SOIL TEST CROP RESPONSE STUDIES FOR BALANCED FERTILIZATION OF TURMERIC (*Curcuma longa* L.) IN A MOLLISOL OF UTTARAKHAND

Thesis

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C E R T I F I C A T E

This is to certify that the thesis entitled **"SOIL TEST CROP RESPONSE STUDIES FOR BALANCED FERTILIZATION OF TURMERIC (*Curcuma longa* L.) IN A MOLLISOL OF UTTARAKHAND"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** with major in **Soil Science** and minor in **Agronomy,** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona-fide* research carried out by **Mr. Sarvesh Kumar, Id. No. 40875**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

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Pantnagar
August, 2016

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Chairman
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CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr. Sarvesh Kumar, Id. No. 40875**, a candidate for the degree of **Doctor of Philosophy** with major in **Soil Science** and minor in **Agronomy**, agree that the thesis entitled **"SOIL TEST CROP RESPONSE STUDIES FOR BALANCED FERTILIZATION OF TURMERIC (*Curcuma longa* L.) IN A MOLLISOL OF UTTARAKHAND"** may be submitted in partial fulfillment of the requirements for the degree.

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Introduction

India is the largest producer of turmeric, supplying 94% of the world's demand. India also dominates the world production scenario contributing to approximately 75% of world's total production producing 6,00,000 tonnes of turmeric annually. India produced about 10.9 lakh tonnes of turmeric from 2.07 lakh hectare in year 2014. Turmeric occupies 6% of the total area under spices and condiments in India **(Rai and Yadav, 2005).** Andhra Pradesh is the leading turmeric producing State in India contributing about approx. 47% of total production followed by Tamil Naidu and Kerala. India has been a traditional producer, consumer and exporter of turmeric, but the productivity of turmeric in India is lowest in the world. The scenario of area, production and yield of spices in Uttarakhand appeared to be encouraging. The share of Uttarakhand in all India area under spices was as low as 0.25 per cent but contribution in production was triple due to higher productivity of 5776 kg ha^{-1} against all India average of 1819 kg ha^{-1} during 2010-11. The state emerged as a second ranking state in terms of yield of spices. The trend of increasing production of spices indicates that farmers are interested of the production technology of spices crops. Uttarakhand produced about 6651 metric tonne of turmeric from an area of 798 ha with productivity of 8.33 metric tonne ha^{-1} in 2010-11.

India is the third largest producer and consumer of chemical fertilizers in the world. The combined output of Nitrogenous (N) and Phosphatic (P) Chemical fertilizers has increased from a modest level of 0.02 million tonnes in nutrient terms in 1951-52 to around 38 million tonnes in the recent years. On the consumption side, use of plant nutrient per hectare of gross cropped area has registered a quantum increase from 0.49 kg ha^{-1} in 1951-52 to around 140 kg ha^{-1} (**Indian Fertilizer Scenario-2014).** Fertilizers play a key role in increasing agricultural production as the crop yields increased considerably by appropriate doses of fertilizers but application fertilizer of any nutrients by the farmer without information on soil fertility status and nutrient requirement by crop affect soil and crop adversely **(Ray *et al.,* 2000).** Intensive cropping and imbalanced fertilizer application are major causes of depletion macronutrients like N, P, K and S. Extent of deficiencies have been at the turn of century have been 89 % N (63% low & 26 % medium), 80 % P (42% low & 38 % medium), 41 % S, 48 % Zn, 33 % B, 12 % Fe, 13 % Mo, 5 % Mn and 3 % Cu **(Singh 2001; Motsara, 2002; Rattan, 2013)**.

In changing scenario of Agriculture due to intensification of cropping system, climate and management practices development of new crop varieties, there is need to develop & evaluation of soil test method particularly those methods which are more accurate, less time consuming & multi nutrient extraction capabilities.

The scope of soil testing gets enlarged and varied with the increased range of uses and also in precision agriculture. As the concept of soil quality changes in an intensive agriculture, environmental issues, recycling, waste disposal, etc. would assume prominence. In the current and future scenario, soil testing has to be rechristened as soil quality assessment and it has to assume a holistic role not limited to guide fertilizer recommendation for a crop based on soil test. The 'Soil testing for fertilizer recommendation' needs to be changed to 'Soil test for soil quality assessment and resource management options for production systems and variable soil uses' **(Goswami, 2006)**. The basic objective of the soil-testing programme is to give farmers a service leading to better and more economic use of fertilizers and better soil management practices for increasing agricultural production. Soil testing is only a means but not an end by itself. It is a basic inventory and necessary information has to be built in the system for translating the results of soil test to achieve the crop production goal. Soil test values supplemented with soil test crop response data, cropping system, soil survey information and management conditions can be used as a valuable guide for predicting fertilizer needs of a crop in a given situation. Therefore, a strong research support in term of local calibration on soil test crop response research is necessary for the effective functioning of the soil testing advisory service. Keeping these factors in view, an All India Coordinated Research Project on Soil Test Crop Response Correlations was started by the Indian Council of Agricultural Research in 1967. Soil test based fertilizer recommendation is based on the basic assumption that an increase or decrease of available nutrient in the soil will directly influence crop yield. It can vary from purely empirical to semi-quantitative and quantitative, depending upon the methodology and approach to soil testing. In the first phase of soil testing, the rating was only diagnostic or indicative of nutrient deficiency or sufficiency on an area basis. In the second stage, critical level of specific nutrient was addressed, which was an improvement in degree of the first one in that its objective was to classify soils within a well defined soil unit according to deficiency or sufficiency in a nutrient based on probability of getting a profitable responses or not to the added nutrients. Targeted yield concept was the third phase in the development of soil testing methodology. This concept is based on quantitative idea of the fertilizer need in accordance with yield and nutritional requirement of the crop, percent contribution of the soil available nutrient and that of the applied fertilizer **(Ramamoorthy *et al.,* 1967).**

Turmeric has a high demand for plant nutrients and generally responds to applied nutrients for yield & quality. The quantity of fertilizers (inorganic or organic) required by the crop depend on the variety as well as soil, and weather conditions prevailing during crop growth **(Karthikeyan *et. al.,* 2009).** Turmeric is member of Curcuma botanical group, belongs to ginger family *Zingiberaceae*. Root and underground stem of the *Curcuma longa L.* plant is crushed and powdered into ground turmeric. Ground turmeric is used worldwide for seasoning, to make curry, due to its medicinal properties. Curcumin, 3% component of turmeric, is most biologically active phytochemical compound. Turmeric can be grown in diverse tropical conditions from sea level to 1500 m height, requires warm (20-35^{0}C temperature) and humid climate with an annual rainfall of 1500 mm or more, under rain fed or irrigated conditions. Though it can be grown on different types of soils, it thrives well in well-drained sandy or clay loam soils with a pH range of 4.5-7.5 and good organic matter status. Turmeric is prized for its ability to impart a brilliant yellow-gold color to food and is an essential ingredient in curry and curry powders, giving culinary dish a characteristic peppery taste (**Ravindran *et al.*, 2007**). The active components in turmeric possess a broad spectrum of biological activities with various beneficial properties e.g. anti-bacterial, anti-fungal, anti-parasitic, anti-mutagen, anti-inflammatory, hypolipidemic, hepatoprotective; lipoxygenase, cyclooxygenase, and protease-inhibitor effects, besides being effective in reactive oxygen species scavengers and lipid peroxidase inhibitors (**Khanna, 1999**). Besides being anti-malarial, anti-inflammatory and anti-tumor forming, it is also known for its anti-mutagenic, anti-carcinogenic, anti-oxidant and chemotherapeutic properties **(Prasad *et al.,* 2014).**

The cured rhizome yield of turmeric ranges from 3-5 mt ha^{-1} in the Erode district, of Tamil Nadu (**Selvarajan and Chezhiyan, 2001**). Inadequate nutrient management and nutrient mining has led to low productivity of fresh rhizome yield in the major turmeric growing regions in South India. In order to study the effect of potassium and magnesium on turmeric production, and on its quality attributes of the crop under conditions of adequate supply of nitrogen and phosphorus, a field experiment was carried out on the Irugur soil series (Inceptisols) in the western zone of Tamil Nadu. While the rhizomes contain carbohydrates (69.4%), fat (5.1%), protein (6.3%) and minerals (3.5%), volatile oil (5.0–6.0%) and oleoresin (7.9–10.4%), the yellow color is due to curcumin (2.5–6.0%).

Plant Nutrition for realizing “Targeted yield of Crops” through soil test based nutrient management, as calibrated from a novel factorial field experiment technique, designed and used under the All India Coordinated Soil Test Crop Response (STCR) project investigations, on various soils and crops, in India over four decades. This approach has validated through hundreds of demonstration trials in farmers fields **Ramamoorthy and Velayutham (2011).** In the era of precision agriculture, the concept of “Soil test based fertilizer recommendation” harmonizes the much debated approaches namely, “Fertilizing the soil” versus “Fertilizing the crop” ensuring for real balance (not apparent balance) between the applied fertilizer nutrients among themselves and with the soil available nutrients. Soil test based fertilizer recommendations result in efficient fertilizer use and maintenance of soil fertility. Soil test based application of plant nutrient helps 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 the nutrients imbalance in soil helps to harness the synergistic effects of balanced fertilization (**Rao and Srivastava, 2000**). Field specific balanced amounts of N, P and K were prescribed for the crop based estimates of indigenous supply of N, P and K and by modeling the expected yield response as a function of nutrient interaction (**Dobermann and White 1998; Witt *et al*., 1999**).

Soil fertility levels are maintained to match with crop’s need and in proper proportions then crop productivity measured in terms of responses to fertilizers can only be sustained. For sustaining the production system, it is very essential that the nutrient demand of a crop to produce a definite yield and the amount removed from the soil should be perfectly matched. Nutrient recovery from applied fertilizers is primarily important and which varies according to crop species, management practices, soil properties and environmental conditions and above all nutrient sources. The importance of balanced fertilization to increase crop productivity is well recognized by policy makers and the scientists. Balanced fertilization would also connote integrated use of all nutrients coming from either organics or inorganic source. Once the nutrient requirements of crops have been assessed, it ensures optimum crop production, improved quality of the produce, maintenance of soil health by judicious and efficient use of nutrient resources available with the farmers.

