellington, Conoor, Nilgiris

#### **3.2.1 Gradient experiment**

The main objective of this experiment was to create wide variation in soil fertility of the experimental field to the extent possible and to create appropriate range of values for each control variable (fertilizer dose) at different levels of uncontrollable variable (soil fertility) which could not be expected to occur at one place normally. Hence, in order to deliberately create the variations in one and the same field and to reduce the

heterogeneity in the soil population studied, management practices adopted and climatic conditions prevailing, the gradient experiment was conducted by adopting the Induction methodology developed by Ramamoorthy *et al.* (1967).

Initially, a composite soil sample were collected for characterizing the experimental soil. The standard dose of  $N_1$  was based on the blanket recommendation.  $P_1$  and  $K_1$  were fixed based on the P and K fixing capacity of the soil. The experimental field was divided into four equal strips and each strip was further divided into six equal plots, thus making a total of 24 plots. After dividing the field into four equal strips, five pre-sowing surface soil (0-15 cm) samples from each fertility strip, a total of 24 samples were collected before applying fertilizers and sowing of gradient crop of potato var Giriraja. The variations in soil fertility was created by applying graded doses of N,  $P_2O_5$  and  $K_2O$  fertilizers in the form of urea, single superphosphate and muriate of potash respectively to each strip as furnished in Table 2.

The first strip received no fertilizer ( $N_0P_0K_0$ ), the second, third and fourth received half ( $N_{1/2}P_{1/2}K_{1/2}$ ), one ( $N_1P_1K_1$ ) and two ( $N_2P_2K_2$ ) times the standard dose of N, P and K respectively. The  $N_1$  level was fixed at  $150 \text{ kg ha}^{-1}$  as per blanket fertilizer recommendation for potato. The  $P_1$  and  $K_1$  levels were fixed at 250 and  $100 \text{ kg ha}^{-1}$  respectively based on P and K fixing capacities of soil. The entire dose of N,  $P_2O_5$  and  $K_2O$  were applied basally to all the four strips and potato was grown adopting the usual agronomic practices and the tuber yield was recorded strip-wise. Twenty four plant samples, six from each strip were collected at harvest. After the harvest of potato, 24 post harvest soil samples were also collected in the same manner from the four strips. The details of crop / varieties and important cultural operations followed are furnished in Table 3.

### **3.2.2 Test crop experiment**

Field experiment with measured levels of fertilizer nutrient was conducted with a test crop of wheat variety HW2044 to develop a relationship between different levels of fertilizer nutrient and the resultant crop yield obtained. After creation of gradient in all the four strips and harvest of gradient crop potato in all the four strips, each fertility strip was be divided into 28 plots so as to accommodate 28 treatments and then the test crop wheat was grown during Rabi season.

#### **3.2.2.1 Treatment Structure and Experimental Design**

The treatment structure was selected in such a way that yield prediction and optimization of fertilizer doses could be made by targeted yield models. There were five levels of N, four levels of P<sub>2</sub>O<sub>5</sub>, four levels of K<sub>2</sub>O, two levels of vermicompost and 2 levels of *Azospirillum*. The experiment was conducted following factorial randomized design as adopted in the All India Coordinated Research Project on Soil Test Crop Response correlation studies. Twenty eight treatment combinations from 4 x 3 x 3 levels of N, P and K were randomly allotted in each strip in such a way that twenty eight treatments were present in all the strips in either direction.

For N, there are three treatment points at zero level, four at first level (50 kg N ha<sup>-1</sup>), ten at second level (100 kg ha<sup>-1</sup>), seven at third level (150 kg ha<sup>-1</sup>) and four at fourth level (200 kg ha<sup>-1</sup>). For P<sub>2</sub>O<sub>5</sub>, there were seven points at zero level, five at first level (30 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>), eight at second level (60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) and eight at third level (90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>). In case of K<sub>2</sub>O, there were eleven at zero level, seven at first level (40 kg K<sub>2</sub>O ha<sup>-1</sup>), ten at second level (80 kg K<sub>2</sub>O ha<sup>-1</sup>) and three at third level (120 kg K<sub>2</sub>O ha<sup>-1</sup>). The treatment points were so chosen to compute the response of each nutrient at each level and response for each total effect of N, P and K treatments.

The treatments of Integrated Plant Nutrition system (IPNS) *viz.*, NPK + vermicompost @ 5 tons ha<sup>-1</sup> (with a moisture content of 40 per cent, N-1.02 %, P<sub>2</sub>O<sub>5</sub> 0.03 %, K<sub>2</sub>O 0.56 %), NPK + *Azospirillum* @ 2 kg ha<sup>-1</sup> and NPK + vermicompost @ 5 tons ha<sup>-1</sup> + *Azospirillum* @ 2 kg ha<sup>-1</sup> and NPK alone were super imposed across the strips. The treatment combinations and the levels of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O for each of four strips are furnished in table (4) & (5) and lay out plan is given in Fig3.

Pre sowing soil samples of test crop were collected from each plot at 0-15 cm depth before the application of fertilizers and organics. Fertilizers, vermicompost and *Azospirillum* were applied as per recommendation wheat seeds were sown continuously with a spacing of 23 cm between rows. Irrigation and top dressing of remaining dose of urea and MOP was done at 25<sup>th</sup> day of sowing and other usual packages of practices were followed. Significant treatment differences were observed between the strips. The control plot in the IV<sup>th</sup> strip was observed healthy compared to the control plot in strip I, because of the fertility gradient and weed population was also higher in strip IV. At harvest plant samples as well as post harvest soil samples were collected from all the experimental plots of test crop experiment.

### **3.3 Analysis of soil and plant samples**

#### **3.3.1 Analysis of soil samples**

The air dried soil samples were processed and sieved through 2mm sieve, labelled and stored in cloth bags. The initial soil sample collected before the gradient crop of potato was analyzed for various physical, physico-chemical and chemical properties. In case of gradient and test crop experiments, the pre- sowing and post harvest soil samples were also collected and analyzed for available N, P and K status.

#### **3.3.2 Analysis of plant samples**

The plant samples were air dried initially and then dried in hot air oven at 60°C for 72 hours. Then the plant samples were powdered in a willey mill, labelled and stored in butter paper covers for analysis.

The root, the grain and the straw samples of wheat were analyzed for moisture, total N, P and K content. The uptake was calculated using dry matter and nutrient contents of plant samples. The analytical methods followed for analysis of soil and plot samples are furnished in Table 6.

### **3.4 Calculation of basic parameters**

Using the data on grain yield of wheat, total uptake of N, P, K, initial soil test values for available N, P and K and doses of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O applied, the basic parameters *viz.*, nutrient requirement (NR), soil efficiency (Cs), fertilizer efficiency (Cf) and organic efficiency (Co) were computed. Making use of these parameters, fertilizer adjustment equations is developed for wheat. The above basic parameters were calculated as furnished below.

## Calculation of basic parameters

### 1. Nutrient requirement (NR) kg q<sup>-1</sup>

$$\text{i) kg N required per quintal of wheat grain production} = \frac{\text{Total uptake of N (kg ha}^{-1}\text{)}}{\text{Grain yield (q ha}^{-1}\text{)}}$$

$$\text{ii) kg P}_2\text{O}_5 \text{ required per quintal of wheat grain production} = \frac{\text{Total uptake of P}_2\text{O}_5 \text{ (kg ha}^{-1}\text{)}}{\text{Grain yield (q ha}^{-1}\text{)}}$$

$$\text{iii) kg K}_2\text{O required per quintal of wheat grain production} = \frac{\text{Total uptake of K}_2\text{O (kg ha}^{-1}\text{)}}{\text{Grain yield (q ha}^{-1}\text{)}}$$

### 2. Per cent nutrient contribution from soil to total nutrient uptake (Cs)

$$\text{i) Per cent contribution of N from soil} = \frac{\text{Total uptake of N in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value for available N in control plot (kg ha}^{-1}\text{)}} \times 100$$

$$\text{ii) Per cent contribution of P}_2\text{O}_5 \text{ from soil} = \frac{\text{Total uptake of P}_2\text{O}_5 \text{ in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value for available P in control plot (kg ha}^{-1}\text{)}} \times 100$$

$$\text{iii) Per cent contribution of K}_2\text{O from soil} = \frac{\text{Total uptake of K}_2\text{O in control plot (kg ha}^{-1}\text{)}}{\text{Soil test value for available K in control plot (kg ha}^{-1}\text{)}} \times 100$$

### 3. Per cent nutrient contribution from fertilizer to total uptake (Cf)

$$\text{i) Per cent contribution of N from fertilizer} = \frac{\text{Total uptake of N in treated plot (kg ha}^{-1}\text{)} - \left( \text{Soil test value for available N in treated plot (kg ha}^{-1}\text{)} \times \text{Average Cs} \right)}{\text{Fertilizer N applied (kg ha}^{-1}\text{)}} \times 100$$

$$\text{ii) Per cent contribution of P}_2\text{O}_5 \text{ from fertilizer} = \frac{\text{Total uptake of P}_2\text{O}_5 \text{ in treated plot (kg ha}^{-1}\text{)} - \left( \text{Soil test value for available P}_2\text{O}_5 \text{ in treated plot (kg ha}^{-1}\text{)} \times \text{Average Cs} \right)}{\text{Fertilizer P}_2\text{O}_5 \text{ applied (kg ha}^{-1}\text{)}} \times 100$$

$$\text{iii) Per cent contribution of K}_2\text{O from fertilizer} = \frac{\text{Total uptake of K}_2\text{O in treated plot (kg ha}^{-1}\text{)} - \left( \text{Soil test value for available K}_2\text{O in treated plot (kg ha}^{-1}\text{)} \times \text{Average Cs} \right)}{\text{Fertilizer K}_2\text{O applied (kg ha}^{-1}\text{)}} \times 100$$

#### 4. Percent nutrient contribution from organics to total uptake (Co)

##### i) Percent contribution from Vermicompost ( $C_{\text{vermi}}$ )

$$\text{iii) Per cent contribution of } C_{\text{vermi}} = \frac{\text{Total uptake of N/P/K in vermi treated plot (kg ha}^{-1}) - \left( \text{Soil test value for available N/P/K in vermi treated plot (kg ha}^{-1}) \times \text{Average } C_s \right)}{\text{Nutrient N/P/K added through vermi (kg ha}^{-1})} \times 100$$

##### ii) Percent contribution from vermi + *Azospirillum* ( $C_{\text{vermi+Azo}}$ )

$$\text{iii) Percent contribution of } C_{\text{vermi+Azo}} = \frac{\text{Total uptake of N in vermi+Azo treated plot (kg ha}^{-1}) - \left( \text{Soil test value for available N in vermi +Azo treated plot (kg ha}^{-1}) \times \text{Average } C_s \right)}{\text{Amount of N contributed through vermi + Azospirillum (kg ha}^{-1})} \times 100$$

#### 3.5. Targeted yield equations

From the above parameters the targeted yield equations were calculated as below.

##### i) Fertilizer Nitrogen (FN)

$$\text{FN} = \frac{\text{NR}}{\text{Cf}/100} \text{ T} - \frac{\text{Cs}}{\text{Cf}} \text{ SN}$$

$$\text{FN} = \frac{\text{NR}}{\text{Cf}/100} \text{ T} - \frac{\text{Cs}}{\text{Cf}} \text{ SN} - \frac{C_{\text{vermi}}}{\text{Cf}} \text{ ON}$$

$$\text{FN} = \frac{\text{NR}}{\text{Cf}/100} \text{ T} - \frac{\text{Cs}}{\text{Cf}} \text{ SN} - \frac{C_{\text{vermi+Azo}}}{\text{Cf}} \text{ ON}$$

##### ii) Fertilizer Phosphorus ( $\text{FP}_2\text{O}_5$ )

$$\text{FP}_2\text{O}_5 = \frac{\text{NR}}{\text{Cf}/100} \text{ T} - \frac{\text{Cs}}{\text{Cf}} \times 2.29 \times \text{SP}$$

$$\text{FP}_2\text{O}_5 = \frac{\text{NR}}{\text{Cf}/100} \text{ T} - \frac{\text{Cs}}{\text{Cf}} \times 2.29 \times \text{SP} - \frac{C_{\text{vermi}}}{\text{Cf}} \times 2.29 \times \text{OP}$$

$$\text{FP}_2\text{O}_5 = \frac{\text{NR}}{\text{Cf}/100} \text{ T} - \frac{\text{Cs}}{\text{Cf}} \times 2.29 \times \text{SP} - \frac{C_{\text{vermi+az}}}{\text{Cf}} \times 2.29 \times \text{OP}$$

### iii) Fertilizer Potassium (FK<sub>2</sub>O)

$$FK_2O = \frac{NR}{Cf/100} T - \frac{Cs}{Cf} \times 1.20 \times SK$$

$$FK_2O = \frac{NR}{Cf/100} T - \frac{Cs}{Cf} \times 1.20 \times SK - \frac{C_{vermi}}{C_f} \times 1.20 \times OK$$

$$FK_2O = \frac{NR}{Cf/100} T - \frac{Cs}{Cf} \times 1.20 \times SK - \frac{C_{vermi+az}}{C_f} \times 1.20 \times OK$$

Where,

- FN : Fertilizer N (kg ha<sup>-1</sup>)  
 FP<sub>2</sub>O<sub>5</sub> : Fertilizer P<sub>2</sub>O<sub>5</sub> (kg ha<sup>-1</sup>)  
 FK<sub>2</sub>O : Fertilizer K<sub>2</sub>O (kg ha<sup>-1</sup>)  
 NR : Nutrient requirement of N or P<sub>2</sub>O<sub>5</sub> or K<sub>2</sub>O (kg ha<sup>-1</sup>)  
 Cs : Per cent contribution from soil  
 Cf : Per cent contribution from fertilizer  
 SN : Soil test value for available N (kg ha<sup>-1</sup>)  
 SP : Soil test value for available P (kg ha<sup>-1</sup>)  
 SK : Soil test value for available K (kg ha<sup>-1</sup>)  
 C<sub>vermi</sub> : Per cent contribution from vermicompost  
 C<sub>vermi + Azo</sub> : Per cent contribution from vermicompost + *Azospirillum*  
 ON : Quantity of nitrogen applied through vermicompost / *Azospirillum*  
 OP : Quantity of phosphorus applied through vermicompost / vermicompost + *Azospirillum*  
 OK : Quantity of potassium applied through vermicompost/ vermicompost+ *Azospirillum*

The above equations serve as a basis for predicting fertilizer doses for specific yield targets (T) for varied levels of soil available nutrients.

### 3.6 Economics

Using the data on grain yield, quantity of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O applied, initial soil test value for available NPK and the cost of nutrients, the efficient and economic use of fertilizers in NPK alone and in IPNS were worked out.

### 3.7 Statistical analysis

The data obtained from this experiment were subjected to statistical analysis to determine the effects due to treatments and other factors (Sukhatme and Amble, 1985).

Targeted yield equations were developed to predict yields and optimize the fertilizer doses for varying soil test values (FAO, 1966; Ramamoorthy *et al.*, 1967).

## CHAPTER IV

### RESULTS

The present investigation, comprising of two field experiments viz., fertility gradient experiment with of Potato *var.* Giriraja and a test crop experiment with wheat variety HW2044 were conducted in the Ooty soil series of Alfisols. The results recorded from the field experiments, the soil test calibrations and the effect of Integrated Plant Nutrition System (IPNS) on wheat are presented in this chapter.

#### 4.1. Soil characteristics of the experimental site (Table 7)

The soil of the experimental site belongs to Ooty series (Ultic Hapludalf), which is a major soil series of Tamil Nadu. The profile description of the soil showed that Ooty series is dark greyish brown to reddish brown, moderately deep, well-drained and non-calcareous soil developed over weathered charnokite.