Turmeric responds well to applications of organic manure and experimental evidences are available on the beneficial effects of organic manure either alone or in combination with inorganic fertilizers on growth, productivity and quality of turmeric **(Rao *et al*., 1975 and Gopalakrishna *et al*., 1997)**. Its nutrient requirement is quite high due to shallow rooting and capacity to produce large amount of dry matter per unit area. Therefore, the need-based application of plant nutrients through organic and inorganic manures is essential to optimum growth. Integrated uses of inorganic with organic manures are necessary for sustaining soil fertility and productivity. Soil test based fertilizer recommendation plays a vital role in ensuring balanced nutrition to crops and fertilizer schedules should, therefore, be based on the magnitude of crop response to applied nutrients at different soil fertility levels. Research work done on the nutrient management of turmeric crop showed that they respond to nutrients added through organics and chemical fertilizers. Currently, a general recommendation of 100:100:100 kg N, P_2O_5, and K_2O ha^{-1}, respectively is being followed along with FYM @ 25 t ha^{-1}. Fertilization based on blanket recommendation results in either over use or under use of fertilizers, so balanced fertilization is a must for realizing higher efficiency and economy of fertilizer use **(Velayutham and Reddy 1990).** It demands the maintenance of optimum balance between all essential nutrients, as per the crop requirements of nutrients and their availability in soil and possible recycling of organic sources. In fertilizing the crop the existing soil fertility and crop requirements should be taken in to account. Such studies are possible only through Inductive cum Targeted yield concept **(Ramamoorthy *et ai. 1967).***

The online fertilizer recommendation technique has been made to design the web based suitable for the recommendation of fertilizers like N, P and K for various location.

The web based online system is user friendly and can be operated without any scientific knowledge. The software was developed with help of information available from AICRP on Soil Test Crop Response project. The project has generated basic information on targeted yield equations, soil fertility index data for different states, crops, districts, seasons and suitable targeted yield for different crops. Software is implemented by designing a database for fertilizer recommendation for different states of the country. This information system is well organized and has related information; it acts as a useful tool for better strategic and administrative planning. Therefore, it is need of time to generate database for online fertilizer recommendation in turmeric also for growing this multi use crop to achieve maximum and quality production.

Turmeric is being produced by many farmers in *tarai* region, Mollisol of Uttarakhand but cultivation practices followed are neither based on scientific research nor such practices have been reported for the region. Among various problems being faced in turmeric production, the use of balanced fertilizer is one of the most important. Besides genetic effect health of the plant is highly influenced with cultural manipulation. Since soil test crop response is a pre-requisite for a healthy and high yielding crop nutritional study becomes very essential for increasing turmeric production. Systematic study has not been conducted so far on N, P and K fertilizer requirements based on soil test values for turmeric grown in Mollisols of Uttarakhand. Keeping the above facts in view to study the relationship between the nutrients supplied by the soil and added fertilizers, their uptake and yield of turmeric to develop balanced fertilizers schedule for maximum production of turmeric in Mollisols is a need of hour. Therefore, the present research work "Soil Test Crop Response Studies for balanced fertilization of Turmeric (*Curcuma longa* L.) in a Mollisol of Uttarakhand" conducted with the following objectives,

1. To study response of soil and applied Nitrogen, Phosphorus, Potassium and FYM on growth, yield and quality of turmeric.
2. Evaluation of availability indices for phosphorus and potassium.
3. To determine the fertilizer doses for targeted, maximum and economic yield of turmeric.
4. To generate data base for online fertilizer recommendations.

Review of Literature

India is called as the "Spice bowl of the world" as it produces variety of spices with quality. Though India leads in production of turmeric, but average productivity is very low due to imbalanced and suboptimal dose of chemical fertilizers, organic manure, bio-fertilizers and micronutrients **(Kandiannan and Chandragiri, 2008).** Since, turmeric is a nutrient responsive crop and removes large amount of nutrients from soil, sufficient quantities of nutrients have to be applied in order to obtain sustainable yield levels.

In the intensive agriculture system, INM based on soil test value provide most appropriate to solve various issues related to sustainability, maximizing crop yield, quality and conserving natural resources in efficient and economical way. Once the nutrient requirements of different crops have been assessed, it ensures optimum crop production, improved quality of the produce, maintenance of soil health and most judicious and efficient use of nutrient resources available with the farmers.

Turmeric being a long duration crop, it requires huge amount of nutrients. However, sandy loam soil with poor soil fertility and also depletion of soil nutrients due to low organic matter in soil is resulting in poor turmeric yields. Sufficient fertilizer application is considered as most important factor in enhancing yield of turmeric crop. The soil test crop response (STCR) approach of targeted yield is unique in indicating both soil test based fertilizer dose and the level of yield that farmer can be achieved with good management practices. In order to sustain the yield and reduce the cost of fertilizers and in turn cost of cultivation, the STCR approach is very important **(Saxena *et al,* 2008 and Chatterjee *et al*., 2010).** Soil test crop response (STCR) studies help to generate fertilizer adjustment equations and calibration charts for recommending fertilizers on the basis of soil tests and achieving targeted yield of crops (**Singh and Biswas, 2000**). ***Gosh et al.*** **(2004)** reported that balanced fertilization is a function of soil type, crop or cropping pattern, inputs, residue effects, available soil nutrients, yield targets, economics of fertilizer use.

Keeping above point of views the effect of soil & applied nutrient were showing on growth, yield and uptake of turmeric with the application of N, P_2O_5, K_2O and quality parameters for develop soil test crop response studies for balanced fertilization of turmeric grown in Mollisol of Uttarakhand under following heads:

2.1 Suitability of different methods of N, P and K to determine available nutrients status

2.1.1 Available nitrogen

Some important chemical methods for estimation of available nitrogen are given as in Table 2.1.

Table 2.1: Important chemical methods to estimate availability index of soil nitrogen

S. No.	Method	Reference
1.	Organic carbon	Walkley and Black (1934) Peterson *et al.* (1960) and Bajaj *et al.* (1962)
2.	Alkaline $KMnO_4$ oxidizable N (0.32% $KMnO_4$ + 2.5% NaOH)	Subbiah and Asija (1956)
3.	Boiling water extractable N	Livens (1959)
4.	0.25 *N* H_2SO_4	Richard *et al.* (1960)
5.	1*N* NaOH	Cornfield (1960)
6.	Ca $(OH)_2$-Nitrogen	Prasad (1961)
7.	Nitrate-nitrogen	Bremner (1965)

Soil Test Crop Response Correlation studies have been carried out by several workers. Reports of ICAR coordinated scheme on STCR correlation at Pantnagar centre revealed that a correlation co-efficient of 0.61 was obtained between alkaline-$KMnO_4$ extractable nitrogen and yield response of wheat and correlation with organic carbon method was also found equally high **(ICAR, 1972)**.

Among chemical methods, available nitrogen extracted by hot $K_2Cr_2O_7$, cold $K_2Cr_2O_7$ and alkaline $KMnO_4$ were found suitable for predicting nitrogen availability to rice. But the $K_2Cr_2O_7$ oxidizable nitrogen methods were simple, rapid, reliable and large number of samples could be handled in a short time **(Laxminarayana and Rajagopal, 2000)**. Estimates of correlation between organic carbon and soil nitrogen were significantly correlated **(Bhaskar Rao *et al.*, 2002)**.

Laxminarayana, (2006) reported that ammonical N is a simple, rapid and reliable method and it is adaptable for routine analysis for determining the available N status in rice soils of Mizoram.

Sati (2008) observed that organic carbon and alkaline-$KMnO_4$ methods were equally suitable for evaluation of available nitrogen from Pantnagar, Uttrakhand.

Xiang *et al.* (2008) proposed that it would be more appropriate to call soil organic N which is obtained by extraction, Extractable Organic N rather than Soluble Organic N.

Bordoloi (2013) conducted a pot experiment study to estimate of soil N-supplying capacity is therefore essential for efficient fertilizer use. In this study involving twenty acidic soils varying widely in properties, they evaluated six chemical indices of soil N-availability viz. organic carbon (Corg), total N (Ntot), acid and alkaline-KMnO4 extractable-N, hot KCl extractable-N (KCl-N) and phosphate-borate buffer extractable-N (PBB-N), based on their strength of correlation with available-N values obtained through aerobic incubation (AI-N) and anaerobic incubation (ANI-N), and also with the dry matter yield (DMY), N percentage and plant (maize) N uptake (PNU). Correlations of the N-availability indices with AI-N and ANI-N decreased in the order: PBB-N (r = 0.784** and 0.901**) > KCl-N (r = 0.773** and 0.743**) > acid KMnO4-N (r = 0.575** and 0.651**) ≥ Corg (r = 0.591** and 0.531**) ≥ alkaline KMnO4-N (r = 0.394** and 0.548**) > Ntot (r = 0.297** and 0.273*). Of all the indices evaluated, PBB-N showed the best correlations with plant parameters as well (r = 0.790** and 0.793** for DMY and PNU, respectively). Based on the highest correlations of PBB-N with biological indices as well as plant responses, they reported PBB-N as an appropriate index of N-availability in the acidic soils of India and other regions with similar soils.

Therefore, the organic carbon and alkaline-$KMnO_4$ oxidizable nitrogen methods seemed to be promising for testing available nitrogen in Mollisol.

2.1.2 Available phosphorus

Common methods used to determine available phosphorus in soil are listed in table 2.2.