The results of the analysis of initial soil sample collected from the experimental site (Table 7) showed that the surface soil texture was sandy clay loam with a bulk density of  $1.48 \text{ Mg m}^{-3}$ . The pH, electrical conductivity and cation exchange capacity of the soil were 4.85,  $0.02 \text{ dSm}^{-1}$  and  $22.7 \text{ c mol (p}^+) \text{ kg}^{-1}$ , respectively. The P and K fixing capacities of the soil were  $250$  and  $100 \text{ kg ha}^{-1}$ , respectively.

The fertility status of the soil was high in  $\text{KMnO}_4\text{-N}$  ( $252 \text{ kg ha}^{-1}$ ) and organic carbon (1.68 per cent), high in Bray-P ( $320 \text{ kg ha}^{-1}$ ) and high in  $\text{NH}_4\text{OAc-K}$  ( $302 \text{ kg ha}^{-1}$ ). The available Fe (46), Mn (14.5), Zn (1.5) and Cu (3.2) ppm were above the critical limits. The total N, P and K status of the soil was 0.27, 0.24 and 0.46 per cent, respectively.

#### 4.2. Fertility gradient experiment with Potato

The functional relationship of crop response (Y) in an IPNS system with soil (S), fertilizer (F) and organic nutrients (O) is  $Y = f(S, F, O)$ .

The variables S, F and O should have sufficient range of crop response surfaces for optimisation purposes. With respect to applied fertilizer (F) and organic (O) nutrients, a range of levels could be maintained. But there is a practical limitation for keeping such range of levels in soils and this can be overcome by creating fertility gradients in one

and the same field by the application of graded doses of fertilizers. Therefore, a fertility gradient experiment was conducted adopting the Inductive methodology proposed by Ramamoorthy *et al.* (1967).

Creation of sufficient range of nutrient levels can be observed by comparing the response of gradient crop in terms of yield and nutrient uptake and soil test values of initial and post-harvest soil samples. The results of the fertility gradient experiment are given below.

#### **4.2.1. Soil analysis**

##### **4.2.1.1. Available nutrient status of pre sowing soil samples (Table 8)**

Twenty four soil samples collected prior to the sowing of the gradient crop potato were analysed for alkaline  $\text{KMnO}_4\text{-N}$ , Bray -P and  $\text{NH}_4\text{OAc-K}$ . The values of alkaline  $\text{KMnO}_4\text{-N}$  ranged from 340 to 375  $\text{kg ha}^{-1}$  with mean values of 352  $\text{kg ha}^{-1}$  for strip I, 363  $\text{kg ha}^{-1}$  for strip II, 367  $\text{kg ha}^{-1}$  for strip III and 366  $\text{kg ha}^{-1}$  for strip IV.

The Bray -P content ranged from 311 to 384  $\text{kg ha}^{-1}$  with mean values of 322  $\text{kg ha}^{-1}$  for the strips I, 331  $\text{kg ha}^{-1}$  for strip II, 337  $\text{kg ha}^{-1}$  for strip III and 373  $\text{kg ha}^{-1}$  for strip IV respectively. With respect to  $\text{NH}_4\text{OAc-K}$ , the values ranges from 53 to 186  $\text{kg ha}^{-1}$  and the mean values were 169  $\text{kg ha}^{-1}$  for the strips I, 179  $\text{kg ha}^{-1}$  for strip II, 173  $\text{kg ha}^{-1}$  for strip III and 176  $\text{kg ha}^{-1}$  for strip IV (Table 8).

##### **4.2.1.2. Available nutrient status of post harvest soil samples**

After the harvest of gradient crop of potato six soil samples from each fertility strip were collected totalling to twenty four soil samples and analysed for available N, P and K with a view to know the effect of application of graded dose of fertilizers. The post harvest soil values were statistically analysed to find out the variations in the fertility status of the soil among the four fertility gradient strips. The mean values of N, P and K status of the four strips are given in Table 8.

##### **4.2.1.1. Soil available nitrogen**

The alkaline  $\text{KMnO}_4\text{-N}$  ranged from 336  $\text{kg ha}^{-1}$  in strip I to 421  $\text{kg ha}^{-1}$  in strip IV and the mean values were 368, 376, 399 and 410  $\text{kg ha}^{-1}$ , strips I to IV respectively. The results showed that there was a progressive increase in  $\text{KMnO}_4\text{-N}$  with the increased doses of added nitrogen and this increase was found to be statistically significant (Table 8).

#### **4.2.1.2. Soil available phosphorus**

The Bray-P status in the soil after the harvest of potato ranged from 319 to 560 kg ha<sup>-1</sup> with mean values of 328, 430, 475 and 514 kg ha<sup>-1</sup>, respectively. The statistical analysis revealed that there was a significant difference among the four strips and creation of soil fertility gradients has occurred (Table 8).

#### **4.2.1.3. Soil available potassium**

The range of NH<sub>4</sub>OAc-K in the post harvest soil of Potato ranged from 165 to 262 kg ha<sup>-1</sup> with mean values of 178, 210, 224 and 246 kg ha<sup>-1</sup> respectively. The statistical analysis showed that each strip was statistically different from the other and the addition of potassium fertilizer in graded levels resulted in significant increase in the availability of K in the soil (Table 8).

Thus the creation of soil fertility gradients for all the three macronutrients with respect to soil test values was confirmed from the soil analytical data.

#### **4.2.2. Potato tuber yield and nutrient uptake by gradient crop**

The yield of tubers in control strip (N<sub>0</sub>P<sub>0</sub>K<sub>0</sub>) was 8162.50 kg ha<sup>-1</sup>, which did not receive any fertilizers. In the second strip (N<sub>1/2</sub>P<sub>1/2</sub>K<sub>1/2</sub>), the yield was 13673 kg ha<sup>-1</sup>, which was significantly higher than strip I. In the third (N<sub>1</sub>P<sub>1</sub>K<sub>1</sub>) and fourth strips (N<sub>2</sub>P<sub>2</sub>K<sub>2</sub>), the yields recorded were 19102 and 23945 kg ha<sup>-1</sup> respectively, which were significantly higher than that of strip II. The yield recorded from each strip also revealed that there was a significant difference among the four strips (Table 10).

The N, P and K contents of the potato var Giriraja samples were analysed and the uptake of nutrients was calculated from dry matter yield. The mean values of N uptake in strips I, II, III and IV were 75.54, 91.61, 171.92 and 201.14 kg ha<sup>-1</sup> respectively. The results indicated that the N uptake was found to increase with increase in the fertilizer doses. With reference to P uptake, the mean values were 60.49, 83.27, 112.6 and 122.64 kg ha<sup>-1</sup> in strips I, II, III and IV respectively. The K uptake was 117.94, 142.19, 185.29 and 210.95 kg ha<sup>-1</sup> in strips I, II, III and IV respectively.

The results of N, P and K uptake by potato var Giriraja recorded progressive increase with increased doses of fertilizers. The differences were statistically significant and thereby indicated that the N, P and K uptake by the gradient crop in each strip was statistically different from the other (Table 10).

### 4.3. Selection of suitable soil test methods for available nutrients

To select suitable soil test methods for available N, P and K for the test crop of wheat, simple correlation study was carried out with different soil test methods. The values obtained from different methods were correlated with yield and nutrient uptake. The results of correlation study are furnished in Table 11.

**Table 11. Correlation of soil test values with response variables of wheat**

Variables correlated	Alkaline KMnO <sub>4</sub> -N	Organic carbon	Bray-P (1:50)	Bray-P (1:10)	NH <sub>4</sub> O Ac-K	0.1 N HNO <sub>3</sub>
Grain yield	0.861**	0.349	0.821**	0.423	0.809**	0.439
Nutrient uptake	0.928**	0.463	0.703**	0.538	0.727**	0.533

\*\* Significant at P = 0.01

For available N, two methods *viz.*, alkaline KMnO<sub>4</sub> and organic carbon methods were tested. The results showed that the alkaline KMnO<sub>4</sub> method was highly correlated ( $r = 0.861^{**}$ ) with the grain yield of wheat. The same method was also highly correlated with total N uptake ( $r = 0.928^{**}$ ). The organic carbon method was not significantly correlated with yield and N uptake.

Regarding P, Bray 1:50-P and Bray 1:10-P methods were tested for their significance. The results showed that Bray1: 50-P method was positively correlated with wheat grain yield and total P uptake ( $r = 0.821^{**}$  and  $0.703^{**}$ ). Bray 1:10-P method was not suitable for the estimation of available P in the soil tested.

From the results it was observed that the neutral normal NH<sub>4</sub>OAc method was significantly correlated with yield ( $r = 0.809^{**}$ ) and total K uptake ( $r = 0.727^{**}$ ). It indicated that the 0.1 N HNO<sub>3</sub> methods were not suitable for estimation of available K in the soil tested.

### 4.4. Test crop experiments

After the development of fertility gradients in the experimental site, the test crop of wheat variety HW 2044 was grown. The range and mean values of initial soil test values, grain yield and nutrient uptake are furnished below.

#### 4.4.1. Initial soil analysis (Tables 12 to 15)

Before sowing the wheat seeds, the initial soil samples were collected and analysed for the three-macro nutrients. In the treated plots (that received either fertilizers or fertilizers plus vermicompost or fertilizers plus *Azospirillum* or fertilizers plus vermi plus *Azospirillum*), the initial soil test values showed that  $\text{KMnO}_4\text{-N}$  increased from  $328 \text{ kg ha}^{-1}$  in strip I to  $386 \text{ kg ha}^{-1}$  in strip IV with the mean values of 353, 355, 360 and  $368 \text{ kg ha}^{-1}$ , respectively. The Bray-P ranged from 281 to  $459 \text{ kg ha}^{-1}$  with the mean values of  $292 \text{ kg ha}^{-1}$  for strip I,  $331 \text{ kg ha}^{-1}$  for strip II,  $338 \text{ kg ha}^{-1}$  for strip III and  $425.8 \text{ kg ha}^{-1}$  for strip IV, while the  $\text{NH}_4\text{OAc-K}$  status varied from 154 to  $239 \text{ kg ha}^{-1}$  with mean values of  $174 \text{ kg ha}^{-1}$  for strips I,  $195 \text{ kg ha}^{-1}$  for strips II,  $202 \text{ kg ha}^{-1}$  for strips III and  $211 \text{ kg ha}^{-1}$  IV.

In the control plots of the four fertility gradients strips, the  $\text{KMnO}_4\text{-N}$  ranged from 319 to 330 with a mean of  $323 \text{ kg ha}^{-1}$ . The Bray -P status ranged from 293 to  $305 \text{ kg ha}^{-1}$  with a mean value of  $299 \text{ kg ha}^{-1}$ , while the  $\text{NH}_4\text{OAc-K}$  status varied from 203 to  $224 \text{ kg ha}^{-1}$  with a mean value of  $214 \text{ kg ha}^{-1}$ .

The results of the initial soil samples showed the existence of operational range of soil test values for N, P and K in the present investigation.

#### **4.4.2. Grain yield of wheat (Tables 12 to 16) ;(Annexure I to IV)**

The grain yield of wheat in the treated plots ranged from 1800 to  $5468 \text{ kg ha}^{-1}$  with mean values of  $2769 \text{ kg ha}^{-1}$  for strip I,  $3784 \text{ kg ha}^{-1}$  for strip II,  $4276 \text{ kg ha}^{-1}$  for strip III and  $4435 \text{ kg ha}^{-1}$  for strip IV.

The results of treated plots (Table 16) indicated that the highest yield of  $5468 \text{ kg ha}^{-1}$  was recorded with N,  $\text{P}_2\text{O}_5$  and  $\text{K}_2\text{O}$  applied @ 200, 90,  $40 \text{ kg ha}^{-1}$  along with vermicompost @  $5 \text{ t ha}^{-1}$  and *Azospirillum* @  $2 \text{ kg ha}^{-1}$  in strip IV. The corresponding initial soil test values of  $\text{KMnO}_4\text{-N}$ , Bray -P and  $\text{NH}_4\text{OAc-K}$  were 386, 455 and  $223 \text{ kg ha}^{-1}$  respectively. The lowest yield in the treated plots was  $1800 \text{ kg ha}^{-1}$  with the application of N @  $50 \text{ kg ha}^{-1}$  and without P and K in strip I with initial soil test values of 337, 292 and  $160 \text{ kg ha}^{-1}$  of  $\text{KMnO}_4\text{-N}$ , Bray-P and  $\text{NH}_4\text{OAc-K}$  respectively. This indicated the importance of balanced use of all the three macronutrients through IPNS and also the contribution of native soil fertility towards yield.

##### **4.4.2.1. Grain yield of wheat in control plots (Table 17)**

In control plots, the yield ranged from 2134 to  $2900 \text{ kg ha}^{-1}$  with a mean value of  $2517 \text{ kg ha}^{-1}$ . Among the control plots, the highest grain yield of  $2900 \text{ kg ha}^{-1}$  was recorded in strip IV with the application of vermicompost @  $5 \text{ t ha}^{-1}$  and *Azospirillum* @

2 kg ha<sup>-1</sup> having initial soil test values of 327, 293 and 221 kg ha<sup>-1</sup> of KMnO<sub>4</sub>-N, Bray-P and NH<sub>4</sub>OAc-K respectively. The lowest yield of 2134 kg ha<sup>-1</sup> was recorded in strip I with absolute control and the initial soil test values were 319, 295 and 203 kg ha<sup>-1</sup> of KMnO<sub>4</sub>-N, Bray -P and NH<sub>4</sub>OAc-K respectively.

#### **4.4.3. Nutrient uptake (Tables 12 to 16) ;( Annexure I to II)**

In treated plots, nitrogen uptake varied from 84.7 to 164.76 kg ha<sup>-1</sup>. The mean values were 114.21, 120.97, 123.70 and 128.03 kg ha<sup>-1</sup> for nitrogen in strips I, II, III and IV respectively. The uptake of phosphorus increased from 27.96 to 89.92 kg ha<sup>-1</sup> with the mean values of 47.16, 52.99, 57.92 and 62.22 kg ha<sup>-1</sup> respectively while the uptake for K ranged from 52.24 to 155.78 kg ha<sup>-1</sup> with the mean values of 76.98, 82.90, 92.51 and 113.65 kg ha<sup>-1</sup>, respectively for strips I, II, III and IV. In control plots, the uptake of nitrogen ranged from 68.03 to 75.11 kg ha<sup>-1</sup> with the mean values of 68.85 kg ha<sup>-1</sup>, while phosphorus and potassium ranged from 22.39 to 39.67 and 44.49 to 69.81 with the mean values of 30 and 56.42 kg ha<sup>-1</sup>, respectively.

#### **4.4.4. Response of wheat to fertilizer nutrients (Table 18)**

Response of wheat to fertilizer nutrients and response ratio to different levels of fertiliser nutrients are furnished in Table 18. For 50 kg of N ha<sup>-1</sup> the response ratio was 66.1 kg of grain per kg of N and the response ratio was 38.89, 28 and 22.9 kg kg<sup>-1</sup> for 100, 150 and 200 kg N ha<sup>-1</sup> respectively. The response ratio of 125.2 kg kg<sup>-1</sup> was recorded for application of 30 kg of P<sub>2</sub>O<sub>5</sub> while it was 63.4 and 50 kg kg<sup>-1</sup> respectively for 60 and 90 kg of P<sub>2</sub>O<sub>5</sub> applied. For K, the initial response to addition of K<sub>2</sub>O @ 40 kg ha<sup>-1</sup> was recorded with a response ratio of 97.3 kg kg<sup>-1</sup> K<sub>2</sub>O. When the dose of K<sub>2</sub>O was increased to 80 and 120 kg ha<sup>-1</sup>, the responses were reduced to 51.4 and 39.3 kg kg<sup>-1</sup> of K<sub>2</sub>O added respectively.

### **4.5. Targeted yield model – optimisation of fertilizer doses for desired yield targets of wheat**

#### **4.5.1. Basic parameters (Table 19)**

To calibrate the soil test values and prescribe fertilizer doses for pre-set yield targets of wheat by targeted yield model, the three basic parameters viz., nutrient requirement in kg per quintal grain yield of wheat (NR), per cent contribution from soil available nutrients (Cs) and fertilizer nutrients (Cf) were calculated and presented. The contribution from soil accounted to 21.65 per cent for nitrogen, 10.01 per cent for phosphorus and 26.26 per cent for potassium. The contribution of nutrients from fertilizer was 39.21,

87.47 and 70.82 per cent respectively for N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O. The response yardstick recorded was 6.63 kg kg<sup>-1</sup>.

#### 4.5.2. Fertilizer prescription equations and optimization of fertilizer doses (Table 20)

The fertilizer prescription equations developed for yield targeting using the basic parameters as estimated by whole field method are presented below.

$$FN = 7.6 T - 0.55 SN$$

$$FP_2O_5 = 3.59 T - 0.26 SP$$

$$FK_2O = 3.88 T - 0.45 SK$$

Where, FN, FP<sub>2</sub>O<sub>5</sub> and FK<sub>2</sub>O respectively are fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in kg ha<sup>-1</sup>; T is the yield target in q ha<sup>-1</sup> and SN, SP and SK respectively are alkaline KMnO<sub>4</sub>-N, Bray-P and NH<sub>4</sub>OAc-K in kg ha<sup>-1</sup>.

Using the above equations, fertilizer prescriptions for pre-set yield targets of 35, 45 and 55 quintals of wheat per hectare were worked out for a range of soil test values and presented. The results indicated that, to produce 45 q ha<sup>-1</sup> grain yield of wheat, with a soil test value of 350 kg ha<sup>-1</sup> of KMnO<sub>4</sub>-N, 400 kg ha<sup>-1</sup> of Bray-P and 250 kg ha<sup>-1</sup> of NH<sub>4</sub>OAc-K, the fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O requirement would be 149.5, 57.55 and 62.1 kg ha<sup>-1</sup> respectively. For the same soil test values, the quantities of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O required to produce 55 q ha<sup>-1</sup> grain yield of wheat would be 226, 93 and 101 kg ha<sup>-1</sup> respectively.

#### 4.6. Integrated Plant Nutrition System (IPNS)

The beneficial effect of conjoint use of chemical fertilizers with vermicompost (vermi), with *Azospirillum* (Azo) and with vermicompost plus *Azospirillum* was studied in the present investigation. The results pertaining to the influence of IPNS on grain yield, nutrient uptake and per cent contribution of nutrients from vermicompost, *Azospirillum* and vermicompost plus *Azospirillum* are presented below.

##### 4.6.1. Initial soil available nutrients in IPNS plots (Tables 21 and 22)

The initial KMnO<sub>4</sub>-N status ranged from 328 to 379 kg ha<sup>-1</sup> in NPK alone, 337 to 380 kg ha<sup>-1</sup> NPK plus vermicompost and 337 to 385 NPK kg ha<sup>-1</sup> with vermicompost plus *Azospirillum* treated plots. The initial Bray-P status ranged from 281 to 459 kg ha<sup>-1</sup> in NPK alone, 285 to 439 kg ha<sup>-1</sup> NPK plus vermicompost, and 287 to 457 kg ha<sup>-1</sup> NPK plus vermicompost plus *Azospirillum* and that of NH<sub>4</sub>OAc-K was from 159 to 226 kg ha<sup>-1</sup> in NPK alone, 168 to 227 kg ha<sup>-1</sup> NPK plus vermicompost and 160 to 239 kg ha<sup>-1</sup> NPK plus vermicompost plus *Azospirillum* treated plots.

#### **4.6.2. Influence of IPNS on grain yield and nutrient uptake by wheat (Tables 22)**

The grain yield of wheat in NPK alone plots ranged from 2084 to 5263 kg ha<sup>-1</sup> with a mean value of 3946 kg ha<sup>-1</sup> recording an increase of 76.40 per cent over absolute control. The range of yield in NPK plus vermicompost plots was from 2400 to 5336 kg ha<sup>-1</sup> with a mean of 3926.3 kg ha<sup>-1</sup> which has recorded 75.55 per cent increase in yield over absolute control. In NPK with vermicompost plus *Azospirillum* plots, the yield ranged from 2250 to 5468 kg ha<sup>-1</sup> with a mean of 4083 kg ha<sup>-1</sup> recording an increase of 82.52 per cent over absolute control.

In vermicompost alone plots, the yield ranged from 2290 to 2900 kg ha<sup>-1</sup> with a mean of 2490 kg ha<sup>-1</sup> and the range of yield in plots treated with *Azospirillum* alone plots was from 2134 to 2695 with a mean value of 2414 kg ha<sup>-1</sup>. The per cent increase in yield over absolute control was 11.31, and 7.9 per cent respectively for vermicompost, and *Azospirillum* plots.

The mean N uptake by wheat was 114.5, 126.3 and 119.9 kg ha<sup>-1</sup>, the mean P uptake was 58.88, 55.23 and 56.54 kg ha<sup>-1</sup> and the mean uptake of K was 106.32, 96.13 and 95.88 kg ha<sup>-1</sup>, respectively for NPK alone, NPK with vermicompost and NPK with vermicompost plus *Azospirillum*. In the vermicompost alone treated plots the mean N, P and K uptake was 71.49, 27.19 and 52.52 kg ha<sup>-1</sup>, in *Azospirillum* alone plots the mean N, P and K uptake was 72.87, 28.02 and 53.49 kg ha<sup>-1</sup> respectively.

#### **4.6.3. Contribution of nutrients from vermicompost and vermicompost with *Azospirillum* (Table 23)**

The contribution of nutrients from vermicompost and vermicompost plus *Azospirillum* is calculated using the data generated from the test crop experiment and the results obtained are furnished below. While computing the contribution from organics, only one third of the total content of N, P and K were taken into account for short duration crops based on the rate of mineralization and nutrient release from organics. The per cent contribution of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O from vermicompost (C<sub>vermi</sub>) were 36, 10.5 and 19.6 respectively and for vermicompost plus *Azospirillum* addition, the per cent contribution of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O were 54, 10.5 and 19.6 respectively (C<sub>vermi + azo</sub>) and the percent contribution of N from *Azospirillum* alone is 31.

#### 4.6.4. IPNS and fertilizer prescription equations

The fertilizer prescription equations for yield targeting of wheat were developed under IPNS using the basic parameters nutrient requirement (NR), contribution of nutrients from soil (Cs), contribution of nutrients from fertiliser (Cf) and contribution of nutrients from vermicompost with *Azospirillum* (Cvermi+Azo) are presented below.

##### **NPK with Vermicompost**

$$\text{FN} = 7.6 \text{ T} - 0.55 \text{ SN} - 1.2 \text{ ON}$$

$$\text{FP}_2\text{O}_5 = 3.59 \text{ T} - 0.26 \text{ SP} - 0.95 \text{ OP}$$

$$\text{FK}_2\text{O} = 3.88 \text{ T} - 0.45 \text{ SK} - 1.2 \text{ OK}$$

##### **NPK with Vermicompost plus *Azospirillum***

$$\text{FN} = 7.6 \text{ T} - 0.55 \text{ SN} - 1.5 \text{ ON}$$

$$\text{FP}_2\text{O}_5 = 3.59 \text{ T} - 0.26 \text{ SP} - 0.95 \text{ OP}$$

$$\text{FK}_2\text{O} = 3.88 \text{ T} - 0.45 \text{ SK} - 1.2 \text{ OK}$$

where, FN,  $\text{FP}_2\text{O}_5$  and  $\text{FK}_2\text{O}$  are fertilizer N,  $\text{P}_2\text{O}_5$  and  $\text{K}_2\text{O}$  in  $\text{kg ha}^{-1}$  respectively; T is the yield target in  $\text{q ha}^{-1}$ ; SN, SP and SK respectively are alkaline  $\text{KMnO}_4\text{-N}$ , Bray-P and  $\text{NH}_4\text{OAc-K}$  in  $\text{kg ha}^{-1}$  and ON, OP and OK are the quantities of N, P and K supplied through vermicompost or through vermicompost plus *Azospirillum* as the case may be.

#### 4.6.5. Optimization of fertilizer doses and yield targeting under IPNS (Tables 24 & 25)

For a range of soil test values and for desired yield targets of wheat, nomograms were formulated for NPK alone, NPK with vermicompost and NPK with vermicompost plus *Azospirillum*. A perusal of the estimates showed that when NPK alone were applied, for a soil test value of  $400 \text{ kg KMnO}_4\text{-N ha}^{-1}$ , the doses of fertilizer N required for desired yield targets of 35, 45 and  $55 \text{ q ha}^{-1}$  were 46, 122 and  $198 \text{ kg ha}^{-1}$  respectively. When vermicompost @  $5 \text{ t ha}^{-1}$  was applied along with NPK, the required fertilizer N doses were 2.8, 78.8 and  $154.8 \text{ kg ha}^{-1}$ . When vermicompost @  $5 \text{ t ha}^{-1}$  plus *Azospirillum* @  $2 \text{ kg ha}^{-1}$  were applied along with NPK; the required fertilizer N doses were 30 and  $144 \text{ kg ha}^{-1}$ .

When NPK alone were applied, for a soil test value of  $350 \text{ kg ha}^{-1}$  of Bray-P, the doses of fertilizer  $\text{P}_2\text{O}_5$  required for desired yield targets of 35, 45 and  $55 \text{ q ha}^{-1}$  were 34.65, 70.55 and  $106.45 \text{ kg ha}^{-1}$  respectively, while the doses were 24.67, 60.2 and  $96 \text{ kg ha}^{-1}$  respectively for the conjoint addition of NPK plus vermicompost @  $5 \text{ t ha}^{-1}$ .

With regard to fertilizer  $\text{K}_2\text{O}$  doses, it was found that to achieve the desired yield targets of 35, 45 and  $55 \text{ q ha}^{-1}$ , for a soil test value of  $200 \text{ kg NH}_4\text{OAc-K}$ , the fertilizer  $\text{K}_2\text{O}$

requirements were 45.8, 84.6 and 123.4 kg ha<sup>-1</sup> respectively for NPK alone. If NPK were combined with vermicompost @ 5 t ha<sup>-1</sup>, the K<sub>2</sub>O doses were 22.28, 61 and 100 kg ha<sup>-1</sup> respectively.

#### **4.6.6. Fertilizer economy under IPNS (Table 26)**

The fertilizer saving under IPNS approach resulted in economy of added fertilizer input, which in turn resulted in increased monetary benefits. In the present study, the fertilizer economy in terms of fertilizer nutrients and rupees, resulted due to the adoption of IPNS was calculated and the results are presented.

Using the fertilizer prescription equations under IPNS, the extent of saving of chemical fertilizers for wheat was computed. The results showed that with the application of vermicompost @ 5 t ha<sup>-1</sup> with 1.02, 0.3 and 0.56 per cent of N, P and K respectively, there was a saving of 43, 10 and 23.5 kg of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O respectively. If *Azospirillum* is applied conjointly with vermicompost the saving was 54 kg fertilizer N. The extent of saving of fertilizer N due to the application of *Azospirillum* was found to be 10 kg N ha<sup>-1</sup>.

The monetary benefit due to the saving of fertilizer inputs was calculated and is furnished in Table 28. An amount of Rs. 816/- for NPK alone, 919/- NPK with vermicompost and Rs 103 /- per hectare could be saved, NPK with vermicompost plus *Azospirillum* treated plots.

#### **4.6.7. IPNS on the sustenance of post-harvest soil fertility (Table 27)**

The influence of IPNS on soil fertility status was assessed by comparing the initial soil test values of the test crop experiment with that of post-harvest soil test data.

##### **4.6.7.1. KMnO<sub>4</sub>-N status**

The mean data on post-harvest soil KMnO<sub>4</sub>-N showed a built up and the extent of increase was 14, 19 and 20 kg ha<sup>-1</sup> for NPK alone, NPK plus vermicompost, NPK with vermicompost plus *Azospirillum* respectively. The absolute control plots recorded a decline of 37 kg ha<sup>-1</sup> of KMnO<sub>4</sub>-N.

##### **4.6.7.2. Bray-P status**

The results pertaining to the changes in mean Bray-P status after the harvest of wheat are furnished in Table 27. The increase in Bray-P status was 23, 29 and 22 kg ha<sup>-1</sup> for NPK alone, NPK plus vermicompost and NPK with vermicompost plus *Azospirillum* respectively. The absolute control plots recorded a decline of 13 kg ha<sup>-1</sup> of Bray-P.

#### 4.6.7.3. $\text{NH}_4\text{OAc-K}$ status

With regard to mean  $\text{NH}_4\text{OAc-K}$  status the increase was found to be 26.55, 19.07 and 19.9  $\text{kg ha}^{-1}$  respectively for NPK alone, NPK plus vermicompost, and NPK with vermicompost plus *Azospirillum* respectively. The absolute control plots recorded a decline of 12.55  $\text{kg ha}^{-1}$  of  $\text{NH}_4\text{OAc-K}$ .

#### 4.6.8. Critical soil test values (Table 28)

The soil test calibration for fertilizer prescription based on the concept of targeted yield of wheat provides a way for the computation of critical soil test values. These values are the soil test levels above which there would be no requirement of fertilizer application for indicated levels of crop yield (Randhawa and Velayudham, 1982). Hence, in the present study, an attempt was made to fix the critical soil test values for  $\text{KMnO}_4\text{-N}$ , Bray-P and  $\text{NH}_4\text{OAc-K}$ . For 35-q  $\text{ha}^{-1}$  yield target, the critical level of NPK was 484, 483 and 302  $\text{kg ha}^{-1}$  under NPK alone; 405, 445 and 250  $\text{kg ha}^{-1}$  for NPK with vermicompost and 385, 445 and 250  $\text{kg ha}^{-1}$  for NPK with vermicompost plus *Azospirillum* respectively. Similarly the critical levels of NPK for 45 and 55 q  $\text{ha}^{-1}$  are also furnished in Table 28. The results showed that IPNS resulted in low critical soil test values over NPK alone.

## CHAPTER V

### DISCUSSION

Crop production systems at the current level of yields are not sustainable when there is a significant depletion of plant nutrients in soil. Build-up and maintenance of soil fertility and consequent provision of balanced nutrition to crops are key to sustain long term crop productivity. Nutrient supplying power of soils, crop responses to added nutrients can safely be assessed through sound soil testing programme. Monitoring soil fertility, against depletion and accumulation of certain elements in toxic proportions over time, is possible through appropriate soil tests. High cost of fertilizers is a hurdle for the farmers to apply adequate fertilizers to crops. Soil test calibration that is intended to establish a relationship between the levels of soil nutrients determined in the laboratory and crop response to fertilizers in the field permits balanced fertilization through right kind and amount of fertilizers.

Wheat is a crop of national importance in India and is grown since time immemorial. The anticipated population of the country by the year 2020 AD is around 1.25 billions with a projected wheat demand of 109 million tones. This calls for increasing the wheat production by around 37 million metric tonnes during the next 15 years. The enormous pressure to produce more from the ever shrinking natural resources is a tough challenge. We must strive hard to reduce the cost of production as well as improve the quality of our produce. With the above views, an attempt has been made to develop a basis to prescribe STCR based fertiliser dose for wheat under IPNS which has a great scope.

The real balance for maximum yield is not between applied nutrients but that after taking into account the relative availability from soil and fertiliser. The sum of the availables from soil and fertiliser together for different nutrients should be in the same ratio in which they are actually needed by the crop and it is possible only by the fertiliser application for targeted yields of crops (Ramamoorthy, 1993).

At this juncture, the present research work on Soil Test Crop Response Correlation under Integrated Plant Nutrition System (STCR - IPNS) for wheat was carried out following the prescription procedure outlined by Truog (1960) and modified by Ramamoorthy *et al.* (1967) as inductive cum targeted yield model. It is a unique field

experimental approach for STCR correlation evolved through creating a macrocosm of soil fertility variability within a microcosm of an experimental field. The technical programme consisted of a gradient experiment with potato var. giriraga and one test crop experiment with wheat variety HW2044. The test crop experiment was conducted using chemical fertilizers alone and in combination with vermicompost or with vermicompost plus *Azospirillum* with the objective of deriving a basis for fertilizer recommendations under IPNS for desired yield targets of wheat and to evaluate the extent to which the inorganic fertilizer needs of wheat can be reduced under IPNS. The experimental data were used for optimization of fertilizer doses for wheat through targeted yield model in Typic Ustropept of Western zone of Tamil Nadu. The results obtained in the present investigation are discussed in this chapter.