Table 2.2: Important chemical methods to determine availability index of soil phosphorus

S.No.	Method	Reference
1.	0.002 N H_2SO_4 (pH 3.0)	Truog (1930)
2.	0.125 N NaOH + 0.175 N NaOAc	Morgan (1941)
3.	0.025 N HCl + 0.03 N NH_4F (Bray I)	Bray and Kurtz (1945)
4.	0.1 N HCl + 0.03 N NH_4F (Bray II)	Bray (1945)
5.	0.05 N HCl + 0.025 N H_2SO_4	Nelson *et al.* (1953)
6.	0.05 N HCl + 0.025 M H_2SO_4	Mehlich No. 1 (1953)
7.	0.5 M $NaHCO_3$ (pH 8.5)	Olsen *et al.* (1954)
8.	Phosphorus fractionation	Chang and Jackson (1957)
9.	Phosphate potential	Beckett and White (1964)
10.	Neutral 0.0025 N Na_2EDTA	Ahmed and Islam (1975)
11.	AB-DTPA (1 M NH_4HCO_3 + 0.005 M DTPA at pH 7.6)	Soltanpour and Schwab (1977)
12.	0.73 M NaOAc + 7.4 M HOAc (at pH 4.8)	Morgan and Wolf (1982)

Laxminarayana (2001) observed that the available phosphorus extracted by the modified Olsen's reagent had highest significant relationship with relative yield (r = 0.79) and relative phosphorus uptake (r = 0.66) in rice growing soils while using several extractants viz. Olsen's method, modified Olsen's method, NH_4HCO_3 method, AB-DTPA method and Pi-strip shaking method. Oxalate extraction method was found to be closely correlated with the Na_2SO_4+NaF extraction **(Fransson, 2001).**

Sarkar and O'connor (2001) used P_i soil test method successfully to assess phosphorus availability in a variety of soils of Florida, USA, followed by Mehlich-1 method.

Sonar and Palwe (2002) conducted an experiment to calibrate soil test methods for available phosphorus in swell-shrink soils for wheat. Soil available P was estimated with six extractants viz. 0.5 *M* $NaHCO_3$ pH 8.5 (Olsen P), 10% NaOAc pH 4.8 (Morgan P), 0.03*N* NH_4F+0.025*N* HCl (Bray P), 1 *M* NH_4- HCO_3+0.005 *M* DTPA pH 6 (Soltanpour P), 0.002 *N* H_2SO_4 pH 3, (Truog P) and 0.05 *N* HCl+0.0025*N* H_2SO_4 (Nelson P). Critical limits using scatter diagram and percent yield and P uptake were calculated. Soils containing low Olsen P recorded lower percent grain yield indicating efficient utilization of applied P than in soils with medium and high Olsen P. Percent wheat yield showed significant relationship with estimates of Olsen, Morgan, Soltanpour and Bray extractable P in soils. The highest correlation coefficient values were observed between Olsen P and percent wheat grain yield (r=0.915) and Olsen P and percent P uptake by wheat (r=0.894). The scatter diagram showed that critical limit of soil P was 29 kg ha-1 according to Olsen's method. Thus, Olsen's method was found to be most suitable for estimating available P in swell-shrink (Inceptisols) soils of Western India.

Bonfim *et al.* (2003) observed phosphorus recovery was in the order: Bray-1>Mehich-3> Mehlich1 and concluded Mehlich-1 and Mehlich-3 were best extractants to estimate the plant available phosphorus in the surface soils collected from Brazil.

Dolui and Majumdar (2003) reported extracting power of different extractants in the order: Bray-2> Olsen> North Carolina>Bray-1> Soltanpour and Schwab, to estimate the available phosphorus status in soils of West Bengal and Uttar Pradesh.

Bolland *et al.* (2003) concluded that for soils of south-western Australia treated with superphosphate (most of the soils), the Mehlich-3 procedure can be used instead of the Colwell sodium bicarbonate procedure to measure soil test P, providing support for the Mehlich-3 procedure to be developed as the multi-element soil test for the region.

Boparai and Sharma (2003) reported the amount of P extracted by different extractants was in the order of Bray P > Olsen P > water soluble P > saturation extract P.

Maftoun, (2003) found that Olsen method gave the best correlation coefficients with rice growth parameters (dry matter yield and P uptake), followed by Colwell and Soltanpour under aerobic and Soltanpour under anaerobic conditions and suggested Olsen test method as a more appropriate extractant for predicting P availability for rice under oxidized and reduced soil conditions.

Ghanei (2004) in his experiment showed that the amount of extractable P decreases in the order: 0.01 *M* $CaCl_2$ <Pi2<AB-DTPA<Pil< Olsen< colwell< Mehlich-1<0.1*M* HCl.

Mallarino and Atia (2005) observed that extraction of phosphorus through ion exchange provided a better estimate of plant available phosphorus. Further calibrated a test based on a commercially available ion- exchange resin membrane (RMP) and compared it with Bray-1 (BP), Mehlich-3 (M_3P) and Olsen's (OP) test with corn and showed that RMP and OP had similar capacity to predict corn response to phosphatic fertilizer but lower than for M_3P and BP was equally good except for high pH and calcareous soil.

Sarkar *et al.* (2014) conducted an incubation study in laboratory to determine the effect of lime (L) as $CaCO_3$ and phosphorus (P) as TSP on soil pH and available soil P in an acid soil. Four rates of L equivalent to 0, 1, 2 and 3 ton CaCO3 ha−1 and four rates of P equivalent to 0, 25, 50 and 75 mg P kg−1 were applied in combinations as treatments. The soil was incubated at field capacity for 8 weeks (wk) after which they were extracted using NaHCO3 (Olsen), Mehlich-3, Kelowna and Bray & Kurtz-1 extractants and soil pH was determined. Mehlich-3 method extracted the largest amount of P (14.54 - 67.35 $mg \cdot kg^{-1}$) while Olsen extracted the smallest amount (3.25 - 32.77 mg·kg−1). The mean extractable P in soils was found to be in the order of Olsen < Kelowna < Bray & Kurtz-1 < Mehlich-3. Although the four methods extracted different amounts of P from soil, values of P extracted by the different methods were strongly correlated among themselves (R2 = 0.87 to 0.95).

The result of this study indicated that a specific extractant did not always hold good to assess the available P status of all soils, as was done in routine soil testing laboratory. In conclusion, it would be mentioned that land use pattern which influenced the physic-chemical characteristics of the soils and thereby stability of different inorganic P forms, must be considered to choose the most suitable soil test method for estimating available P status. Therefore it may be inferred that among all the methods mentioned above, Olsen's method is mostly used for neutral and alkaline soils to determine available phosphorus is soil.

2.1.3 Available potassium

Important chemical methods to determine availability index of soil potassium are listed in table 2.3.

Table 2.3 : Important chemical methods to determine availability index of soil potassium

S.No.	Method	Reference
1.	1 *N* NHO_3 soluble (1: 10 soil extractant ratio, 10 min shaking)	Wood and De Turk (1940)
2.	0.125 *N* NaOH + 0.175 *N* NaOAc	Morgan (1941)
3.	1 *N* neutral NH_4OAc (1:5 soil extractant ratio, 5 min shaking)	Hanway and Hiedal (1952)
4.	Acetic acid soluble (1:2 soil extractant ratio, 30 min shaking)	Willium and Stewart (1955)
5.	1.38 *N* H_2SO_4 soluble (1:2 extractant ratio, 15 min. shaking)	Hunter and Pratt (1957)
6.	Q/I parameters	Beckett (1964)
7.	Water soluble (1:5 soil water ratio, 30 min shaking)	American Society of Agronomy (1965)
8.	AB-DTPA (1 *M* NH_4HCO_3 + 0.005 *M* DTPA at pH 7.6)	Soltanpour and Schwab (1977)

Tiwari *et al.* (2001) conducted an experiment to evaluate soil test methods for soil potassium and found boiling 1*N* HNO_3 and 1*N* NH_4OAc (pH 7.0) methods superior over other methods.

Soil potassium supply power was studied by **Ziadi *et al.* (2001)** in Canada to evaluate efficiency by electro-ultra filtration (EUF) and chemical methods. Potassium extracted by various methods were as follows: EUF at 200 V and 20^0C (59 mg kg^{-1}), EUF at 400 V and 80^0C (68 mg kg^{-1}), Mehlich III (202 mg kg^{-1}), 1 *M* NH_4OAC (214 mg kg^{-1}) and 1 *M* HNO_3 (1808 mg kg^{-1}). But highly significant relationships ($0.97<R^2<0.99$) between potassium extracted by EUF at 200 V and 20^0C and time were obtained.

Shanwal and Singh (2004) observed that 0.5 *N* HNO_3 at 25^0C extractable potassium was found best method for barley and maize and 3 N HNO_3 at 40^0C extractable potassium for wheat and bajra, while testing fifteen soil samples collected from light textured soils of Haryana, Punjab and Rajasthan.

Morituska and Matsumoto (2006) proposed a new experimental approach that enables to evaluate the chemical availability of soil potassium to pot-grown plants and followed a stepwise extraction of potassium with neutral 1 *M* NH_4OAc and then repeated treatment with 0.01 *M* HCl in the Fluvisol of Japan.

Matula (2009) in his experiment proved the highest universality of NH_4-acetate soil test over Mehlich-3 and water extraction for the nutrients (K, Mg, P, Mn, B) in relation to the plant.

Wang *et al.* (2010) reported that the (NaBPh4) method was improved to evaluate potassium (K) plant availability in various soils. The amount of soil K extracted by the $NaBPh_4$ method was significantly influenced by K extracting power (KEP) of the method which is determined by salt concentration and extracting period used. At lowest KEP, the $NaBPh_4$ method can only extract soluble and exchangeable K in soils, which was equivalent to the K extracted sequentially by three times of conventional NH_4OAc method. With increased KEP, the $NaBPh_4$ method not only extracted all NH_4OAc-extracted K, but also an increased portion of easy releasable non-exchangeable K (NEK).

Hosseinpur and Zarenia (2012) using nine extracting solutions for extraction soil potassium were classified in 4 groups on the basis of the mechanism of the extraction. The first group of extractants were acidic extractants, boiling 1 mol/L HNO_3, 0.1 mol/L HNO_3, 0.1 mol/L HCl, and Mehlich 1. The second group includes 0.1

mol/L $BaCl_2$, and 0.01 mol/L $CaCl_2$. The third group includes 1 mol/L NH4OAc (ammonium acetate), and AB-DTPA (ammonium bicarbonate-diethylenetriamine pentaaceticacid), and finally distilled water. The correlation studies showed that NH4OAc, AB-DTPA, 0.1 mol/L $BaCl_2$, 0.1 mol/L HCl, and boiling 1 mol/L HNO_3 could not be used as available K extractants. But the correlation of other extractants with relative yield, plant response, concentration K, and K uptake were significant. Therefore, these extracting solutions can be used as available K extractants.