### **5.1 Description of the experimental field**

The soil of the experimental site belongs to Ooty series (Ultic Hapludalf), which is a major soil series of Tamil Nadu. The profile description of the soil indicated that Ooty series is dark greyish brown to reddish brown, moderately deep, well-drained and non-calcareous soil developed over weathered charnokite.

The initial soil sample of the experimental site had a surface texture of sandy clay loam of acidic in reaction with a bulk density of  $1.48 \text{ Mg m}^{-3}$ . The organic carbon status of the soil was high with CEC of  $22.7 \text{ c mol (p}^+) \text{ kg}^{-1}$ . The fertility status of soil in terms of  $\text{KMnO}_4\text{-N}$ , Bray-P and  $\text{NH}_4\text{OAc-K}$  was high. The DTPA extractable micronutrients viz., Fe, Mn, Zn and Cu were above the critical limits.

### **5.2 Fertility gradient experiment**

This experiment forms the preparatory one for the conduct of test crop experiment in the succeeding seasons. The purpose of conducting this experiment was to create desired fertility gradient in one and the same field so as to obtain workable range in the uncontrollable variable viz., soil fertility status which is quite imperative to calculate the realistic optimum doses of fertilizer nutrients through soil –test calibrations.

In this study a deliberate attempt was made to create variation in soil fertility status by the application of graded doses of N,  $\text{P}_2\text{O}_5$  and  $\text{K}_2\text{O}$  and growing the gradient crop of potato as an exhaustive crop, so that the fertilizers undergo transformations in the

soil with plant and microbial agencies. The creation of fertility variations as reflected in terms of soil analytical data, tuber yield and nutrient uptake are discussed below.

### 5.2.1 Creation of soil fertility gradient (Fig.4)

The initial and post-harvest  $\text{KMnO}_4\text{-N}$ , Olsen-P and  $\text{NH}_4\text{OAc-K}$  status of the gradient experiment was assessed. When the post-harvest soil test values of available N, P and K were compared with that of initial soil test values, a significant increase in the levels of all the three nutrients was recorded among the various fertility strips.

The mean values of pre-sowing soil test values of  $\text{KMnO}_4\text{-N}$  were  $359 \text{ kg ha}^{-1}$ , Bray-P of  $347 \text{ kg ha}^{-1}$  and  $\text{NH}_4\text{OAc-K}$  of  $195 \text{ kg ha}^{-1}$ . When the post harvest soil test values of NPK were compared with the pre –sowing soil test values, a marked increase in the levels of all the three nutrients was observed.

In the control plots, there was a decline of 37, 7.5 and  $12.55 \text{ kg ha}^{-1}$  of N, P and K respectively. The reduction of available N, P and K in control plots may be attributed to the crop removal in the absence of external source of nutrients (Sharma and Kamala Singh, 1991).

In the strips that had received the fertilizer doses at graded levels, there was a significant increase in the fertility status of major nutrients. With increased application of nitrogen the available nitrogen status in soil was also increased from the initial status (Hazara and Tripathi, 1986). The increase might be attributed to the adsorption of N as  $\text{NH}_4^+$  ions in the clay (Tisdale *et al.*, 1990) or better management would have reduced the volatilisation losses of added urea. The magnitude of increase was higher for P followed by K and N. The pronounced increase in alkaline  $\text{KMnO}_4$  in the treated strip as compared to that of untreated control strips (N0P0K0) lent support for the created soil fertility gradient.

There was a pronounced increase in available P status which might be due to the addition of fertilizer P over and above the P fixing capacity of the experimental soil and would have resulted in increasing the concentration of extractable P and orthophosphate ions in soil solution. Similar findings were reported by Wild (1988) and Murugappan *et al.* (1998). Since the application rates were high, more of P would have remained in the soil solution (Dibb *et al.*, 1990). Further, Phosphorus being an immobile nutrient and subject to rapid adsorption, the loss through leaching would have been negligible.

There is also a stable fertility build up of available K in the strips. The fertility build up of potassium might be due to the application of potassic fertilizers over and above the fixing capacity of the soil and also the probable retention of the added K in the crystal lattices of exchangeable complexes of colloids in exchangeable form. In case of potassium, the loss through leaching could have been very less and the added K was retained in the experimental soil (Natarajan, 1991).

The increased availability of N, P and K status of soil due to graded dose of fertilizer application created fertility gradient in the same field. The statistical analysis also indicated the creation of fertility gradient in the experimental site. Similar fertilizer gradient was created artificially due to graded dose of fertilizer application by Andi (1998). The creation of fertility gradients is well depicted by the variations in the post harvest soils. Reports on creation of such fertility gradient by the addition of graded levels of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O were made by Natarajan (1991) Murugesu Boopathi (1995) Smitha John (2004) and Kasthuri Thilakam (2004) in Inceptisol, Gayathri (2003) and Umadevi (2005) in Alfisol.

### **5.2.2. Tuber yield and nutrient uptake (Figs 5 and 6)**

Crop yield is a function of soil fertility under optimal levels of other production factors, which is substantiated by the results recorded in the present study. Thus the marked fertility build up due to fertiliser addition at graded levels to create fertility gradient was evident from the crop response data also. Almost in all types of soil the fertility variations were developed by the application of graded doses of NPK fertilizers (Anon 1994 a, b & c).

The tuber yield of potato increased with progressive increase in fertilizer doses applied to various strips. With regard to nutrients uptake also, the same pattern was observed. The results of the statistical analysis of the yield and uptake data indicated that each strip was significantly different from each other and confirmed the creation of fertility gradients.

### **5.3. Test Crop experiment**

After establishing the operational range of soil fertility variations in the experimental field, the test crop wheat variety HW2044 was grown. The range and mean of initial soil test values, grain yield of wheat and nutrient uptake are discussed below.

### 5.3.1 Range in soil test values and yield

The range and mean values of initial soil test values from control and treated plots of the test crop experiment of wheat clearly showed that the satisfactory operational range of soil available N, P and K has been obtained in the present investigation. However, the magnitude of variation in the case of available N was low when compared to P and K. The data on grain yield of wheat and nutrient uptake revealed that in all the fertility strips, with increase in the dose of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O and with the application of vermicompost plus *Azospirillum*, the yield and nutrient uptake were also increased. Similar findings were reported by Meena *et al.* (2001) and Santhi *et al.* (2002b) for onion and Gayathri (2003) for potato, Smitha John (2004) for cabbage, Kasthuri Thilakam (2004) for cauliflower and Umadevi (2005) for carrot.

The data on the maximum and minimum yield obtained from treated plots revealed that the maximum yield was obtained in strip IV and also with Vermicompost @ 5 t ha<sup>-1</sup> and *Azospirillum* @ 2 kg ha<sup>-1</sup> in strip IV. This showed the positive interaction among the nutrients from soil, inorganic and organic sources on the yield of wheat. The favourable influence of organics, inorganics and biofertilisers on chemical, physical and biological properties of soil under IPNS would have resulted in such maximum yields of wheat. Similar trend of results were also reported by Selvakumari *et al.* (2000b) for various crops. The minimum yields were obtained in strip I. This emphasizes the importance of N and balanced use of all the three-macro nutrients through IPNS.

In the control plots, the maximum yield was obtained with the application of vermicompost plus *Azospirillum* alone in strip IV and the minimum yield was obtained with the absolute control in strip I. The probable reason might be due to the relatively higher initial soil fertility of the former when compared to the latter indicating the effect of initial soil fertility on yield and nutrient uptake by wheat. The results emanated from the present study have clearly revealed that initial soil fertility and IPNS had a profound influence on the grain yield and nutrient uptake pattern of wheat.

### 5.3.2. Response of wheat to fertilizer nutrients

The response for N increased with increased levels of applied N. Adequate levels of nitrogen is essential for proper plant growth, as it is constituent chlorophyll, enzymes, amino acids and proteins and is used for building plant tissues and cell organelles. The increased nutrient uptake is due to the increased availability of nutrients and higher adsorptive area, which resulted in higher grain yield. These results are in conformity with

the findings of Wiebe (1985) in carrot, Sharma and Acharya (1997), Kundu *et al.*, (2000). For N, there was a progressive increase in response from N<sub>50</sub> to N<sub>200</sub>.

For P<sub>2</sub>O<sub>5</sub>, the response increased upto 90 kg ha<sup>-1</sup>. Phosphorus is a key element in almost every process taking place in plants. The importance of phosphorus is related to the transfer of energy (ATP, NADPH<sub>2</sub>) from sunlight to the plant. This energy is essential to the plant activities occurring during the life cycle of a plant to allow germination, growth, maturation and reproduction leading to the next generation of plants. The higher yield may be due to increased nutrient availability and the P supplied through chemical fertilizers always associated with increased root growth. Root proliferation increased the nutrients and water supply to the plant, which finally increased the vegetative growth and there by the yield was increased (Sharma and Rana 1993).

With respect to K<sub>2</sub>O, there was progressive response upto 120 kg ha<sup>-1</sup>. The response to applied N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O increased with increasing levels and this might be due to the fact that the application of nutrients increased the availability of nutrients and absorptive area, which resulted in higher grain yield of wheat. The yield increase might be attributed to the fact that these nutrients being important constituents of nucleotides, proteins, chlorophyll and enzymes involve in various metabolic processes, which have direct impact on yield. These results substantiated the findings of Akhilesh *et al.* (2003) in carrot, (Rawat *et al.*, 2001) and Dilip Kumar Bastia and Ajay Kumar Rout (2001) for wheat.

#### **5.4 Selection of suitable soil testing methods for estimating available nutrients**

Kanwar (1971) stated "Soil testing is a key weapon in the armoury of a soil scientist and an agronomist for the advisory work on the judicious fertilizer use". Soil testing has been recognized as an effective tool for determining fertilizer requirements of crops under all situations. Intensive efforts are being made from time and again to invent procedures that would extract nutrients in about the same proportion as growing plants would extract them. The ability to extract proportional amount of available nutrient, dependability and rapidity are universal principles for a successful soil test. Several extractants are proved to be excellent under specific conditions. Fertilizer adjustment or targeted yield equations developed for fertilizer recommendations are valid only when the indicated soil test methods are used to estimate the available nutrients in the soil. These will not be normally valid whenever any other method is used for estimating the available nutrients.

Soil testing procedures are often compared by working out simple correlation between available soil nutrients and crop responses. To select suitable soil test methods for available N, P and K for the test crop of wheat, simple correlation study was carried out with different soil test methods. The values obtained from different methods were correlated with yield and nutrient uptake.

In the present study also, the fertility status of the soil was assessed by employing alkaline  $\text{KMnO}_4$  and organic carbon methods for available N, Bray I methods in 1:10 ratio and 1:50 for available P and neutral normal  $\text{NH}_4\text{OAc}$  and 0.1 N  $\text{HNO}_3$  methods for available K.

The results showed that the alkaline  $\text{KMnO}_4$  method was highly correlated ( $r = 0.861^{**}$ ) with the grain yield of wheat. The same method was also highly correlated with total N uptake ( $r = 0.928^{**}$ ). The organic carbon method was not significantly correlated with yield and N uptake. Alkaline  $\text{KMnO}_4\text{-N}$ , being a direct measure of  $\text{NH}_4^+$ , released from the oxidisable organics of the soil and organic carbon an indirect measure of soil nitrogen, the former could be expected to contribute more towards the uptake and yield of crops than the latter.  $\text{KMnO}_4\text{-N}$  would have extracted more of amino acid and hydrolysable  $\text{NH}_4^+\text{-N}$  fractions of soil. Similar was the observations by Murugesu Boopathi (1995) in rice and Gayathri (2003) in potato, Smitha John in cabbage (2004) and Kasthuri Thilagam in cauliflower (2004) and Umadevi (2005) in carrot.

Regarding P, Bray 1:50-P and Bray 1:10-P methods were tested for their significance. The results showed that Bra I: 50-P method was positively correlated with wheat grain yield and total P uptake ( $r = 0.821^{**}$  and  $0.703^{**}$ ). Bray I :10-P method was not suitable for the estimation of available P in the soil tested. With regard to Bray's reagent, it could extract Fe-P and Al-P from the soils. The available P increased with increase in soil: solution ratio and also with shaking time. However, in Bray method, shaking time had less effect on amount of P extracted as compared to soil: solution ratio. This result was similar with the findings of Chandra Sekhara Rao and Bajaj (1994), Gayathri (2003) and Umadevi (2005).

From the results it was observed that the neutral normal  $\text{NH}_4\text{OAc}$  method was significantly correlated with yield ( $r = 0.809^{**}$ ) and total K uptake ( $r = 0.727^{**}$ ). It indicated that the 0.1 N  $\text{HNO}_3$  method was not suitable for estimation of available K in

the soil tested. The findings of Chandra Prakash and Vinay Singh (1986), Murugesu Boopathi (1995) and Umadevi (2005) support the present study. A number of studies carried out in various parts of the country also showed that available K extracted with  $\text{NH}_4^+$  by using 1N  $\text{NH}_4\text{OAc}$  was found to be significantly correlated with K content and crop yield (Pasricha, 2004).

### **5.5 Targeted yield model – optimization of fertilizer doses for different yield targets**

Field experiments integrate the crop and soil factors. The crop uptake is affected by soil type and there is a strong relationship between fertilizers applied and crop nutrition. Fertilisers are to be used economically for crop /cropping sequence. The soils as well as the nutrient requirement are to be adequately defined to use fertilizer economically. According to the concept of fertilizer prescription for specified yield targets, the fertilizer use in optimum amounts and proportions mainly depends on the ability of soil to supply the native nutrient, the efficacy of applied nutrient and the requirement of the crops Randhawa and Velayutham(1982) and Velayutham *et al.*, (1985). The prescription procedure outlined by Truog (1960) and modified by Ramamoorthy *et al.*, (1967) as Inductive cum Targeted yield model concept strikes a balance between ‘fertilizing the crop’ and ‘fertilizing the soil’. This model provides a scientific basis for balanced fertilization and balance between applied nutrients and soil available nutrients. Further, it is assumed that there is a linear relationship between the yield and nutrient uptake by the crop and for obtaining a particular yield, a definite amount of nutrients are taken up by the crop. Once this requirement is known for a given level of yield, the fertilizer needed can be estimated taking into consideration the contribution of available nutrients from soil.

#### **5.5.1 Basic parameters (Fig.7)**

To calibrate soil test values and prescribe fertilizer doses for pre-set yield targets of wheat by targeted yield model, the three basic parameters viz., i) nutrient requirement (NR) in kg per quintal grain yield of wheat, per cent contribution from soil available nutrients (Cs) and fertilizer nutrients (Cf) were calculated and are discussed below.

#### **5.5.2 Nutrient requirement of wheat**

The results indicated that 2.98 kg of N, 3.14 kg of  $\text{P}_2\text{O}_5$  and 2.7 kg of  $\text{K}_2\text{O}$  were required for producing one quintal of wheat grains. The requirement of  $\text{K}_2\text{O}$  and N were almost similar followed by the requirement for  $\text{P}_2\text{O}_5$ . Similar trends of results

were reported by Kadu *et al.* (2001) for cabbage, Meena *et al.* (2001) for onion and Umadevi (2005) for carrot.

### **5.5.3 Per cent contribution of nutrients from soil and fertilizers to total uptake**

By adopting the whole field method, the per cent contribution of nutrients from soil (Cs) and fertilizers (Cf) to total uptake were estimated. The contribution from soil accounted 21.65 per cent for nitrogen, 9.94 per cent for phosphorus and 26.26 per cent for potassium. Among the three nutrients, the contribution from soil was higher for K<sub>2</sub>O followed by N and P<sub>2</sub>O<sub>5</sub>. The contribution from fertilizer nutrients was 39.21, 87.47 and 70.82 per cent respectively for N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O. The response yardstick recorded was 6.63 kg kg<sup>-1</sup>.