Affinnih *et al.* (2014) check the responses to potassium (K) by potted Sorghum (Sorghum bicolor) were determined in soils taken from four Local Government Areas in Kwara State and regressed with K extracted with five laboratory methods. Potassium extracted with N NH4OAc pH 7.0 gave the best indication of dry matter yields when K was not applied, with the equation, $Y = 0.005X + 3.1902$, $r = 0.1622$. However, K extracted with hot N HNO3 was almost equal with a higher value in virtually all soils to exchangeable K extracted with N NH4OAc and could be used in place of this extractant as it also accounts for the replenishable form of K in soil.

2.2 Different approaches of calibration of soil test value, interpretation and fertilizer recommendation

Successful use of soil test depends upon its proper calibration with yield response. The process of determining the crop soil relationship is commonly referred as calibration of chemical soil test value. A calibrated soil test value indicates the degree of deficiency of that nutrient and amount of nutrient that applied as fertilizer to correct the deficiency. Sound soil test crop response correlation studies help in making fertilizer recommendation for better crop yield. Such studies need to be crop, soil and climate specific **(Ramamoorthy and Velayutham, 1971). Ghosh *et al.* (2004)** reported that balanced fertilization is a function of soil type, crop or cropping pattern, inputs, residue effects, available soil nutrients, yield targets, economics of fertilizer use and time. Correlation studies are conducted to provide the basis for selecting the lab tests that will provide the best index of nutrient availability to plants in the tested soil samples.

During mid 19th century Bossingault applied manures and showed crop response on it in field plot experiment. While Liebig gave the Law of Restitution (1840) and the Law of Minimum (1862), which are valid till today and become the basis of targeted yield concept.

Various approaches for calibration of soil test values for fertilizer recommendation are as follows:

2.2.1 Mitscherlich's approach

Relationship between yield, added fertilizer and amount of nutrient present in soil was mathematically expressed by the Mitscherlich's equation "the law of the soil" and later as "the law of the action of the growth factors".

Mitscherlich (1909) derived the 'law of diminishing return' which was based on the assumption.

$$\frac{dY}{dX} = C\,(A - Y)$$

Where,

dY= Increase in yield caused by small increment of growth factor X

dX = Increment of growth factor X

A = Maximum yield under optimum supply of growth factors

C = Proportionality constant, called efficiency factor

The integration of the above equation leads to:

$$\log (A-Y) = \log A - CX$$

Where,

Y = Yield obtained with X quantity of growth factors

X = amount of growth factor

Range of C = 0-30

According to Mitscherlich's equation, the value of C is same for a soil as well as for a fertilizer form of nutrient.

2.2.2 Mitscherlich-Bray equation

However, **Bray (1944)** suggested that the efficiency factor (C) depends on nature of growth factor and has different values for soil and nutrient sources. He modified the Mitscherlich's equation as:

$$\log (A-Y) = \log A - C_1 b - CX$$

Where,

A= Maximum yield when all nutrients are present in adequate quantities

Y = Yield obtained with nutrient b, when it is less than adequate.

C_1 = Efficiency factor for nutrient, supplied by soil

X = Quantity of fertilizer nutrient

C = Efficiency factor for method of applying the fertilizers

This equation gave only the effect of growth factor on the yield of plants. It did not take into account that different types of plants grown on the same soil give different yield **(Wilcox, 1949)**.

2.2.3 Targeted yield approach

Concept of fertilizer prescriptions for desired targeted yields based on the available nutrient status was first put for- ward by **Truog (1960)**. **Ramamoorthy *et al.* (1967)** established theoretical basis and experimental verification for the principle of fertilizer application for the targeted yield of field crops. Among the various methods of fertilizer recommendation , the one based on yield targeting is unique in the sense that it method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve if good agronomic practices are followed in raising the crop. The essential basic data required for formulating fertilizer recommendation for targeted yield are:

i. Nutrient requirement (NR) per quintal of grain (economic yield) production

ii. Percent contribution of nutrient from soil (Cs)

iii. Percent contribution of nutrient from targeted fertilizer or fertilizer use efficiency proportion (C_F)

Targeted fertilizer or yield equation functions properly when

i. Used for similar soils of particular agro-eco region.

ii. Maximum target should not exceed 75-80 per cent of the highest yield achieved of the crop in the area.

iii. Fertilizer nitrogen recommendation for legumes should be same as general dose of the crop of area.

iv. Adjustment equation must be made within experimental range of soil test values.

v. Good and recommended agronomic practices to be followed.

vi. Secondary and micronutrients are not limiting in soil

vii. For obtaining the real benefit of fertilizer application based on targeted yield approach, soil testing need to be done as frequently as possible.

2.2.4 Multiple regression approach

A wide variation in the soil fertility is created at one and the same location and the complex experiments are conducted at few such locations **(Ramamoorthy and Velayutham, 1971)**.

In this approach, the data generated at few of these selected locations in the country are to be pooled to refine these calibrations to include other variations in soil, climate and varietal parameters. The field experiments, statistical design and treatment combinations have been framed in such a way as to account for local and area wise heterogeneity in the soil, interaction of soil and fertilizer form of nutrients and interactions of nutrients among themselves. All care is taken to avoid any intrapolation or extrapolation of data and efforts made to cover wide fertility range and response to very low and very high fertilizer doses. Work under the All India Coordinated Research project on soil test crop response correlation had shown that instead of usual response types following the law of diminishing return, there are as many as eight types of response functions that are possible **(ICAR, 1974)**.

The multiple regression enables fertilizer recommendation based on soil tests to be very dynamic to meet various demands of the country from time to time for (i) maximum yield per hectare (ii) maximum profit per hectare at varying input and produce prices and (iii) maximum profit per rupee invested on fertilizer. Another feature of this dynamic approach is being made to develop and extend a methodology for making fertilizer recommendation for varying yield targets which are particularly suited to the situation of resource constraint in India and other countries.

It may be concluded that this approach seems more logical and practical under Indian conditions. Periodical assessments of the reproducibility and utility of the data, however, are not ruled out. In the present investigation of fertilizer requirement and nutrient use efficiency, therefore, the multiple regression approach as per the methodology evolved by the 'All India Coordinated Soil Test Crop Response Project.

2.2.5 Diagnosis and recommendation integrated system (DRIS) approach

It is an approach proposed by **Beaufils (1973)**, DRIS is a perfect combination of soil test and plant analysis. It defines all the nutritional factors that retard crop production. Nutrient concentration changes with the physiological growth stage of plant and varies in different plant parts. Here the results of plant analysis are compared with critical nutrient concentration.

2.2.6 Integrated nutrient management (INM) concept

Indiscriminate use of chemical fertilizers adversely affects soil health, sustainability of agricultural production and causing environmental hazards. It is a sustainable agricultural system which includes the conjunctive use of chemical fertilizer along with soil organic matter, biofertilizers, vermicomposts, animal manures, crop residues, green manures, sewage sludge and food industry wastes etc without deterioration of soil health. Five basic principles of sustainable integrated

Nutrient management system may be described as **(Meelu, 1996).**

(i) Nutrient removed must be returned to the soil.

(ii) Organic carbon levels should be maintained and enhanced.

(iii) Soil physical conditions should be maintained and upgraded.

(iv) Build up of abiotic stress should be minimal.

(v) Degradation of land due to soil erosion must be controlled.

2.2.7 Site specific nutrient management (SSNM) approach

Considerable progress has been made in recent years in developing site-specific nutrient management (SSNM) approach, as alternative to blanket recommendations for NPK fertilizers **(Buresh *et al.,* 2005; Dobermann and Fairhurst, 2000)**. For increasing nutrient use efficiency it is therefore essential to match the dynamic crop demand with nutrient supply. Thus, the site-specific nutrient management (SSNM) approach allows working out fertilizer recommendations on a field specific basis to account for the variability in indigenous nutrient supply and yield target.

There are five cardinal principles of site-specific nutrient management:

Principle 1: Balanced fertilization based on crop requirements

Principle 2: Plant based estimation of soil nutrient supplies

Principle 3: Need based fertilizer N management

Principle 4: Sustainable P and K management

Principle 5: Increasing profitability

A nutrient decision support system (NuDSS) based on SSNM principles have recently been developed by **Witt *et al.* (2005)**. This is generic decision support system for irrigated rice. This software combines various models into one user-friendly package to deliver recommendation for efficient fertilizer use, high and sustainable yield and increased farmer profit.

2.2.8 System for quantitative evaluation of the fertility of tropical soils (QUEFT)

In this system, chemical soil fertility is conceived as the capacity of a soil to provide plants with nutrients. In many unfertilized soils, crop growth is limited by a low supply of one or more of the major nutrients N, P and K, while there is a relatively ample supply of secondary and trace elements. Therefore the QUEFTS system is as yet restricted to an appraisal of the status of N, P and K **(Janssen *et al.*, 1990).**

This system is described for a quantitative evaluation of the native fertility of tropical soils, using calculated yields of unfertilized maize as a yardstick. The system is applicable to well drained, deep soils, that have a pH in the range of 4.5-7.0, and values for organic carbon, Olsen's –P and exchangeable potassium below 70 g kg^{-1}, 30 mg kg^{-1} and 30 mmol kg^{-1}, respectively (0-20 cm). Soil fertility is interpreted as the capacity of a soil to provide plants with nitrogen, phosphorus and potassium, but the methodology allows for including other nutrients.

The procedure consists of four successive steps. First the potential supplies of nitrogen, phosphorus and potassium are calculated, applying relationship between chemical properties of the 0-20 cm soil layer and the maximum quantity of those that can be taken up by maize, if no other nutrients and no other growth factors are yield-limiting. In the second steps the actual uptake of each nutrient is calculated as a function of potential supply of that nutrient, taking into account the potential supplies of the other two nutrients. Step 3 comprises the establishment of three yield ranges, as depending on the actual uptake of nitrogen, phosphorus and potassium, respectively. Next, these yield ranges are combined in pairs, and the yield estimated for pairs of nutrients are averaged to obtain an ultimate yield estimate (Step 4). The relationship used in Steps 1 and 3 were derived from empirical data of field trials in Suriname and in two strongly different agro-ecological zones in Kenya. The equations developed for Steps 2 and 4 were mainly based on theoretical considerations. The equation used to calculate the potential supplies of nutrients (Step 1) should be applied only to soils with the indicated properties. The other equations are more generally applicable. QUEFTS may be a very useful tool in quantitative land evaluation. Its principles may be applied to other crops, soils, nutrients and agro-ecological regions than those involved in this study.

2.3 Response of soil and applied N, P, K and FYM on growth, yield and quality of turmeric

2.3.1 Growth and Yield

Meerabai *et al.* (2000) was reported that higher yields for turmeric grown with higher doses of N and K applied in a balanced manner. Application of 120-120-2-10 kg N-K_2O-B-Zn ha^{-1} resulted in the highest average rhizome yield of 19.8 t ha^{-1} over two years, produced maximum economic yield. **Nath and Karla (2000)** calculated economics of ginger and found maximum net profit (Rs. 97,175) and cost benefit ratio of ginger with application of 100:50:50 kg ha^{-1} NPK along with biofertilizers.

Meenakshi *et al.* (2001) stated that application of varying levels of P_2O_5 and K_2O increased the height of plant, number of tillers, number of leaves, leaf area and total dry matter production and enhanced the levels of P_2O_5 and K_2O besides resulted in higher growth rate in turmeric.

Yamgar *et al.* (2001) performed a field study at Akola, Maharashtra and found that maximum plant height, number of leaves, leaf length and green rhizome yield was obtained at 200:100:100 kg NPK ha^{-1}, respectively. Application of FYM (5 t/ha) resulted in the highest plant height (47.55 cm), number of leaves (15.4) and number of tillers (3.8) in turmeric **(Selvarajan and Chezhiyan, 2001).**

Baghla (2001) studied the integrated nutrient management for turmeric in an acid soil of Palampur, Himachal Pradesh and reported that the rhizome yield increased with increasing nutrient doses of N, P and K. The highest yield (110 q ha-1) was obtained in the treatment where N, P and K were applied at the rate of 60, 30 and 60 kg ha-1, respectively, along with 10 tonnes of FYM ha-1.

Majumdar *et al.* (2002) reported in an acidic soil of ICAR complex at Umiam, Meghalaya, the rhizome and straw yield of turmeric enhanced significantly with addition of farmyard manure at each level of applied N, and maximum rhizome and straw yields were recorded at 90 kg of N ha^{-1} with 5 tonnes FYM ha^{-1}. Addition of farmyard manure provided additional rhizome yield of 0.3-0.48 tonnes ha^{-1}**.**

The application of 130 kg N + 90 kg P_2O_5 + 70 kg K_2O ha^{-1} resulted in highest yield of turmeric (350.6 q ha^{-1}) as revealed by **Dubey and Yadav (2001)** while the growth and yield potential of turmeric increased by the application of NPK at the rate of 75:60:150 kg ha^{-1}, correspondingly in a study at Allahabad, Uttar Pradesh **(Thomas *et al.*, 2002).**

Velmurugan (2002) stated that the combined application of FYM along with bio-fertilizers expressed tallest plants with more number of tillers, more number of leaves and greater leaf area. **Thomas *et al.* (2002)** conducted a experiment on turmeric variety Suvarna with three levels of nitrogen (45, 60 and 75 kg ha^{-1}) and three levels of potassium (90, 120 and 150 kg ha^{-1}) at Allahabad, indicated that the growth and yield potential of the crop can be increased by applying NPK at the rate of 75:60:150 kg ha^{-1}and also recorded that the highest fresh weight (458.9 g) of the rhizome was found when plants were supplied with 75 kg N ha^{-1} and 150 kg K_2O ha^{-1}.

Velmurugan *et al.* (2002) obtained greater rhizome yields due to the application of FYM (30 t ha-1) along with Azospirillum (10 kg ha^{-1}) + Phosphobacteria (10 kg ha^{-1}) + VAM (500 kg ha^{-1} and also exhibited greater net returns and benefit cost ratio with lesser cost of cultivation. **Majumdar *et al.* (2002)** found that the combination of 90 kg N along with 5 tonnes of farmyard manure was optimum for higher turmeric production (3.33 t ha-1).

Medda and Hore (2003) was conducted an experiment on turmeric carried out at Naidie, West Bengal**,** it was revealed that N and K both independently and in their interactions behaved positively in terms of different growth and yield attributing characters. The application of both the nutrients produced a progressive trend in increasing the rhizome yield and maximum yield of 332 q ha^{-1} was recorded under treatment combination of 200 kg each of N and K ha^{-1}.

Sharma *et al.* (2003) conducted a field experiment in a clay loam soil at Jabalpur, Madhya Pradesh, to study the effect of organic manures and chemical fertilizers alone and in amalgamation with each other on yield of turmeric. They revealed that application of chemical fertilizers decreased turmeric yield in succeeding year whereas; addition of organics (either vermicompost or FYM) enhanced the yield of turmeric by 7 to 10 per cent over preceding year.

In a field study, **Jadhao *et al.* (2005)** found that the highest turmeric rhizome yield of 49.12 q ha^{-1} was obtained in the treatment combination of 120:60:60 kg of NPK ha^{-1}, respectively, while in another a field study at Palampur Himachal Pradesh, **Dixit and Bhardwaj (2006)** reported that highest turmeric rhizome yield of 193.3 q ha^{-1} was recorded at 150 % NPKSMg +15t FYM ha^{-1}.

Kandiannan and Chandaragir (2006) conducted a experiment in well-drained sandy loam soil with irrigation at Agricultural Research Station, Bhavanisagar, during 2000-01 and 2001-02 and they observed that higher nitrogen produced taller plants with more leaf area index and dry matter production. Higher N level promoted the growth on an average and high rate of N recorded 21.0 and 10.4%

higher dry matter production at harvest than 125 and 150 kg N/ha, respectively. The fresh and dry rhizome yields were higher under 175 kg N/ha compared to 125 and 150 kg N/ha.

Madhuri *et al.* (2006) conducted studies on the effect of organic manure and biofertilizers on growth and yield of turmeric at Nagpur during 2003-2004. Application of $N:P_2O_5:K_2O$ at 120:60:60 kg ha^{-1} recorded higher plant height, number of leaves, size and surface area of leaves, number of tillers $plant^{-1}$ and fresh yield (t/ha) of turmeric over FYM applied at 10 t ha^{-1} in combination with bio-fertilizer.

Velmurugan *et al.* (2007) stated that combined application of FYM along with Azospirillum + Phosphobacteria + VAM recorded the supremacy for yield attributes viz., more number of mother rhizomes $plant^{-1}$ (3.98), more number of primary rhizomes $plant^{-1}$ (13.19) and secondary rhizomes $plant^{-1}$ (19.89).

Sanwal *et al.* (2007) stated that the application of 90:60:90 kg N, P_2O_5 and K_2O ha^{-1} produced 21.58 fingers $plant^{-1}$ exhibiting a weight of 430.00 g $plant^{-1}$ with a overall total yield of 29.58 t ha^{-1}.

Akamine *et al.* (2007) reported that separate application of P and K could not increase growth and yield of turmeric, whereas N alone increased both growth and yield. The combined application of N and K (NK) or N, P and K (NPK) provided 4 to 6 times greater shoot biomass and 8 to 9 times higher yield.

Haque *et al.* (2007) conducted a field study of nitrogen (N) and potassium (K) on turmeric was carried out at South-Eastern hill soils at Hill Tracts Agricultural Research Station, Ramgarh, Khagrachari to evaluate the response of turmeric to various levels of N and K. It is revealed that N and k both either in single or in combination had significant effect on yield and yield contributing characters of turmeric. It was also observed that turmeric was found to be more responsive especially to N and K. However, the combined effect of N and K and increased the yield and other yield parameters up to N180 K100 kg/ha and significantly differed over control (N0K0). The highest plant height (110.2cm and 107.3cm), maximum leaves number per plant (13.8 and 14.3 /plant) and number of fingers (55.10 and 46.8 /plant) were recorded with N180 K100 kg/ha. Similarly, finger size, finger weight and yield were also significantly influenced by applying N and K. The highest finger size

(8.7cm x 8.3cm and 8.6cm x 8.7cm), maximum finger weight (450g and 457g /plant), the height turmeric yield (26.7 t/ha and 28.2 t/ha) and the mean yield 27.45 t/ha was recorded by said treatment combination of N180 K100 kg/ha which was highly differed over other treatment and control (N0K0).

Halder *et al*. (2007) done a field study of Zn and B on the yield of turmeric was carried out at Brown Hill Soils (Eutrochrepts) of South Eastra Hilly region of at Hill Tracts Agricultural Research Station, Ramgarh, Khagrachari during the Kharif season of 2001-2005, respectively. The objective was to evaluate the response of turmeric to Zn and B fertilization. Four levels of B (0, 1, 2 & 3 $kgha^{-1}$) and four levels of Zn (0, 1.5, 3 & 4.5 $kgha^{-1}$) oxide were included in this study. A combined blanket dose of N_{130}, $P_{35,}$ $K_{8,}$ S 20kg and CD 5 tha^{-1} were also mixed in all the treatments plots. It was evident from two years study that both Zn and B either in single or in combination had significant effect on the growth and yield attributes of turmeric in Zn-B deficient soil at experimental site. B produced approximately 11 & 18.19 percent higher yield than Zn in both the year. However, the highest turmeric yield (21.4 & 25.5 tha^{-1}) was recorded with the maximum B level (B_{30} $kgha^{-1}$) which was 79.58 percent higher over B control (B_0) while Zn produced 28.57 & 66.43 percent higher yield compared to Zn control (Zn_0 Treatments). However, the integrated effect of Zn and B was found to be highly responsive and markedly dominated the turmeric yield and their yield attributes.

Bose *et al.* (2008) observed that a significant increase in the weight of the mother rhizome of turmeric at the 44 kg S ha^{-1} and 22 kg Mg ha^{-1} dose, which then declined with further increases in S and Mg levels. Significant variation in weight of primary fingers was observed due to S and Mg applications, also peaking with 44 kg S ha^{-1} and 22 kg Mg ha^{-1}. No significant effect was found on percent dry weight or curcumin content.

Karthikeyan *et al.* (2009) conducted a field experiment in Inceptisol at Tamil Nadu for the effect of potassium on the yield and quality of turmeric. They observed that increasing the application rate of potassium in the form of KCl enhanced growth, nutrient uptake and utilization, increasing yield and quality of turmeric. The application of 260 kg K_2O ha^{-1} should be recommended.