With regard to N and K<sub>2</sub>O, comparatively more contribution was recorded from fertilizers than from soil. Split application of N at the critical stages of crop growth would have resulted in better utilization of applied N, which was also indicated by the relatively higher response ratio recorded for fertilizer N. With regard to K<sub>2</sub>O, comparatively lower Cs was recorded which might be due to the preferential nature of wheat crop towards applied K<sub>2</sub>O than native K<sub>2</sub>O. Similar trend of Cs and Cf were reported by Gayathri (2003) for potato and Umadevi (2005) for carrot. The estimates of Cf indicated that the contribution of fertilizer was higher when compared to soil (Cs) with regard to P<sub>2</sub>O<sub>5</sub>. This might be due to the prevalence of temperate climate where the soil temperature was very low and this restricted the microbial activity. Due to low microbial activity it resulted in low availability of soil nutrients to plants (Umadevi, 2005).

### **5.6 Fertilizer prescription equations and optimization of fertilizer doses**

The fertilizer prescription equations developed using the basic parameters as estimated by whole field method are presented below.

$$FN = 7.6 T - 0.55 SN$$

$$FP_2O_5 = 3.59 T - 0.26 SP$$

$$FK_2O = 3.88 T - 0.45 SK$$

where, FN, FP<sub>2</sub>O<sub>5</sub> and FK<sub>2</sub>O are fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in kg ha<sup>-1</sup> respectively, T is the yield target in q ha<sup>-1</sup> and SN, SP and SK are alkaline KMnO<sub>4</sub>-N, Olsen-P and NH<sub>4</sub>OAc-K in kg ha<sup>-1</sup> respectively.

Using the above equations, fertilizer prescriptions for pre-set yield targets of 35, 45 and 55 quintals of wheat per hectare were worked out for a range of soil test values and presented. The results indicated that to produce 45 q ha<sup>-1</sup> grain yield of wheat, with a

soil test value of 350 kg ha<sup>-1</sup> of KMnO<sub>4</sub>-N, 400 kg ha<sup>-1</sup> of Bray-P and 250 kg ha<sup>-1</sup> of NH<sub>4</sub>OAc-K, the fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O requirement would be 149.5, 57.55 and 62.1 kg ha<sup>-1</sup> respectively. For the same soil test values, the quantities of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O required to produce 55 q ha<sup>-1</sup> grain yield of wheat would be 225.5, 93.45 and 100.5 kg ha<sup>-1</sup> respectively.

The fertilizer prescription based on targeted yield is unique in the sense that this approach not only indicates soil test based fertilizer doses but also the level of yield the farmer can hope to achieve if good agronomic practices is followed in raising the crop (Velayutham, 1979). The results of the present investigation is site and situation specific *i.e.* it pertains to Alfisols and could be extrapolated to allied soil groups so that the advantages of soil testing and its utility are further enhanced.

### **5.7 Integrated Plant Nutrition System (IPNS)**

The soil test based fertilizer requirement calibration for targeted yields could provide critical levels of nutrients in Ooty series of TamilNadu. The response to fertilizer application above the critical levels could not be expected for the indicated targeted yield of wheat. The critical levels of N, and K<sub>2</sub>O were low for IPNS as compared to inorganics alone. The reduction of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O treatment under IPNS was of higher magnitude and that would have led to the reaching of critical levels well in advance as compared to that of fertiliser alone system.

To increase the production, contribution of nutrients from all sources *viz.*, the soil, fertilizers, organic and biological sources must be accounted and managed carefully in order to eliminate over or under usage of applied nutrients. The use of chemical fertilizers, the “restorer inputs” is a must for Indian agriculture, but atleast one third of the total nutrients must be supplied through organic sources for enhancing the efficiency of the inorganic component, cost effectiveness and reducing the burden of environmental damage (Sankaram, 1997). With this background , attempts were made to develop fertilizer recommendations under IPNS for wheat. The results pertaining to the beneficial aspects of IPNS recorded in the present investigation are discussed below.

#### **5.7.1. Influence of IPNS on grain yield and uptake of wheat (Figs 8 & 9)**

The grain yield of wheat in the NPK alone treated plots recorded an increase of 76.40 per cent over the absolute control. The application of NPK with vermicompost and application with vermicompost and *Azospirillum* recorded an increase of 75.55 and

82.52 per cent over absolute control respectively. The per cent increase in yield over absolute control was 11.31, and 7.9 per cent respectively for vermicompost, and *Azospirillum* plots. Response in terms of grain yield was highly pronounced for IPNS as compared to NPK alone. This might be due to the favourable influence of organics, inorganics and biofertilizer on chemical, physical and biological properties of the soil under IPNS. Similar findings were also reported by Jeeva Jothi *et al.*, (1993) and Maraikar *et al.*, (1996) for cabbage, Thiyageshwari and Rani perumal (1998) for black gram, Ajit *et al.*, 2001 and Dileep-Kachroo *et al.*, (2005) for wheat .

The mean N uptake by wheat was 114.5, 126.3 and 119.9 kg ha<sup>-1</sup>, the mean P uptake was 58.88, 55.23 and 56.54 kg ha<sup>-1</sup> and the mean uptake of K was 106.32, 96.13 and 95.88 kg ha<sup>-1</sup>, respectively for NPK alone, NPK plus vermicompost and NPK plus vermicompost plus *Azospirillum*. In the vermicompost alone plots the mean N, P and K uptake was 71.49, 27.19 and 52.52 in *Azospirillum* alone plots the mean N, P and K uptake was 72.87, 28.02 and 53.49 respectively. Among the nutrient uptake, N uptake by wheat was high in NPK with vermicompost, P uptake and K uptake in NPK alone treated plots.

### **5.7.2 Contribution of nutrients from vermicompost and vermicompost with *Azospirillum***

The contribution of nutrients from vermicompost and vermicompost plus *Azospirillum* was calculated using the data generated from the test crop experiment . While computing the contribution from organics, only one third of the total content of N, P and K were taken into account for short duration crops based on the rate of mineralization and nutrient release from organics. The per cent contribution of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O from vermicompost (C<sub>vermi</sub>) were 36, 10.5 and 19.6 respectively and for vermicompost plus *Azospirillum* addition, the per cent contribution of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O were 54, 10.5 and 19.6 respectively (C<sub>vermi +azo</sub>) and the per cent contribution of N from *Azospirillum* alone is 31. Similar were the results reported by Santhi *et al.* (2002b) for onion and Gayathri (2003) for potato, Smitha John in cabbage (2004) and Kasthuri Thilagam in cauliflower (2004) Umadevi (2005) in carrot.

The addition of vermicompost showed better results because of its higher nutrient content and also the use of vermicompost resulted in introduction of earthworms in the field and it tilled the soil and made it porous and loose, thus increased the aeration which resulted in better root ramification. Vermicompost also contains more number of nitrogen fixing, phosphate solublising and other beneficial microbes, antibiotics, vitamins, hormones, enzymes etc which have better effects on growth and yield of wheat plants

(Ajit *et al.*, 2001) . The ability of crops to utilize nutrients from organic sources (manures and bio-fertilizers) and inorganic sources (fertilizers) are to be assessed so that the extent to which the recommended fertilizer doses can be reduced due to the conjoint use of manures can be arrived at. Keeping these thoughts ahead, an attempt was made in the present study and the per cent contribution of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O from vermicompost and vermicompost plus *Azospirillum* was quantified as the fourth basic parameter for the targeted yield model.

### 5.7.3 Fertilizer prescriptions through IPNS (Figs 10 to 12)

To bridge the gap between ‘concept’ and ‘practice’ of balanced fertilization, soil testing research should be directed to calibrate the soil test values for recommending chemical, organic and biofertilizers for targeted yield of crops (Reddy *et al.*, 1987).

The fertilizer prescription equations for yield targeting of wheat developed under IPNS using the basic parameters (NR, Cs, Cf, C<sub>vermi</sub> and C<sub>vermi+Aso</sub>) are presented below.

#### NPK with Vermicompost

$$FN = 7.6 T - 0.55 SN - 1.2 ON$$

$$FP_2O_5 = 3.59 T - 0.26 SP - 0.95 OP$$

$$FK_2O = 3.88 T - 0.45 SK - 1.2 OK$$

#### NPK with Vermicompost plus *Azospirillum*

$$FN = 7.6 T - 0.55 SN - 1.5 ON$$

$$FP_2O_5 = 3.59 T - 0.26 SP - 0.95 OP$$

$$FK_2O = 3.88 T - 0.45 SK - 1.2 OK$$

where, FN, FP<sub>2</sub>O<sub>5</sub> and FK<sub>2</sub>O are fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in kg ha<sup>-1</sup> respectively; T is the yield target in q ha<sup>-1</sup>; SN, SP and SK respectively are alkaline KMnO<sub>4</sub>-N, Bray-P and NH<sub>4</sub>OAc-K in kg ha<sup>-1</sup> and ON, OP and OK are the quantities of N, P and K supplied through vermicompost or through vermicompost plus *Azospirillum* as the case may be.

These fertilizer prescription equations would serve as a tool to adjust the actual quantities of fertilizer doses under IPNS for the different levels of vermicompost or vermicompost plus *Azospirillum* applied along with fertilizers for wheat. For a range of soil test values and for desired yield targets of wheat, nomograms were formulated for NPK alone, NPK with vermicompost and NPK with vermicompost plus *Azospirillum*. A perusal of the estimates showed that when NPK alone were applied, for a soil test

value of 400 kg  $\text{KMnO}_4\text{-N ha}^{-1}$ , 350 kg  $\text{ha}^{-1}$  of Bray-P and 200 kg  $\text{ha}^{-1}$   $\text{NH}_4\text{OAc-K}$  the doses of fertiliser N required for desired yield targets of 45q  $\text{ha}^{-1}$  were 122 kg  $\text{ha}^{-1}$  N, 70.55 kg  $\text{ha}^{-1}$   $\text{P}_2\text{O}_5$  and 84.6 kg  $\text{ha}^{-1}$  of  $\text{K}_2\text{O}$ . When vermicompost @ 5 t  $\text{ha}^{-1}$  was applied along with NPK, the fertiliser dose was 78.8 kg  $\text{ha}^{-1}$  N, 60.2 kg  $\text{ha}^{-1}$   $\text{P}_2\text{O}_5$  and 61 kg  $\text{ha}^{-1}$  of  $\text{K}_2\text{O}$ .

The fertilizer prescriptions under IPNS can be recommended for adoption and these recommendations can play a greater role in practicing site and situation specific fertilizer recommendations. However, they can be advocated to related soil series occurring in other agro-climatic zones of Tamil Nadu.

#### **5.7.4 Efficient use of fertilizers under IPNS**

Suitable application of mineral fertilizer is an efficient and reliable way of boosting crop production, but their cost and other constraints frequently deter farmers from using them. Hence a combination of mineral fertilizers with locally-available organic sources of plant nutrients is recommended. Such mixed applications are also complementary because organic material benefits the soil beyond its nutrient content, including improved soil physical conditions, improved water retention, enhanced nutrient retention capacity and biological activity. Integrated Plant Nutrition is an approach which adapts plant nutrition to a specific farming system to particular yield targets, physical resource base, locally available and accessible nutrient sources of both organic and mineral origin and the socio-economic background

An attempt was made in the present study to bring out the influence of conjoint use of chemical fertilizers along with vermicompost or vermicompost plus *Azospirillum* on the efficient use of applied fertilizers was assessed in terms of response ratio ( $\text{kg kg}^{-1}$ ). The results clearly revealed that irrespective of yield targets, the response ratio increased under IPNS over NPK alone, exhibiting the efficient use of applied nutrients. However, the response ratio decreased with increase in yield targets. The findings corroborate with the findings of Santhi *et al.* (2002b) for onion and Gayathri (2003) for potato, Smitha John (2004) for cabbage, Kasthuri Thilakam (2004) for cauliflower and Umadevi (2005) for carrot.

#### **5.7.5 Economy of fertilizer use under IPNS**

On account of escalating cost of fertilizer inputs and the need to increase the use efficiency of applied nutrients, IPNS play a vital role to recycle the farm wastes and economize the amount a farmer need to spend on the fertilizer inputs. The fertilizer

saving under IPNS resulted in economy of added fertilizer input, which in turn resulted in increased monetary benefits.

Using the fertilizer prescription equations under IPNS, the extent of saving of chemical fertilizers for wheat was computed. The results showed that with the application of vermicompost @ 5 t ha<sup>-1</sup> with 1.02, 0.3 and 0.56 per cent of N, P and K respectively, there was a saving of 43, 10 and 23.5 kg of fertilizer N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O respectively. If *Azospirillum* is applied conjointly with vermicompost the saving was 54 kg of fertilizer N. The extent of saving of fertilizer N due to the application of *Azospirillum* alone was found to be 10 kg ha<sup>-1</sup>.

The monetary benefit due to the saving of fertilizer inputs was calculated. An amount of Rs.816/-, 919/- and 103 /- per hectare could be saved for NPK alone, NPK with vermicompost and NPK plus vermicompost plus *Azospirillum* respectively. Santhi *et al.* (1998), Gayathri (2003) and Dileep-Kachroo *et al.*, (2005) for wheat.

#### **5.7.6 Sustenance of post-harvest soil fertility under IPNS**

In the post-harvest soil, there was a built up of KMnO<sub>4</sub>-N, Olsen-P and NH<sub>4</sub>OAc-K in NPK alone as well as IPNS treatments. However, the magnitude of built up was marked when NPK were combined with vermicompost or with vermicompost plus *Azospirillum*. Despite higher removal of nutrients, the fertility status was maintained at a relatively higher level in IPNS as compared to NPK alone. The increase in available N content in soil due to IPNS can be attributed to the supply of available N to available soil nutrient pool through organics during decomposition processes. Increase in available P may be due to the release of organic acid which would have facilitated the solubility of P besides replacing a part of absorbed P. Further, the organic anions compete with phosphate ions and chelate or complex, the Al<sup>3+</sup>, Fe<sup>3+</sup> and Ca<sup>2+</sup>. This decreased the phosphate precipitation and increased P availability (Duraismi and Mani, 2000). Application of K fertilizers along with vermicompost increased the K availability. Gabhane *et al.* (1998), reported that the application of FYM in combination with 100 per cent NPK increased the available K status of the soil over control and they attributed this to the reduced K fixation and enhanced release of K due to interaction of organic matter with soil. This might be attributed to the prevention of losses of nutrients under IPNS, even after meeting the crop requirements. The findings of Santhi and Selvakumari (1998), Muneshwar Singh and Sammi Reddy (2001), Pachauri and Vinay Singh (2001) and Duraismi *et al.* (2002) also support the results recorded in the present study.

### 5.7.7 Critical levels of soil test values

The soil test calibration for fertilizer prescription based on the concept of yield targeting of wheat provides a means for the computation of critical soil test values. These values are the soil test levels above which there would be no requirement of fertilizer application for indicated levels of crop yield (Randhawa and Velayudham, 1982). The findings of the present study revealed that the critical soil test values for  $\text{KMnO}_4\text{-N}$ , Bray -P and  $\text{NH}_4\text{OAc-K}$  were low under IPNS treatments (NPK plus FYM and NPK with FYM plus *Azospirillum*) as compared to NPK alone. This in turn resulted in saving of NPK fertilizers. Irrespective of treatments, higher yield targeting resulted in higher critical levels of nutrients in the soil. The reduction of fertilizer N,  $\text{P}_2\text{O}_5$  and  $\text{K}_2\text{O}$  requirements under IPNS would have led to attaining the critical levels well in advance as compared to that of NPK alone. The findings of Santhi *et al.* (2003) in onion and Umadevi (2005) in carrot and Gayathri *et al.*, (2006) supports the results of the present investigation.