Banwasi and Singh (2010) conducted a field experiment at Raigarh (Chattisgarh) to study the effect of five levels of phosphorus (0, 50, 100, 150 and 200 kg P_2O_5 ha^{-1}) on growth and yield of turmeric (*Curcuma longa*) (var. TCP-1). A common dose of N @ 150 kg ha^{-1}and K_2O @ 120 kg ha^{-1}was applied in all the treatments. Application of phosphorus significantly influenced various growth characters and yield. The highest yield of fresh rhizome (156.3 q ha^{-1}) was recorded with application of 150 kg P_2O_5 ha^{-1} followed by 149.2 and 147.9 q ha^{-1} rhizomes with application of 100 and 200 kg P_2O_5 ha^{-1}, respectively. These treatments were significantly superior over other treatments and on par with each other. However cost : benefit ratio was highest in the treatment with application of 150 kg P_2O_5.

Dhanbir and Dixit (2010) observed the highest germination percentage (87.5), number of fingers rhizome-1 (5.95), turmeric rhizome yield per plant (151.3 g) and total rhizome yield (150.8 qha^{-1}) were recorded in 100% NPKS+20t FYM ha^{-1} as soil mulch. Maximum plant height of 112.8 cm and straw yield of 16.0 q ha^{-1} were recorded in integrated treatment of 100% NPKS + 20t FYM as soil incorporation. Highest N and K concentration in turmeric rhizome were registered in 100 % NPKS + 20 t FYM ha^{-1} as soil mulch whereas, maximum P and S concentration were recorded in 100 % NPKS + 20t FYM ha^{-1} as soil incorporation.

Singh *et al.* (2010) represent an investigation on turmeric (*Curcuma longa* L.) was carried out to study the effect of organic, inorganic manure and bio-fertilizers on turmeric with reference to rhizome yield and its attributes. The study revealed that, turmeric showed better response to the application of organic, inorganic and bio-fertilizer. The combined application of inorganic N (10%) + Azospirilum + FYM 5t ha^{-1} recorded the supremacy for yield attributes of turmeric**.**

Manhas and Gill (2010) conducted a field experiment during 2007–08 and 2008–09 to study the effect of different planting materials, mulch levels and farmyard manure on growth, yield and quality of turmeric. Application of 45 tonnes/ ha farmyard manure produced significantly more number of mother, primary, secondary and total rhizomes/plant compared to 30 tonnes/ha and also observed the highest weights of mother, primary, secondary and total rhizomes/plant were recorded with 45 tonnes/ha farmyard manure. When FYM was applied @ 45 tonnes/ha farmyard manure resulted in significant increase in fresh, dry and processed rhizome yield compared to 30 tonnes/ha farmyard manure treatment during both the years

Yanthan *et al.* (2010) reported that the most profitable treatment combination was 50% NPK + 50% pig manure followed by 50% NPK + 50% FYM which resulted in maximum cost benefit ratio 1:4.35 and 1:4.31, respectively. The net return obtained due to 50% NPK + 50% pig manure treatment was observed to be higher by Rs.62,499/- over control suggesting the better economics of fertilizer use. The net return was invariably high with combined application of organic manures and inorganic fertilizers.

Kamal and Yousuf (2012) was carried out to evaluate the effect of different organic manures on turmeric with reference to vegetative growth, biomass production, rhizome yield and its attributes of turmeric (*Curcuma longa* L.). Turmeric showed better response to the application of organic manures. Plant with neem cake application had the taller plant (79.30 cm), maximum number of tillers per plant (5.40), leaf number (5.40), leaf area (44.09) leaf area index (0.429), fresh weight of halum (190.05g), fresh weight of root (49.13 g), fresh weight of rhizome per plant (256.21 g) and dry weight of halum (15.21g), dry weight of root (7.32 g), dry weight of rhizome per plant (40.35 g), total dry matter yield (6.85 t ha-1) than those received other types of manures. Moreover, yield attributes such as number of mother rhizomes per plant-1 (1.75), more number of primary rhizomes per plant-1 (5.19), secondary rhizomes per plant-1 (18.03) and tertiary rhizomes per plant (7.69) were also highly accelerated by neem cake application. Similarly, the same treatment expressed the best in terms of size of mother rhizome (7.69 cm), primary rhizome (21.86 cm) and secondary rhizomes (7.05 cm). All these parameters in cumulative contributed to produce the highest estimated fresh rhizomes yield & cured rhizomes yield (29.48 t ha-1, 5.59 t ha-1 respectively). The highest curing percentage (20.28) was observed in T3 treatment having mustard cake@ 2.0 t/ha.

Somasundaram and Shanthi (2014) conducted a field experiment at Tamil Nadu to study the effect of organic sources of nutrients on growth, yield and quality parameters of turmeric. The results showed that higher Leaf area index (LAI) of 12.30 at 180 days after planting (DAP) and rhizome yield (26,076 kg ha^{-1}) was recorded with the application of 100% RDF + 40% Wellgro soil. Similarly application of Wellgro soil and chemical fertilizer registered higher curcumin, oleoresin and essential oil content (4.34, 9.38 and 3.82, respectively), which was on par with 75% RDF + 40% Wellgro pellets. Higher benefit cost ratio (2.82) was also recorded with the application of 100% RDF + 40% wellgro soil.

Chamroy *et al.* (2015) conducted an experiment during the year 2011-2012 at Vegetable Research Farm, Department of Horticulture, Sam Higginbotom Institute of Agriculture, Technology and Sciences (SHIATS), Allahabad (U.P.), India; to evaluate the effect of organic and inorganic manurial combinations on turmeric (*Curcuma longa* L.). The different treatment combinations i.e. T1 : 75% N through urea + 25% N (Vermicompost), T2 : 75% N (urea) + 25% N (Poultry manure), T3 : 75% N (urea) + 25% N (Farmyard manure), T4 : 50% N (urea) + 50% N (Vermicompost), T5 : 50% N (urea) + 50% N (Poultry manure), T6 : 50% N (urea) + 50% N (Farmyard manure), T7 : 25% N (urea) + 25% N (Vermicompost), T8 : 25% N (urea) + 25% N (Poultry manure) and T9 : 25% N (urea) + 25% N (Farmyard manure) and T0 : full dose of RDF with chemical fertilizers (60 : 50 : 120 kg NPK/ha) were used. The results clearly indicate that the treatment T5 significantly increased plant height, leaf length, leaf width, leaf area, number of leaves/plant and number of tillers/clump followed by T4 over the control. The highest fresh rhizome yield (154.18 q/ha), dry rhizome yield (34.73 q/ha) and curcumin content (5.2%) were recorded in the treatment T5.

Modupeola and Olaniyi (2015) conducted a field experiment at Ibadan to determine effects of Nitrogen (N) fertilizer and plant spacing on the growth and rhizome yield of Turmeric (*Curcuma longa* L.) in south-west Nigeria. The treatments consist of five nitrogen fertilizer rates: 0, 60, 90, 120 and 150 kg N ha^{-1} applied in the form of urea and three plant spacing: 25×20cm, 25×25cm and 25×30cm**,** with turmeric as the test crop. The results showed significant ($P \leq 0.05$) influenced of N fertilizer and plant spacing on turmeric growth and rhizome yield. Application of 120 kg N ha^{-1} with 25x25 cm plant spacing produced the best rhizome yield of 70 t ha^{-1} while the least yield of 28 t ha^{-1} was obtained from 0 kg N ha^{-1} with 25x30 cm spacing (widest spacing). During the cropping period, turmeric produced total yield of 70 t ha^{-1}. It was concluded that application of N fertilizer applied at 120 kg ha^{-1} with plant spacing at 25x25cm will enhance the growth and yield of turmeric.

Ahirwar *et al.* (2015) conducted a field experiment at Madhya Pradesh for the study on effect of nitrogen and potassium on growth, yield and nutrients uptake of turmeric Roma, PCT-8 and Suroma genotypes. Roma recorded the fresh rhizome yield (101.72 q ha^{-1}) with net income of Rs. 474564 ha^{-1}. Fertility level upto $N_{200}K_{200}$ resulted in maximum growth, yield attributes and rhizome yield (100.90 q ha^{-1}) with net income of Rs. 468560 ha^{-1}. Thus, Roma may be grown with $N_{200}K_{200}$ to achieve maximum profit under the existing agro-climatic conditions. Roma producing 101.72 q ha^{-1} fresh rhizomes took up the maximum nutrients (162.0 kg N, 53.6 kg P and 109.9 kg K ha^{-1}). Application of $N_{200}K_{200}$ resulted in highest uptake of N, P and K (158.6 kg N, 51.9 kg P and 107.8 kg K ha^{-1}).

2.3.2 Nutrient content and uptake

The crop growth period of turmeric can be divided into four phases: a phase of moderate vegetative growth, a phase of active vegetative growth, a period of slow vegetative growth and a phase approaching senescence. Uptake of nutrients by turmeric is influenced by many factors *viz.* dry matter yield, nutrient content, applied nutrient, and soil test value etc.

Peter *et al.* (2000) reported that maximum nutrients uptake in turmeric was observed in active vegetative growth phase. Higher uptake of K up to third, N up to fourth and P up to fifth months of development was observed with subsequent decrease in their uptake. The uptake of nutrients in turmeric was in the order of potassium > nitrogen > magnesium > calcium.

Baghla (2001) in a field study at Palampur, H. P. found that N, P and K uptake increased with addition of 10t FYM ha^{-1} over control by 40, 38 and 35 per cent, respectively. In an another study on the nutritional requirement of turmeric at Palampur, N, P, K and S uptake amplified with the use of 15t FYM ha^{-1} as compared to control treatment with enhancement of 23, 46, 41 and 15 per cent, respectively **(Sood, 2003).**

Velmurugan *et al.* (2007) confined an experiment analysis that the application of FYM (30 t ha^{-1}) along with Azospirillum (10 kg ha^{-1}) + Phosphobacteria (10 kg ha^{-1}) + VAM (500 kg ha^{-1}) recorded highest nitrogen content (0.87 per cent), phosphorous content (0.21 per cent), nitrogen uptake (291.74 kg ha^{-1})

and phosphorous uptake (70.42 kg ha^{-1}). However, the application of digested coir pith compost (10 t ha^{-1}) + Azospirillum (10 kg ha^{-1}) + Phosphobacteria (10 kg ha^{-1}) + VAM (500 kg ha^{-1}) expressed greater potassium content (0.90 per cent) and potassium uptake (285.05 kg ha^{-1}).