Thus, in Soil Test Crop Response Integrated Plant Nutrition System (STCR-IPNS) technology for wheat, the fertilizer doses are tailored to the needs of the specific yield levels of wheat taking into account the contribution of nutrients from soil and other IPNS components. These STCR-IPNS packages are useful to recycle the farm wastes, ensure balanced fertilization, increase efficient fertilizer use, avoid excess or under usage of fertilizer inputs, sustain the soil health and production potentials of wheat, conserve biodiversity and improve farmer's socio-economic status. On account of the balanced nutrition and reduction in the losses of nutrients to the environment, this technology can be described as "eco-friendly and efficient soil fertility building nutrient application approach" as stated by Goswami and Rattan (2000). The gainful utilization of wastes of various kinds for crop production makes this system as the best 'resource recycling technology'. The dream of 'Precision Agriculture' for maximizing the productivity of crops will come true through the adoption of STCR-IPNS technology for wheat.

## CHAPTER VI

### SUMMARY AND CONCLUSION

Crop production systems at current level of yields are not sustainable when there is significant depletion of plant nutrients in soil. Build up and maintenance of soil fertility and consequent provision of balanced nutrition to crops is a key to sustain long term crop productivity. Soil testing with associated plant and water analysis is the only tool known which helps to control soil fertility. Soil test based application of plant nutrients helps to realize higher response ratios and benefit cost ratios as the nutrients are applied in proportion to the magnitude of deficiency of a particular nutrient and the correction of nutrient imbalances in soil helps to harness the synergistic effects of balanced fertilisation. Choosing of the right targets and application of appropriate amounts of plant nutrients help to sustain soil fertility and crop yield. With the increase of cost of fertilisers, it is imperative to make accurate advice of site specific fertilizer requirements for pre determined yield levels.

At this juncture, adoption of soil test based fertiliser recommendations under IPNS for desired yield targets would increase the fertilizer use efficiency and reduce the losses to avoid anticipated pollution problems in future. The approach of targeting yield on the basis of soil test ensures balanced fertilization to crops and on addition provides estimate of yield a farmer can hope to achieve with proper management. This strategy, therefore, implies judicious use of fertilizer and tailors rightly to the needs of every economic category of farmers.

With in a normal range of applied fertilizer and available nutrient status of soils, a linear relationship between nutrient uptake and grain yield is an essential feature of targeted yield concept of crops. Research were carried out with this aspect in the All India Coordinated Project on Soil Test Crop Correlation and has generated valuable information regarding nutrient requirement per unit weight of harvested crop and efficiency of soil available and applied nutrients under various soil type and agro climatic regions.

With a view to develop soil test based fertilizer recommendation for wheat by targeted yield models and for evaluating the extent of savings on fertilizer needs under

IPNS, the present investigation was carried out and the salient findings and conclusion of the study are presented below.

### **Creation of fertility gradient**

The field experimentation was done as per Ramamoorthy's Inductive methodology. The soil test crop response study was conducted for wheat under IPNS on Ooty series (Ultic Hapludalf), which is a major soil series of Tamil Nadu. This approach has two stages. In the first stage given field was divided into four strips and artificial fertility gradients were created deliberately by applying graded doses of fertilizer nutrients N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O viz., N<sub>0</sub>P<sub>0</sub>K<sub>0</sub>, N<sub>1/2</sub>P<sub>1/2</sub>K<sub>1/2</sub>, N<sub>1</sub>P<sub>1</sub>K<sub>1</sub> and N<sub>2</sub>P<sub>2</sub>K<sub>2</sub> and growing an exhaustive crop of potato variety Giriraja. Creation of fertility gradient was well depicted in the post-harvest soil fertility levels, yield and nutrient uptake of gradient crop.

### **Test crop experiment**

The test crop experiment with wheat, variety HW 2044 was conducted with 28 treatment combinations of fertilizer NPK which were super imposed over each fertility gradient strip. The IPNS treatments with Vermicompost and *Azospirillum* treatments were also super imposed across the gradient. A total of 28 treatments were randomized in such a way that all of them occur in all the four strips running in the north to south or east to west directions. The statistical design adopted was fractional factorial randomized block design, which facilitated the study of nutrient-soil interactions also.

### **Basic parameters**

Soil samples were collected and analysed for available N, P and K and plant samples collected from each plot were analysed for total N, P and K content and nutrient uptake. The basic parameters viz., nutrient requirement, soil and fertilizer efficiencies were computed. The fertilizer and soil efficiencies indicate the nutrient supplying power of soil and fertilizer. This indicated that the adoption of general recommendation without considering soil efficiency would definitely lead to either wastage or deficiency of added fertilizer nutrients. It emphasized the importance of soil test based fertilizer recommendation. Soil test based application of plant nutrients helps to realize higher response ratios and benefit cost ratios as the nutrients are applied in proportion to the magnitude of deficiency of a particular nutrient and the correction of nutrient imbalances in soil helps to harness the synergistic effects of balanced fertilisation.

## Soil test methods

The results of correlation study indicated that  $\text{KMnO}_4\text{-N}$  method, Bray-P method in 1:50 ratio and  $\text{NH}_4\text{OAc-K}$  methods were the best suited methods for the estimation of available N, P and K respectively for the soil under study.

## Fertilizer Prescription Equations based on targeted yield model

Making use of the basic parameters computed from the soil test crop response experiments, the following fertilizer prescription equations were developed based on targeted yield model for fertilizer alone.

$$\text{FN} = 0.93 \text{ T} - 0.79 \text{ SN}$$

$$\text{FP}_2\text{O}_5 = 0.44 \text{ T} - 1.74 \text{ SP}$$

$$\text{FK}_2\text{O} = 0.44 \text{ T} - 0.18 \text{ SK}$$

Based on these equations nomograms were prepared for 35, 45 and 55  $\text{q ha}^{-1}$  of wheat yield targets.

## Fertilizer prescription equations under IPNS

Using the efficiencies of vermicompost and *Azospirillum*, fertilizer prescription equations were developed under IPNS. The equations are

### Fertilizer + Vermicompost

$$\text{FN} = 0.93 \text{ T} - 0.79 \text{ SN} - 0.63 \text{ ON}$$

$$\text{FP}_2\text{O}_5 = 0.44 \text{ T} - 1.74 \text{ SP} - 0.85 \text{ OP}$$

$$\text{FK}_2\text{O} = 0.44 \text{ T} - 0.18 \text{ SK} - 0.46 \text{ OK}$$

### Fertilizer + Vermicompost + *Azospirillum*

$$\text{FN} = 0.93 \text{ T} - 0.79 \text{ SN} - 0.80 \text{ ON}$$

## Response of wheat under IPNS

Grain yield of wheat was higher under IPNS as compared to the application of fertilizer alone. The application of vermicompost @ 5  $\text{t ha}^{-1}$  and *Azospirillum* @ 2  $\text{kg ha}^{-1}$  along with N, P and K fertilizers was found to increase the grain yield and uptake of wheat. Higher response ratio in IPNS treatments indicated the effective utilization of added fertilizer nutrients under IPNS.

## Fertilizer use efficiency and soil fertility under IPNS

The fertilizer estimates under IPNS clearly indicated better utilization of added fertilizer nutrients by recording of high response ratio. The increased availability of nutrient status observed in the post harvest soil showed the possibility of sustenance of soil fertility under IPNS practice. Thus the increased availability of plant nutrients and built up of soil fertility under IPNS prevented the mining of native soil nutrients. The conjoint application of organics with fertilizers resulted in saving of 35, 25 and 28 kg ha<sup>-1</sup> of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O respectively. Further, inclusion of bio-fertilizer *viz.*, *Azospirillum* @ 2 kg ha<sup>-1</sup> resulted in the saving of 10 kg ha<sup>-1</sup> of fertilizer N. Despite higher removal of nutrients, the fertility status was maintained at a relatively higher level in IPNS as compared to NPK alone.

### **Conclusion**

The judicious and efficient use of mineral fertilizers, organic sources and microbial inoculants integrated with optimum soil and crop management practices is of great relevance for the farmers. The combined use of these different nutrient sources increase the yield above those obtainable with equal quantities of fertilizer nutrients from either of sources alone

Site and situation specific STCR-IPNS fertilizer recommendation packages based on soil tests for desired yield targets of wheat were developed for Ooty soil series (Ultic Hapludalf) of Tamil Nadu. These recommendations could be passed on to farmers for adoption, after the validation at farmer's holdings having similar or allied soil series. Soil test based balanced fertilizer recommendations under STCR - IPNS for wheat not only helped in achieving higher yield targets but also in the maintenance and built up of soil fertility.

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\* Original not seen.

**Table 1. Meteorological data recorded during the cropping period**

<b>Month</b>	<b>Temperature (°C)</b>		<b>Relative humidity (%)</b>	<b>No. of rainy days (per month)</b>	<b>Rainfall (mm)</b>
	<b>Maximum</b>	<b>Minimum</b>			
July 2004	22.3	14.8	78	7	96.2
August 2004	22.3	14.7	77	5	36.9
September 2004	21.0	14.7	87	18	391.1
October 2004	20.9	14.0	86	20	654.2
November 2004	19.3	12.8	90	12	505.9
December 2004	20.7	10.0	64	2	10.9
January 2005	21.6	10.8	74	2	24.2
February 2005	22.4	11.6	59	3	25.7
March 2005	23.7	13.3	72	3	107.0

Source: Wheat Regional Research Station, Wellington, Ooty.

**Table 2. Graded doses of fertilizers applied to the gradient crop of potato**

Strip	Levels of Nutrients			Fertilizer doses (kg ha <sup>-1</sup> )		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
I	N <sub>0</sub>	P <sub>0</sub>	K <sub>0</sub>	0	0	0
II	N <sub>1/2</sub>	P <sub>1/2</sub>	K <sub>1/2</sub>	75	125	50
III	N <sub>1</sub> *	P <sub>1</sub> **	K <sub>1</sub> **	150	250	100
IV	N <sub>2</sub>	P <sub>2</sub>	K <sub>2</sub>	300	500	200

\* N<sub>1</sub> : As per blanket recommendation

\*\*P<sub>1</sub> and K<sub>1</sub> : As per P and K fixing capacities of the experimental soil

**Table 3. Levels of fertilizer nutrients, Vermicompost and Azospirillum**

Level	N (kg ha <sup>-1</sup> )	P <sub>2</sub> O <sub>5</sub> (kg ha <sup>-1</sup> )	K <sub>2</sub> O (kg ha <sup>-1</sup> )	Vermi (t ha <sup>-1</sup> )	<i>Azospirillum</i> (kg ha <sup>-1</sup> )
1	0	0	0	0	0
2	50	30	40	5	2
3	100	60	80	-	-
4	150	90	120	-	-
5	200	-	-	-	-

**Table 4. Details of crops / varieties and important cultural operations**

<b>Sl. No.</b>	<b>Details of cultural operations</b>	<b>Potato</b>	<b>Wheat</b>
1.	Variety / Hybrid	Giriraja	HW 2044
2.	Season	July - November	November - March
3.	Strip / Plot size (m <sup>2</sup> )	-	7.04 m <sup>2</sup>
4.	Date of sowing	23.07.04	19.11.04
5.	Spacing (cm)	-	23 cm between the row continues lining
6.	Date of basal dressing	23.07.04	19.11.04
7.	Date of top dressing	10.09.04	14.12.04
8.	Date of harvest	03.11.04	23.03.05

**Table 5. Treatment structure of test crop experiment**

Sl. No.	Treatment Combinations			Levels of nutrients (kg ha <sup>-1</sup> )		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
1.	0	0	0	0	0	0
2.	0	0	0	0	0	0
3.	0	2	2	0	60	80
4.	1	2	2	50	60	80
5.	1	0	0	50	0	0
6.	1	1	0	50	30	0
7.	1	1	1	50	30	40
8.	2	0	0	100	0	0
9.	2	0	1	100	0	40
10.	2	0	2	100	0	80
11.	2	1	1	100	30	40
12.	2	1	2	100	30	80
13.	2	2	0	100	60	0
14.	2	2	1	100	60	40
15.	2	2	2	100	60	80
16.	2	2	3	100	60	120
17.	2	3	2	100	90	80
18.	3	0	0	150	0	0
19.	3	1	1	150	30	40
20.	3	2	2	150	60	80
21.	3	3	0	150	90	0
22.	3	3	1	150	90	40
23.	3	3	2	150	90	80
24.	3	3	3	150	90	120
25.	4	2	2	200	60	40
26.	4	3	1	200	90	40
27.	4	3	2	200	90	80
28.	4	3	3	200	90	120

**Table 6. Methods of soil and plant analysis**

S. No.	Determination	Method	References
<b>A. Physical properties of soil</b>			
1.	Particle size analysis	International pipette method	Piper (1966)
2.	Bulk density	Core method	Gupta and Dakshinamurthi (1981)
<b>B. Physico-chemical properties</b>			
1.	Soil reaction (pH)	Potentiometry (1:2.5 soil : water)	Jackson (1973)
2.	Electrical conductivity (EC)	Conductometry (1: 2.5 soil : water)	Jackson (1973)
3.	Cation exchange capacity (CEC)	Neutral normal ammonium acetate (pH 7.0)	Jackson (1973)
4.	P fixing capacity	Equilibrium with monocalcium phosphate	Waugh and Fitts (1966)
5.	K fixing capacity	Equilibrium with potassium chloride	Waugh and Fitts (1966)
<b>C. Chemical properties of soil</b>			
1.	Total nitrogen	Macro Kjeldahl digestion method	Jackson (1973)
2.	Total phosphorus	Ammonium phosphomolybdate method	Pemberton (1945)
3.	Total potassium	Flame photometry	Stanford and English (1949)
4.	Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
5.	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
6.	Available phosphorus	Extraction with 0.5 M NaHCO <sub>3</sub>	Olsen <i>et al.</i> (1954)

<b>S. No.</b>	<b>Determination</b>	<b>Method</b>	<b>References</b>
7.	Available phosphorus	Extraction with 0.03N NH <sub>4</sub> F + 0.025N HCl	Bray and Kurtz (1945)
8.	Available potassium	Neutral normal NH <sub>4</sub> OAc (pH 7.0)	Stanford and English (1949)
9.	Available potassium	0.1 N HNO <sub>3</sub> extraction	Ramanathan (1977)
10.	Exchangeable calcium and magnesium	Versenate titration (Neutral normal NH <sub>4</sub> OAc extract)	Jackson (1973)
11.	Micronutrients (Available iron, zinc, manganese and copper)	DTPA extractant	Lindsay and Norvell (1978)
<b>D. Plant analysis</b>			
1.	Nitrogen	Micro Kjeldahl	Humphries (1956)
2.	Phosphorus	Vanadomolybdate yellow colour in HNO <sub>3</sub> medium (Triple acid extract)	Jackson (1973)
3.	Potassium	Flame photometry (Triple acid extract)	Jackson (1973)

**Table 7. Characteristics of initial surface soil sample of the experimental site**

S. No.			Value
<b>A. Physical properties of soil</b>			
1.	Coarse sand (per cent)	-	31.0
2.	Fine sand (per cent)	-	28.9
3.	Silt (per cent)	-	7.0
4.	Clay (per cent)	-	31.5
5.	Texture	-	Sandy clay loam
6.	Bulk density ( $\text{Mg m}^{-3}$ )	-	1.48
<b>B. Physico chemical properties of soil</b>			
1.	pH	-	4.85
2.	EC ( $\text{dS m}^{-1}$ )	-	0.02
3.	CEC ( $\text{c mol (p}^+) \text{ kg}^{-1}$ )	-	22.7
4.	P fixing capacity ( $\text{kg ha}^{-1}$ )	-	250
5.	K fixing capacity ( $\text{kg ha}^{-1}$ )	-	100
<b>C. Chemical properties of soil</b>			
1.	Total nitrogen (per cent)	-	0.27
2.	Total phosphorus (per cent)	-	0.24
3.	Total potassium (per cent)	-	0.46
4.	$\text{KMnO}_4$ -N ( $\text{kg ha}^{-1}$ )	-	252
5.	Organic carbon (per cent)	-	1.68
5.	Bray P ( $\text{kg ha}^{-1}$ )	-	320
6.	$\text{NH}_4\text{OAc}$ -K ( $\text{kg ha}^{-1}$ )	-	302
7.	DTPA Fe (ppm)	-	46
8.	DTPA Mn (ppm)	-	14.5
9.	DTPA Zn (ppm)	-	1.5
10.	DTPA Cu (ppm)	-	3.2