Yanthan *et al.* (2010) conducted a field experiment to evaluate the sole and integrated effect of nutrient application in ginger. Maximum uptake of nitrogen (141.05 kglha) was observed with treatment combination 50% NPK+ 50% pig manure. However, maximum uptake of phosphorus (15.38 kg ha^{-1}) and potassium (214.03 kg ha^{-1}) was recorded with 50% NPK +50% FYM and was at par with 50% NPK+ 50% pig manure and 100% FYM + *Azospirillum.*

Ahirwar *et al.* (2015) reported that the maximum N, P and K uptake was 162.0, 53.6 and 109.9 kg ha^{-1}, respectively. The significant increase in the uptake of NPK in turmeric (Var. Roma) might be due to similar increases in NPK contents in rhizomes as well as increased rhizome yields. The similar trend was also followed in other turmeric varieties viz., PCT-8 and Suroma genotypes which ranked in the second and third positions, respectively. The fertility levels did not affect the N uptake upto significant extent, whereas P and K uptake were influenced significantly due to fertility levels. The highest fertility level (N200K200) resulted in maximum uptake of N (158.6 kg ha-1), P (51.9 kg ha-1) and K (107.8 kg ha-1). In case of P and K uptake by rhizomes, higher fertility levels (N200K100, N200K150 and N200K200) proved significantly superior to the lower fertility levels (N100K100, N100K150 and N100K200). The increased uptake of NPK due to increased levels of applied N and K was due to increase in the NPK contents in rhizomes as well as increased rhizome yield. They also found that amongst the three genotypes of turmeric (Roma, PCT-8 and Surona), Roma gave the maximum net income (Rs. 474564 ha^{-1}) and B:C ratio (4.50). The second best genotype was PCT-8 giving a net profit of Rs. 461350 ha^{-1} with B:C ratio 4.40. Suroma stood the third best genotype. The difference in net income amongst the genotypes was in accordance with the variation in their rhizome yield.

Srinivasan *et al.* (2016) conducted a field experiments for three years from 2010 to 2013 involving three nutrient management regimes viz., organic nutrient management (ONM) involving application or organic manures (Farmyard manure + neem cake + vermicompost + ash + Azospirillum lipoferum + Pseudomonas fluorescens), conventional nutrient management (CNM) involving application of inorganic fertilizers (60–50–120 kg ha^{-1} NPK applied as diammonium phosphate and muriate of potash, respectively) and integrated nutrient management (INM) involving a combination of inorganic fertilizers (50% N + full dose of P and K, i.e. 30–50–120 kg ha^{-1} NPK) and organic manure (20.0 t ha^{-1} FYM + Bacillus megaterium var. Phosphaticum). Most of the nutrient elements (N, P, K) registered significantly higher uptake levels in the INM treatment. Among the three treatments, the ONM treatment registered the lowest N, P and K uptake (54.42, 14.34 and 63.40 Kg ha^{-1}), respectively. As stated earlier, greater nutrient uptake by the crop in the INM i.e. 66.69, 15.79 and 6.60 Kg ha^{-1} N, P and K uptake, respectively, treatment indicated good synchrony between nutrient release and crop requirement during the active vegetative growth stage.

2.3.3 Quality parameters

Nandlal (2000) reported that the application of 20 tonnes of farmyard manure in conjunction with 30 kg each of N and P_2O_5 and 60 kg K_2O ha^{-1} improved the quality parameters of turmeric rhizomes like protein and curcumin content. Further, there was an improvement of 19.8 and 4.6 per cent in both due to application of potassium at the rate of 60 kg ha^{-1} over control. In another study, curcumin production was maximum in FYM +1/2 as Gafasa phos (GP), which was at par with FYM + Raj phosphate (RP) or Mussorie rock phosphate (MRP) treatments **(Srinivasan *et al*., 2000).**

Kumar *et al.* (2000) revealed that N, P, S, Ca, Mg, Fe, Mn, Zn, and Cu had no significant correlation with curcumin content in turmeric rhizomes. The increased availability of phosphorus increased proportion of curcumin in turmeric. The curcumin content of 3.64 per cent was recorded at highest dose of P and K (100:100 kg ha-1) and was 16 per cent higher than the control **(Meenakshi *et al*., 2001).**

Nampoothiri (2001) found that organic manure application had great influence on yield (13.5 t/ha), curcumin (4.03%), oleoresin (10.1%) and curing percentage (21.4%) compared to chemical manuring in turmeric. **Sharma *et al.* (2001)** in an experiment on turmeric in acid soil of Palampur, H.P. found that the quality parameters of turmeric such as curcumin and protein content improved with the application of phosphorus and potassium. The improvement in curcumin and protein content was 33.9 and 37.6 per cent due to application of phosphorus at the rate of 30 kg P_2O_5 ha^{-1} and 19.8 and 4.6 per cent due to the application of 60 kg K_2O ha^{-1}, respectively, as compared to control.

Manjunathgoud *et al.* (2002) in a field study at Bangalore found that the curcumin content of turmeric increased (from 3.42 to 3.65 %) with increased fertilizer levels i.e. zero to 150:125:250 kg NPK ha^{-1}, in the respective order. **Jadhao *et al.* (2005)** in a field study found that the highest curing percentage (19.18 %) and curcumin content (5.50 %) were acquired in the treatment combination of 120:60:60 kg of NPK ha^{-1}, respectively.

Sharma *et al.* (2002) obtained the highest curcumin content (5.67 per cent) mainly due to the application of 10 t ha^{-1} of FYM than application of 60 K_2O ha^{-1} (4.61). However, **Thomas *et al.* (2002)** observed that maximum curing percentage of 29.17% was found with 75 kg N ha^{-1} and 150 kg K_2O ha^{-1}.

Venkatesh *et al.* (2003) found that application of both rock phosphate and SSP in 1:1 proportion along with FYM (10 t/ha) produced the highest dry yield (46.0 q/ha), while highest curcumin (6.02%) was recorded with the application of rock phosphate + SSP (1:3) along with FYM (10 t/ha) in turmeric.

Tripathi and Hazara (2003) found that oil and protein content groundnut pods were greatly improved with sulphur application over no sulphur application in the soil. The average data of two years indicated that the magnitude of increase being 7, 10, 11% in oil and 6, 9, 11%, in protein on course Alfisol at the level of 15, 30 and 45 kg S ha^{-1} over control plots.

Sood (2003) investigated that maximum curcumin content was recorded in the treatment combination of 150 per cent NPKS along with 15 tonnes FYM ha^{-1}. The starch content also increased with increasing levels of nutrients in both the years and the application of N, NP, NPK and NPKS increased the starch content of turmeric rhizomes over control. Similar trend was observed in case of protein content.

Jadhao *et al.* (2005) in a field study found that the highest curing percentage (19.18 %) and curcumin content (5.50 %) were acquired in the treatment combination of 120:60:60 kg of NPK ha-1, respectively.

Dixit and Bhardwaj (2006) reported that the highest curcumin content was recorded at 150 % NPKSMg (3.38 %) which was significantly at par with 125 % NPKSMg (3.38 %) and 100 % of NPKSMg (3.32%). They further reported that addition of sulphur did not increase curcumin content substantially in turmeric rhizomes and the per cent augment in curcumin content was 3, 7, 15, 16 with 100 % each of recommended N, NP, NPK and NPKS over control. **Sanwal *et al.* (2007)** opined that the application of 90:60:90 kg N, P_2O_5 and K_2O ha^{-1} produced maximum curcumin content (6.27 per cent) in turmeric.

Kamal and Yousuf (2012) observed that highest curing percentage (20.28) was excelled by the treatment having mustard cake@ 2.0 t/ha followed by treatment having cowdung @ 15 t ha^{-1}. With regard to curcumin recovery percentage on turmeric, among the treatments, neem cake gave highest (3.73%) followed by treatment with mustard cake @2.0 t ha-1(3.76%).

Chamroy *et al.,* (2015) observed the maximum curcumin content (5.20%) was found in T5 (50% N through urea + 50% N through poultry manure) followed by T4 (50% N (urea) + 50% N (Vermicompost),) i.e. 5.13%. **Srinivasan *et al.,* (2016)** observed the rhizome quality was measured in terms of volatile oil content, oleoresin content and curcumin content. Across the three years, oil content varied from 1.87–3.46% (mean 2.44 ± 0.88) in Organic Nutrient Management (ONM), 2.11–3.38% (mean 2.66 ± 0.65) in CNM and 2.17–3.53% (mean 2.67 ± 0.75) in INM. Oleoresin content varied from 11.88–12.40% (mean 12.06 ±0.29%) in ONM;11.00–12.05% (mean 11.55 ± 0.53%) in CNM and 11.58–12.50%(mean 12.13 ± 0.48%) in INM and curcumin content varied from4.57–5.42% (4.93 ± 0.45%) in ONM, 4.25–5.60% (mean 4.95 ± 0.68%)in CNM and 4.09–5.29% (mean 4.66 ± 0.60%) in INM.

2.4 Effect of applied Nitrogen, Phosphorus and Potassium on soil fertility status

2.4.1. Available Nitrogen

Continuous cropping for five years slightly increased the available N with the use of fertilizer N in combination with P and K fertilizer, however, available N content of soil significantly increased with green manuring and FYM treatments **(Yaduvanshi, 2001).**

Bhandari ***et al.*** **(2002)** studied the nutrient changes in long term rice-wheat rotation and observed that the nitrogen content decline significant except in the treatments which had received FYM treatment.

Jagtap ***et al.*** **(2007)** observed an increase in the ammonium nitrogen content of soil due to the use of nutrients with FYM. The release of ammonium form of nitrogen was more with the integration of more than one nutrient. The increase in ammonical nitrogen content may result due to application of nitrogen through inorganics and/ or organics (**Begum** ***et al.,*** **2007**).