**Table 8. Available nutrient status of pre- sowing and post harvest soil samples of gradient experiment (kg ha<sup>-1</sup>)**

Strip	Pre- sowing soil test values			Post harvest soil test values		
	KMnO <sub>4</sub> – N	Bray-P	NH <sub>4</sub> OAc-K	KMnO <sub>4</sub> – N	Bray-P	NH <sub>4</sub> OAc-K
<b>I</b>  N <sub>0</sub> P <sub>0</sub> K <sub>0</sub>	340	321	153	367	337	165
	337	328	182	378	329	191
	354	330	164	389	331	175
	350	317	163	356	319	183
	366	311	171	336	322	171
	362	324	182	384	330	185
	<b>Mean</b>	<b>352</b>	<b>322</b>	<b>169</b>	<b>368</b>	<b>328</b>
<b>II</b>  N <sub>1/2</sub> P <sub>1/2</sub> K <sub>1/2</sub>	354	323	175	372	438	201
	369	330	181	342	444	205
	365	324	183	401	430	199
	357	339	171	381	426	225
	356	334	186	398	415	217
	374	333	180	367	428	215
	<b>Mean</b>	<b>363</b>	<b>331</b>	<b>179</b>	<b>376</b>	<b>430</b>
<b>III</b>  N <sub>1</sub> P <sub>1</sub> K <sub>1</sub>	373	344	174	392	486	212
	367	336	179	409	452	220
	363	344	165	406	461	237
	366	340	185	389	474	227
	359	331	167	411	495	214
	374	329	169	384	482	231
	<b>Mean</b>	<b>367</b>	<b>337</b>	<b>173</b>	<b>399</b>	<b>475</b>
<b>IV</b>	375	386	186	418	505	220

**Table 9. Effect of application of graded levels of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O on post harvest soil fertility status of gradient experiment**

Strip	Fertilizer dose (kg ha <sup>-1</sup> )			KMnO <sub>4</sub> -N	Bray-P	NH <sub>4</sub> OAc- K
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O			
				..... (kg ha <sup>-1</sup> ).....		
I	0	0	0	368	328	178
II	75	125	50	376	430	210
III	150	250	100	399	475	224
IV	300	500	200	410	514	246
SEd				10	17	6
CD (5%)				22	37	13

**Table 10. Effect of application of graded levels of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O on yield and Nutrient uptake of potato (Giriraja)**

Strip	Fertilizer doses (kg ha <sup>-1</sup> )			Yield (kg ha <sup>-1</sup> )	Nutrient uptake (kg ha <sup>-1</sup> )		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O		N	P	K
I	0	0	0	8163	75.54	60.48	117.94
II	75	125	50	13673	91.61	83.27	142.19
III	150	250	100	19102	171.92	112.6	185.29
IV	300	500	200	23945	201.14	122.64	210.95
SEd				951	11	4	3
CD (5%)				2152	25	8	8

**Table 12. Initial soil available nutrients, yield and uptake by wheat in strip I**

Parameters (kg ha <sup>-1</sup> )	Range (kg ha <sup>-1</sup> )		Mean (kg ha <sup>-1</sup> )
	Minimum	Maximum	
KMnO <sub>4</sub> -N	328	372	353
Bray-P	281	305	292
NH <sub>4</sub> OAc-K	154	191	174
Yield	1800	4187	2769
N uptake	84.47	138.86	114.21
P uptake	27.96	75.04	47.16
K uptake	52.24	120.02	76.98

**Table 13. Initial soil available nutrients, yield and uptake by wheat in strip II**

Parameters (kg ha <sup>-1</sup> )	Range (kg ha <sup>-1</sup> )		Mean (kg ha <sup>-1</sup> )
	Minimum	Maximum	
KMnO <sub>4</sub> -N	332	379	356
Bray-P	299	358	331
NH <sub>4</sub> OAc-K	166	206	195
Yield	2231	5336	3784
N uptake	86.55	150.62	120.97
P uptake	29.60	80.76	52.99
K uptake	59.01	125.32	82.90

**Table 14. Initial soil available nutrients, yield and uptake by wheat in strip III**

<b>Parameters (kg ha<sup>-1</sup>)</b>	<b>Range (kg ha<sup>-1</sup>)</b>		<b>Mean (kg ha<sup>-1</sup>)</b>
	<b>Minimum</b>	<b>Maximum</b>	
KMnO <sub>4</sub> -N	339	380	360
Bray -P	310	374	338
NH <sub>4</sub> OAc-K	167	227	202
Yield	3179	5373	4276
N uptake	86.34	160.34	123.70
P uptake	36.45	86.75	57.92
K uptake	66.87	135.65	92.51

**Table 15. Initial soil available nutrients, yield and uptake by wheat in strip IV**

<b>Parameters (kg ha<sup>-1</sup>)</b>	<b>Range (kg ha<sup>-1</sup>)</b>		<b>Mean (kg ha<sup>-1</sup>)</b>
	<b>Minimum</b>	<b>Maximum</b>	
KMnO <sub>4</sub> -N	341	386	369
Bray-P	370	459	426
NH <sub>4</sub> OAc-K	169	239	211
Yield	3402	5468	4435
N uptake	92.34	164.76	128.03
P uptake	40.90	89.92	62.22
K uptake	76.70	155.78	113.65

**Table 16. Initial soil available nutrients, yield and uptake by wheat in over all treated plots**

Parameters (kg ha <sup>-1</sup> )	Range (kg ha <sup>-1</sup> )		Mean (kg ha <sup>-1</sup> )
	Minimum	Maximum	
KmnO <sub>4</sub> –N	328	386	359.70
Bray–P	281	459	346.88
NH <sub>4</sub> OAc-K	154	239	195.30
Yield	1800	5468	3962.56
N uptake	84.47	160.76	123.22
P uptake	27.96	89.92	55.07
K uptake	52.24	155.78	91.51

**Table 17. Initial soil available nutrients, yield and uptake by wheat in control plots**

Parameters (kg ha <sup>-1</sup> )	Range (kg ha <sup>-1</sup> )		Mean (kg ha <sup>-1</sup> )
	Minimum	Maximum	
KMnO <sub>4</sub> –N	319	330	323
Bray–P	293	305	299
NH <sub>4</sub> OAc-K	203	224	214
Yield	2134	2900	2465.00
N uptake	68.03	75.11	68.85
P uptake	22.39	39.67	30.00
K uptake	44.49	69.81	56.42

**Table 18. Response of wheat to different levels of fertilizer nutrients**

S. No.	Nitrogen (N)		Phosphorus (P <sub>2</sub> O <sub>5</sub> )		Potassium (K <sub>2</sub> O)	
	Level (kg ha <sup>-1</sup> )	Response Ratio (kg kg <sup>-1</sup> )	Level (kg ha <sup>-1</sup> )	Response Ratio (kg kg <sup>-1</sup> )	Level (kg ha <sup>-1</sup> )	Response Ratio (kg kg <sup>-1</sup> )
1.	50	66.1	30	125.2	40	97.3
2.	100	38.9	60	63.4	80	51.4
3.	150	28.0	90	50	120	39.3
4.	200	22.9	-	-	-	-

**Table 19. Nutrient requirement, per cent contribution from soil and fertilizer nutrients for wheat**

Parameters	Basic data			Response yard stick (kg kg <sup>-1</sup> )
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	
Nutrient requirement (kg q <sup>-1</sup> )	2.98	3.14	2.75	6.63
Per cent contribution from soil	21.65	10.01	26.26	
Per cent contribution from fertilizers	39.21	87.47	70.82	

**Table 21. Initial soil available nutrients, yield and uptake by wheat in IPNS plots (kg ha<sup>-1</sup>)**

Parameters	Range		Mean
	Minimum	Maximum	
<b>NPK alone</b>			
KMnO <sub>4</sub> -N	328	379	353.5
Bray-P	281	459	370
NH <sub>4</sub> OAc-K	159	226	192.5
Grain yield	2084	5263	3674
N uptake	68.21	147.77	114.5
P uptake	29.93	73.34	55.2
K uptake	56.85	135.65	96
<b>NPK+ vermicompost</b>			
KMnO <sub>4</sub> -N	337	380	358.5
Bray -P	285	439	362
NH <sub>4</sub> OAc-K	168	227	197.5
Grain yield	2400	5336	3868
N uptake	92.34	160.34	119.9
P uptake	29.71	80.76	56.6
K uptake	56.61	139.52	96.1
<b>NPK+vermicompost+Azospirillum</b>			
KMnO <sub>4</sub> -N	337	385	361
Bray-P	287	457	372
NH <sub>4</sub> OAc-K	160	239	199.5
Grain yield	2250	5468	3858
N uptake	92.03	160.76	126.3
P uptake	39.75	87.82	58.9
K uptake	52.24	155.78	106.3

**Table 22. Influence of IPNS on head yield of wheat**

Treatments	Head yield (kg ha <sup>-1</sup> )	Increase in grain yield over absolute control (kg ha <sup>-1</sup> )	Per cent increase over absolute control
Absolute Control	2237	-	-
NPK alone	3706	1709	76.40
Vermicompost alone	2490	253	11.31
<i>Azospirillum</i> alone	2414	177	7.9
NPK+Vermicompost	3926	1689	75.55
NPK+ Vermicompost + <i>Azospirillum</i>	4183	1846	82.52

**Table 23. Per cent contribution of nutrients from vermicompost and vermicompost + *Azospirillum* for wheat**

Parameters	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Per cent contribution from (C <sub>vermi</sub> )	36	10.5	19.6
Per cent contribution from <i>Azospirillum</i> (C <sub>vermi+AZO</sub> )	31	-	-

**Table 26. Fertilizer economy under IPNS**

S. No.	Particulars	Nutrients saving (kg ha <sup>-1</sup> )			Monetary Saving *(Rs.ha <sup>-1</sup> )			Total (Rs.ha <sup>-1</sup> )
		N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	
1.	NPK + Vermi	43	10	23.5	443	198	175	816
2.	NPK+Vermi+Azospirillum	53	10	23.5	546	198	175	919
3.	NPK+ Azospirillum	10	-	-	103	-	-	103

\* Cost of one kg of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O as urea, SSP and MOP- Rs.10.31, 19.75 and 7.43 kg<sup>-1</sup> respectively.

**Table 27. Influence of IPNS on available nutrients in post harvest soil (kg ha<sup>-1</sup>)**

Treatments	Initial STV	Post harvest STV
<b>Nitrogen</b>		
Absolute Control	319	282
NPK alone	343	357
NPK + Vermi	360	379
NPK + Vermi + <i>Azospirillum</i>	382	402
<b>Phosphorus</b>		
Control	30	22
NPK alone	59	67
NPK + Vermi	67	80
NPK + Vermi + <i>Azospirillum</i>	81	96
<b>Potassium</b>		
Control	57	44
NPK alone	90	113
Vermi + NPK	92	121
Vermi + NPK + <i>Azospirillum</i>	107	129

**Table 28. Critical levels of soil test values for wheat as influenced by yield targeting under IPNS (kg ha<sup>-1</sup>)**

S. No.	Treatments	35 (q ha <sup>-1</sup> )			45 (q ha <sup>-1</sup> )			55 (q ha <sup>-1</sup> )		
		N	P	K	N	P	K	N	P	K
1.	NPK alone	484	483	302	622	621	388	760	759	474
2.	NPK + Vermi	405	445	250	543	582	336	681	721	422
3.	NPK + Vermi + <i>Azospirillum</i>	385	445	250	523	582	336	662	721	422

**Table 20. Estimates of soil test based fertilizer doses for various yield targets by targeted yield model (kg ha<sup>-1</sup>) for NPK alone treated plots**

Soil test values (kg ha <sup>-1</sup> )			35 (q ha <sup>-1</sup> )			45 (q ha <sup>-1</sup> )			55 (q ha <sup>-1</sup> )		
KMnO <sub>4</sub> - N	Bray- P	NH <sub>4</sub> O Ac-K	FN	FP <sub>2</sub> O <sub>5</sub>	FK <sub>2</sub> O	FN	FP <sub>2</sub> O <sub>5</sub>	FK <sub>2</sub> O	FN	FP <sub>2</sub> O <sub>5</sub>	FK <sub>2</sub> O
150	100	150	184	100	68	250	136	107	334	171	146
200	150	200	156	87	46	232	123	85	308	158	123
250	200	250	129	74	23	205	110	62	281	145	101
300	250	300	101	61	0.8	177	97	40	253	132	78
350	300	350	74	48	-	150	84	17	226	119	56
400	350	400	46	35	-	122	71	-	198	106	33
450	400	450	19	22	-	95	58	-	171	93	-
500	450	500	-	9	-	67	45	-	-	80	-
550	500	550	-	-	-	-	32	-	-	67	-





## APPENDIX II

### Treatment Structure, yield, uptake and initial soil test values for wheat-Strip I

S.No	Yield	UN	UP	UK	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	Azo (kg ha <sup>-1</sup> )	Vermin+ Azo
	kg ha <sup>-1</sup>												
1.	2084	84.47	33.36	64.71	328	305	159	0	60	80	0	0	0
2.	2652	88.7	39.64	67.89	330	281	154	50	60	80	0	0	0
3.	1800	92.03	30.72	54.76	332	300	158	50	0	0	0	1	0
4.	2250	90.02	29.71	52.24	337	292	160	50	30	0	1	1	1
5.	2341	96.3	33.68	60.32	331	294	167	50	30	40	0	1	0
6.	2400	98.26	27.96	56.61	343	291	168	100	0	0	1	0	0
7.	2350	100.16	33.32	64.9	341	290	170	100	0	40	0	0	0
8.	2936	104.14	39.91	72.52	344	293	173	100	0	80	0	0	0
9.	2520	94.2	39.92	69.41	352	299	170	100	30	40	1	0	0
10.	2990	97.05	40.05	78.61	354	285	174	100	30	80	1	0	0
11.	2760	101.34	44.92	58.01	356	290	162	100	60	0	0	1	0
12.	2417	104.65	49.63	70.91	361	287	167	100	60	40	1	1	1
13.	2794	109.02	53.28	84.71	355	289	177	100	60	80	0	1	0
14.	2747	114.95	57.8	99.03	360	295	179	100	60	120	1	1	1
15.	2850	112.54	37.63	89.32	356	297	181	100	90	80	0	1	0
16.	2363	132.57	37.41	57.25	357	291	164	150	0	0	0	0	0
17.	2226	137.78	46.6	74.76	354	300	170	150	30	40	0	1	0
18.	3065	136.68	64.25	92.51	358	295	181	150	60	80	0	1	0
19.	2996	126.91	44.6	60.15	364	289	184	150	90	0	1	1	1
20.	2652	136.92	75.04	77.63	361	282	176	150	90	40	0	1	0
21.	3092	126.78	70.69	99.06	363	300	183	150	90	80	1	0	0
22.	4187	135.71	47.29	106.71	369	285	187	150	90	120	1	0	0
23.	3175	135.92	69.8	92.62	370	289	190	200	60	80	1	1	1
24.	3018	136.86	53.85	79.95	364	295	182	200	90	40	0	0	0
25.	3405	138.86	59.3	96.79	371	292	184	200	90	80	0	0	0
26.	3926	136.66	65.78	120.02	372	294	191	200	90	120	1	1	1
27.	2134	71.11	22.39	44.49	319	295	203	0	0	0	0	1	0
28.	2290	70.32	25.04	49.75	326	294	204	0	0	0	1	0	0

### APPENDIX III

#### Treatment Structure, yield, uptake and initial soil test values for wheat-Strip II

S.No	Yield	UN	UP	UK	SN	SP	SK	FN	FP	FK	Vermi (t ha <sup>-1</sup> )	AZO (kg ha <sup>-1</sup> )	Vermin + Azo
	kg ha <sup>-1</sup>												
1.	2942	<b>86.55</b>	37.67	68.31	332	308	166	0	60	80	0	0	0
2.	3794	99.49	48.99	69.84	334	309	173	50	60	80	0	0	0
3.	2231	98.55	36.6	59.01	337	315	179	50	0	0	0	1	0
4.	3297	99.3	32.71	65.76	335	317	187	50	30	0	0	1	0
5.	3534	97.11	39.75	67.34	341	299	198	50	30	40	1	1	1
6.	3157	104.34	29.6	68.88	344	311	195	100	0	0	0	1	0
7.	3493	99.55	39.15	65.08	352	327	187	100	0	40	1	0	0
8.	3855	101.55	46.35	79.51	350	329	193	100	0	80	1	1	1
9.	3931	104.52	44.13	69.62	345	325	195	100	30	40	0	1	0
10.	4155	105.2	49.21	80.78	356	327	196	100	30	80	1	1	1
11.	3297	111.6	50.54	70.12	353	328	199	100	60	0	0	0	0
12.	3621	114.82	54.98	74.54	358	327	200	100	60	40	1	0	0
13.	3774	118.56	59.78	84.35	359	330	201	100	60	80	1	1	1
14.	5018	126.66	66.43	107.52	359	335	203	100	60	120	0	1	0
15.	4286	126.14	39.01	86.67	358	331	194	100	90	80	0	0	0
16.	3132	132.3	43.41	75.71	358	329	199	150	0	0	0	1	0
17.	3670	133.77	52.19	79.08	360	325	198	150	30	40	0	0	0
18.	4642	133.66	73.34	89.15	368	335	201	150	60	80	1	1	1
19.	4360	136.62	49.86	79.75	363	339	194	150	90	0	0	1	0
20.	5018	137.91	80.76	82.07	364	340	205	150	90	40	1	0	0
21.	5150	142.56	77.37	105.91	364	341	206	150	90	80	0	0	0
22.	4734	142.88	54.01	119.61	365	356	204	150	90	120	1	0	0
23.	4531	144.23	76.21	96.67	371	354	203	200	60	80	0	1	0
24.	3581	148.86	57.67	85.25	370	357	201	200	90	40	0	1	0
25.	5206	147.77	67.16	99.51	373	358	199	200	90	80	1	1	1
26.	5468	150.62	70.9	125.32	379	358	204	200	90	120	1	0	0
27.	2280	75.11	26.89	50.96	330	301	206	0	0	0	1	0	0
28.	2237	74.64	29.93	56.85	328	303	209	0	0	0	0	0	0

**APPENDIX IV**  
**Treatment Structure, yield, uptake and initial soil test values**  
**for wheat-Strip III**

S.No	Yield	UN	UP	UK	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	Azo (kg ha <sup>-1</sup> )	Vermin +Azo
1.	3651	<b>92.34</b>	39.88	74.67	339	312	190	0	60	80	1	0	0
2.	3710	103.76	49.99	78.98	341	316	198	50	60	80	0	1	0
3.	3232	104.67	43.8	66.87	348	320	168	50	0	0	1	1	1
4.	3245	106.54	37.61	69.48	343	319	167	50	30	0	0	0	0
5.	4434	110.64	42.63	70.84	345	321	199	50	30	40	0	1	0
6.	4026	114.61	36.45	75.51	357	310	205	100	0	0	1	0	0
7.	3179	120.82	47.45	72.45	352	311	203	100	0	40	0	0	0
8.	3978	123.45	57.37	84.73	355	317	210	100	0	80	1	1	1
9.	4162	128.9	48.12	75.24	358	323	207	100	30	40	1	1	1
10.	4332	128.69	50.36	92.02	356	327	211	100	30	80	0	1	0
11.	3984	131.98	54.47	79.98	362	328	167	100	60	0	1	1	1
12.	4907	132.55	59.39	79.89	361	329	198	100	60	40	1	1	1
13.	4838	134.86	66.79	94.71	363	334	217	100	60	80	1	1	1
14.	5013	139.56	73.86	109.57	361	336	219	100	60	120	0	0	0
15.	5263	134.87	49.44	99.88	359	339	213	100	90	80	0	0	0
16.	4081	135.78	52.8	84.14	364	346	174	150	0	0	0	1	0
17.	4149	143.72	56.34	84.61	362	349	196	150	30	40	0	0	0
18.	4363	145.23	77.61	109.71	366	352	204	150	60	80	0	1	0
19.	4684	144.76	49.09	86.93	371	354	187	150	90	0	1	0	0
20.	4740	149.88	86.75	89.71	365	359	206	150	90	40	0	1	0
21.	5249	150.98	79.41	122.74	372	361	219	150	90	80	1	0	0
22.	4984	153.87	56.6	125.91	369	360	226	150	90	120	0	0	0
23.	4943	155.67	83.91	118.94	373	362	220	200	60	80	0	1	0
24.	4563	154.9	59.48	96.57	375	367	195	200	90	40	0	1	0
25.	5216	160.76	69.42	125.58	374	366	221	200	90	80	0	0	0
26.	5336	160.34	76.9	135.65	380	374	227	200	90	120	1	0	0
27.	2900	69.04	29.64	56.92	329	294	222	0	0	0	1	0	0
28.	2484	70.33	32.75	60.1	327	293	221	0	0	0	0	0	0

## APPENDIX V

### Treatment Structure, yield and initial soil test values for wheat-Strip IV

S.No	Yield	UN	UP	UK	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	AZO (kg ha <sup>-1</sup> )	Vermin +Azo
	kg ha <sup>-1</sup>												
1.	3723	86.34	44.47	94.31	341	370	212	0	60	80	0	0	0
2.	4086	93.76	53.01	99.27	354	374	218	50	60	80	1	1	1
3.	3402	98.67	48.8	76.7	351	388	190	50	0	0	0	1	0
4.	4363	99.54	40.9	79.91	352	387	189	50	30	0	0	0	0
5.	4505	100.64	44.06	84.01	354	389	211	50	30	40	0	0	0
6.	4112	107.11	43.61	84.34	365	398	217	100	0	0	1	1	1
7.	4494	110.82	54.5	89.76	359	409	226	100	0	40	0	1	0
8.	4605	115.45	63.07	103.51	364	395	233	100	0	80	1	1	1
9.	4565	119.9	51.5	102.24	365	401	239	100	30	40	1	1	1
10.	4702	117.69	57	112.03	369	425	213	100	30	80	1	0	0
11.	4563	124.98	57.47	89.51	367	416	169	100	60	0	0	0	0
12.	4764	123.55	62.31	111.52	370	427	198	100	60	40	1	0	0
13.	4852	126.88	69.85	117.38	365	439	219	100	60	80	1	0	0
14.	4878	127.56	73.65	119.52	369	450	221	100	60	120	0	1	0
15.	5087	126.87	49.74	125.89	368	447	215	100	90	80	0	0	0
16.	4368	129.78	59.04	94.39	371	454	176	150	0	0	0	1	0
17.	4984	133.72	62.74	125.97	373	457	198	150	30	40	1	1	1
18.	4926	134.23	79.83	133.51	379	440	206	150	60	80	1	0	0
19.	4894	135.76	52.14	99.31	380	442	189	150	90	0	1	0	0
20.	4900	138.88	89.92	132.98	378	459	208	150	90	40	1	1	1
21.	5178	143.98	87.82	155.78	379	457	222	150	90	80	0	0	0
22.	4982	144.87	57.81	140.61	378	458	228	150	90	120	0	1	0
23.	5073	148.67	86.32	140.02	382	440	223	200	60	80	0	1	0
24.	5291	143.9	69.23	139.52	383	455	197	200	90	40	1	1	1
25.	5303	152.76	78.9	147.08	381	444	225	200	90	80	0	1	0
26.	5373	164.67	79.9	155.78	380	452	231	200	90	120	0	1	0
27.	2695	68.03	33.65	62.5	324	304	220	0	0	0	0	1	0
28.	2700	68.21	39.67	69.81	321	305	224	0	0	0	0	0	0

**APPENDIX VI**

**Treatment Structure, yield and post-harvest soil test values  
for wheat-Strip I**

S.No	Yield	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	AZO (kg ha <sup>-1</sup> )	Vermin + Azo
	kg ha <sup>-1</sup>									
1.	2084	331	328	172	0	60	80	0	0	0
2.	2652	343	298	180	50	60	80	0	0	0
3.	1800	351	341	183	50	0	0	0	1	0
4.	2250	359	347	194	50	30	0	1	1	1
5.	2341	347	357	197	50	30	40	0	1	0
6.	2400	360	353	198	100	0	0	1	0	0
7.	2350	358	345	200	100	0	40	0	0	0
8.	2936	363	334	198	100	0	80	0	0	0
9.	2520	380	341	203	100	30	40	1	0	0
10.	2990	372	329	209	100	30	80	1	0	0
11.	2760	381	337	189	100	60	0	0	1	0
12.	2417	390	344	211	100	60	40	1	1	1
13.	2794	363	333	205	100	60	80	0	1	0
14.	2747	379	340	199	100	60	120	1	1	1
15.	2850	376	356	214	100	90	80	0	1	0
16.	2363	397	353	189	150	0	0	0	0	0
17.	2226	384	338	198	150	30	40	0	1	0
18.	3065	388	349	200	150	60	80	0	1	0
19.	2996	394	357	220	150	90	0	1	1	1
20.	2652	381	330	197	150	90	40	0	1	0
21.	3092	383	344	225	150	90	80	1	0	0
22.	4187	399	347	224	150	90	120	1	0	0
23.	3175	402	344	257	200	60	80	1	1	1
24.	3018	388	350	257	200	90	40	0	0	0
25.	3405	397	362	240	200	90	80	0	0	0
26.	3926	389	377	241	200	90	120	1	1	1
27.	2134	326	330	220	0	0	0	0	1	0
28.	2290	343	329	229	0	0	0	1	0	0

**APPENDIX VII**

**Treatment Structure, yield and post-harvest soil test values  
for wheat-Strip II**

S.No	Yield	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	Azo (kg ha <sup>-1</sup> )	Vermin +Azo
	kg ha <sup>-1</sup>									
1.	2942	375	339	199	0	60	80	0	0	0
2.	3794	377	326	195	50	60	80	0	0	0
3.	2231	366	340	200	50	0	0	0	1	0
4.	3297	371	344	217	50	30	0	0	1	0
5.	3534	388	349	236	50	30	40	1	1	1
6.	3157	379	336	229	100	0	0	0	1	0
7.	3493	378	350	216	100	0	40	1	0	0
8.	3855	384	354	240	100	0	80	1	1	1
9.	3931	380	359	240	100	30	40	0	1	0
10.	4155	392	362	248	100	30	80	1	1	1
11.	3297	383	358	236	100	60	0	0	0	0
12.	3621	399	360	240	100	60	40	1	0	0
13.	3774	396	366	242	100	60	80	1	1	1
14.	5018	379	356	238	100	60	120	0	1	0
15.	4286	368	354	218	100	90	80	0	0	0
16.	3132	400	349	243	150	0	0	0	1	0
17.	3670	381	363	219	150	30	40	0	0	0
18.	4642	409	369	255	150	60	80	1	1	1
19.	4360	391	374	244	150	90	0	0	1	0
20.	5018	394	370	233	150	90	40	1	0	0
21.	5150	387	364	238	150	90	80	0	0	0
22.	4734	399	377	228	150	90	120	1	0	0
23.	4531	400	378	241	200	60	80	0	1	0
24.	3581	402	382	247	200	90	40	0	1	0
25.	5206	408	393	249	200	90	80	1	1	1
26.	5468	395	389	240	200	90	120	1	0	0
27.	2280	363	345	241	0	0	0	1	0	0
28.	2237	360	340	237	0	0	0	0	0	0

**APPENDIX VIII**

**Treatment Structure, yield and post-harvest soil test values  
for wheat-Strip III**

S.No	Yield	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	AZO (kg ha <sup>-1</sup> )	Vermin + Azo
	kg ha <sup>-1</sup>									
1.	3651	355	336	233	0	60	80	1	0	0
2.	3710	366	346	228	50	60	80	0	1	0
3.	3232	369	349	225	50	0	0	1	1	1
4.	3245	377	338	210	50	30	0	0	0	0
5.	4434	373	352	217	50	30	40	0	1	0
6.	4026	352	357	225	100	0	0	1	0	0
7.	3179	376	334	244	100	0	40	0	0	0
8.	3978	386	356	248	100	0	80	1	1	1
9.	4162	399	345	247	100	30	40	1	1	1
10.	4332	377	349	241	100	30	80	0	1	0
11.	3984	390	353	209	100	60	0	1	1	1
12.	4907	402	367	211	100	60	40	1	1	1
13.	4838	388	369	237	100	60	80	1	1	1
14.	5013	384	354	250	100	60	120	0	0	0
15.	5263	389	360	233	100	90	80	0	0	0
16.	4081	399	366	219	150	0	0	0	1	0
17.	4149	394	370	241	150	30	40	0	0	0
18.	4363	401	376	254	150	60	80	0	1	0
19.	4684	409	374	246	150	90	0	1	0	0
20.	4740	397	377	255	150	90	40	0	1	0
21.	5249	370	380	249	150	90	80	1	0	0
22.	4984	382	386	260	150	90	120	0	0	0
23.	4943	398	387	249	200	60	80	0	1	0
24.	4563	385	390	246	200	90	40	0	1	0
25.	5216	410	399	271	200	90	80	0	0	0
26.	5336	413	379	265	200	90	120	1	0	0
27.	2900	366	342	246	0	0	0	1	0	0
28.	2484	370	333	240	0	0	0	0	0	0

## APPENDIX IX

### Treatment Structure, yield and post-harvest soil test values for wheat-Strip IV

S.No	Yield	SN	SP	SK	FN	FP	FK	vermi (t ha <sup>-1</sup> )	AZO (kg ha <sup>-1</sup> )	Vermin + Azo
	kg ha <sup>-1</sup>									
1.	3723	370	389	223	0	60	80	0	0	0
2.	4086	379	398	234	50	60	80	1	1	1
3.	3402	368	402	220	50	0	0	0	1	0
4.	4363	377	409	215	50	30	0	0	0	0
5.	4505	386	399	219	50	30	40	0	0	0
6.	4112	397	420	245	100	0	0	1	1	1
7.	4494	393	417	243	100	0	40	0	1	0
8.	4605	402	434	254	100	0	80	1	1	1
9.	4565	395	454	258	100	30	40	1	1	1
10.	4702	384	437	234	100	30	80	1	0	0
11.	4563	386	429	209	100	60	0	0	0	0
12.	4764	390	455	226	100	60	40	1	0	0
13.	4852	379	460	250	100	60	80	1	0	0
14.	4878	383	466	245	100	60	120	0	1	0
15.	5087	392	453	225	100	90	80	0	0	0
16.	4368	389	469	278	150	0	0	0	1	0
17.	4984	399	479	239	150	30	40	1	1	1
18.	4926	393	459	234	150	60	80	1	0	0
19.	4894	380	466	228	150	90	0	1	0	0
20.	4900	402	479	256	150	90	40	1	1	1
21.	5178	390	487	257	150	90	80	0	0	0
22.	4982	389	469	260	150	90	120	0	1	0
23.	5073	410	473	237	200	60	80	0	1	0
24.	5291	416	480	250	200	90	40	1	1	1
25.	5303	409	474	239	200	90	80	0	1	0
26.	5373	401	468	247	200	90	120	0	1	0
27.	2695	339	327	240	0	0	0	0	1	0
28.	2700	339	305	237	0	0	0	0	0	0

Fig.1.Location of the experimental site