INM practices increased the available N content in the soil **(Singh. 2007).** INM of tarai soils significantly increased the quality in terms of enhanced ammonical and nitrate nitrogen **(Jagtap** ***et al.,*** **2007).** Application of chemical fertilizers alone resulted in slightly decreased available nitrogen content from initial values **(Babu** ***et al.,*** **2007).** The influence of integrated nutrient management resulted in higher contents of ammonical, nitrate and alkaline $KMnO_4$ oxidizable (available) N in the soil **(Begum** ***et al.,*** **2007). Yanthan** ***et al.,*** **(2010)** reported that Application of 100% NPK recorded the maximum (3063.6 kg ha^{-1}) of residual soi! N followed by FYM @ 20 tonnes/ha (280.5 kg ha^{-1}).

2.4.2. Available Phosphorus

Parasuraman ***et al.*** **(2000)** reported that the phosphorus availability was more in fields of sorghum, which were treated with recommended dose of fertilizer with FYM in comparison to fields, which were treated, with only recommended dose of fertilizer. Continuous application of 100 per cent NPK and its combined use with green manures or FYM, significantly increased available phosphorus. The integrated use of organic manures along with phosphatic fertilizers had resulted not only in the improved efficiency but also resulted in a significant increase in the available P (**Vats** ***et al.,*** **2001**). **Yaduvanshi (2001)** reported that in a *tarai* soil use of chemical fertilizers with and without organics and green manures in rice-wheat cropping system enhanced available phosphorus content in soil. The addition of organic amendments may increase P availability through competition for P binding sites, solubilization of poorly soluble pools and increased solution pH**.** Application of organic manures, green manuring and their integrated use along with chemical phosphatic fertilizers improves efficiency of phosphatic fertilizers levels of available phosphorus in soil. The application of FYM @ 20 t ha^{-1} showed significant increase in available P content of the soil **(Yadav and Chhipa, 2007).**

Yaduvanshi and Sharma (2007) showed that the available P content of the soil increased with the application of wheat residue with organic manures. Application of FYM with inorganic and biofertilizers significantly increased the available phosphorus **(Babu *et al.,* 2007; Jagtap *et al.,* 2007). Yanthan *et al.,* (2010)** observed that the control treatment recorded the lowest (15.4 kg ha^{-1}) residual P content.

2.4.3. Available Potassium

The available K content of soil showed an increase with the continuous application of fertilizer K and organic manures over the initial values **(Yaduvanshi. 2001)** while **Bhandari *et al.* (2002)** observed the declining trend in available pool of K in the soil with continuous rice-wheat cropping system. **Yadav and Chhipa (2007)** conducted an experiment for two consecutive rabi seasons of 2001-02 and 2002-03 on wheat (*Triticum aestivum* L.) as a test crop and they reported a significant increase in the potassium content of the soil with the application of FYM @ 20 t ha^{-1}. **Yaduvanshi and Sharma (2007)** conducted an experiment to evaluate the management of wheat residue with *Sesbania*, green manuring and sulphitation pressmud (SPM) on soil properties and they observed that registered increased available potassium content of soil due to application of wheat residue with organic manures. INM practices improved soil quality over time in terms of potassium content reported by **Singh (2007). Babu *et al.* (2007)** recorded enhanced available potassium content with the application of organic manures. **Yanthan *et al.* (2010)** found that 100% FYM + *Azospirillum* treatment recorded the maximum (220.3 kg ha^{-1}) residual K content followed by vermicompost @ 5 tonnes ha^{-1}and FYM @ 20 tonnes ha^{-1}.

Materials and Methods

Chapter 3 MATERIALS AND METHODS

The details of the materials used and methodology adopted during the research work entitled “Soil Test Crop Response Studies for balanced fertilization of Turmeric (*Curcuma longa* L.) in a Mollisol of Uttarakhand” are described in this chapter.

3.1 Description of Experimental Site

3.1.1 Site

Field experiment was conducted in D_7 block of Norman E. Borlaug Crop Research Centre (CRC), G.B. Pant University of Agriculture and Technology, Pantnagar, Distt. U.S. Nagar, Uttarakhand during 2013-14 and 2014-15, respectively. The experimental field is situated at the foot hills of shivalik range of Himalayas at 29^0 N latitude, $79^0$29’ E longitudes and an altitude of 243.84 m above the mean sea level.

3.1.2 Weather and climate

Climate of this area is humid, sub-tropical with hot and dry summers and cool winters. The monsoon season usually starts from third week of June and extends up to last week of September. Few spell of downpours are generally received during winter season (November to March). The average annual rainfall of the area is 37.41 and 16.48 cm during 2013-14 and 2014-15, respectively. Approximately 70 percent of it is received during rainy season. Total rainfall is 1945.2 (mm) and 857.4 (mm) from April 2013 to March 2014 and April, 2014 to March, 2015, respectively. Mean relative humidity remains almost 70.52 and 68.85 percent from April 2013 to march 2014 and April 2014 to march 2015, respectively. Different weather parameters during the period of experimentation (April 2013 to march 2014 and April 2014 to march 2015,) as recorded at the meteorological observatory located at CRC are depicted in figure 3.1 and 3.2 presented Appendix I & II.

3.1.3 Soil

The soil of the experimental site was classified **(Despande *et al.*, 1971)** as

Order	–	Mollisol
Suborder	–	Udoll
Great group	–	Hapludoll
Subgroup	–	Aquic hapludoll
Family	–	Fine, mixed loamy, hyperthermic
Soil series	–	Pattharchatta Sandy loam

Soils of this region are developed from medium to moderately coarse textured calcareous alluvium brought down from mountains by numerous streams flowing through the *Bhabar* and *Tarai*. These are mainly silty and loamy in texture with weak fine to medium fine granular structure, having good moisture storage capacity and are highly productive.

Soil samples from several spots (0-15 cm. soil depth) were collected from the experimental field before start of the experiment. Composite soil samples were processed and analyzed for various physico-chemical properties (Table 3.1). A profile study was also conducted at experimental site. Detail of the profile study is given in table 3.2. Soil samples from different layers were collected and analyzed for their physical and chemical properties mentioned in table 3.1.

3.1.4. Study of Soil Profile

Soil profile details of experimental site are listed in table 3.2. Other soil characteristics of experimental site were as follows:

- Slope : 1-3%
- Drainage : Moderately well to well drined
- Present land use : Cultivated land.
- Colour : Yellowish brown
- Soil texture : Sandy loam
- Consistency : Moist friable to loose
- Soil Structure : Granular

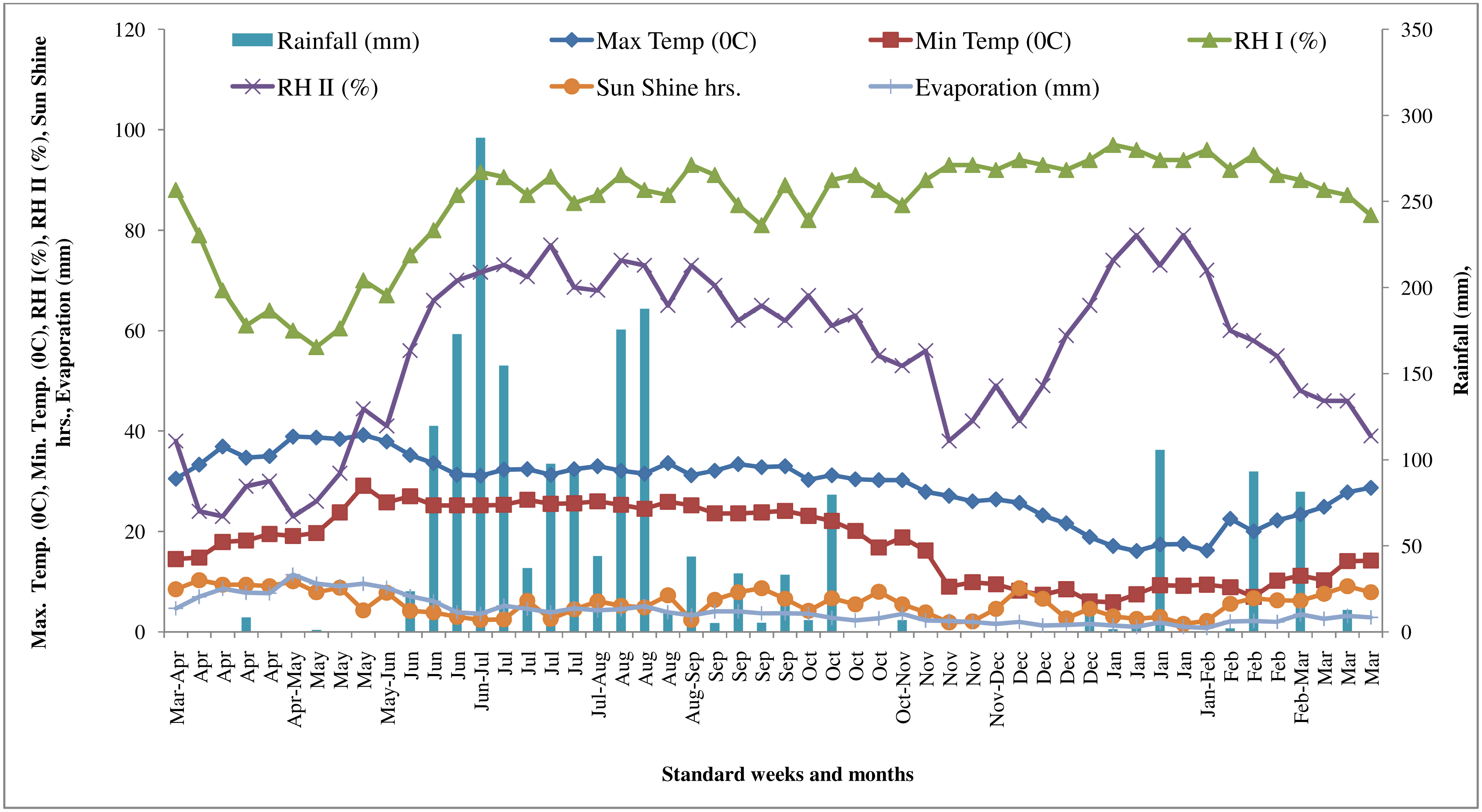

Fig 3.1: Weather data during experimental period April 2013 – March 2014

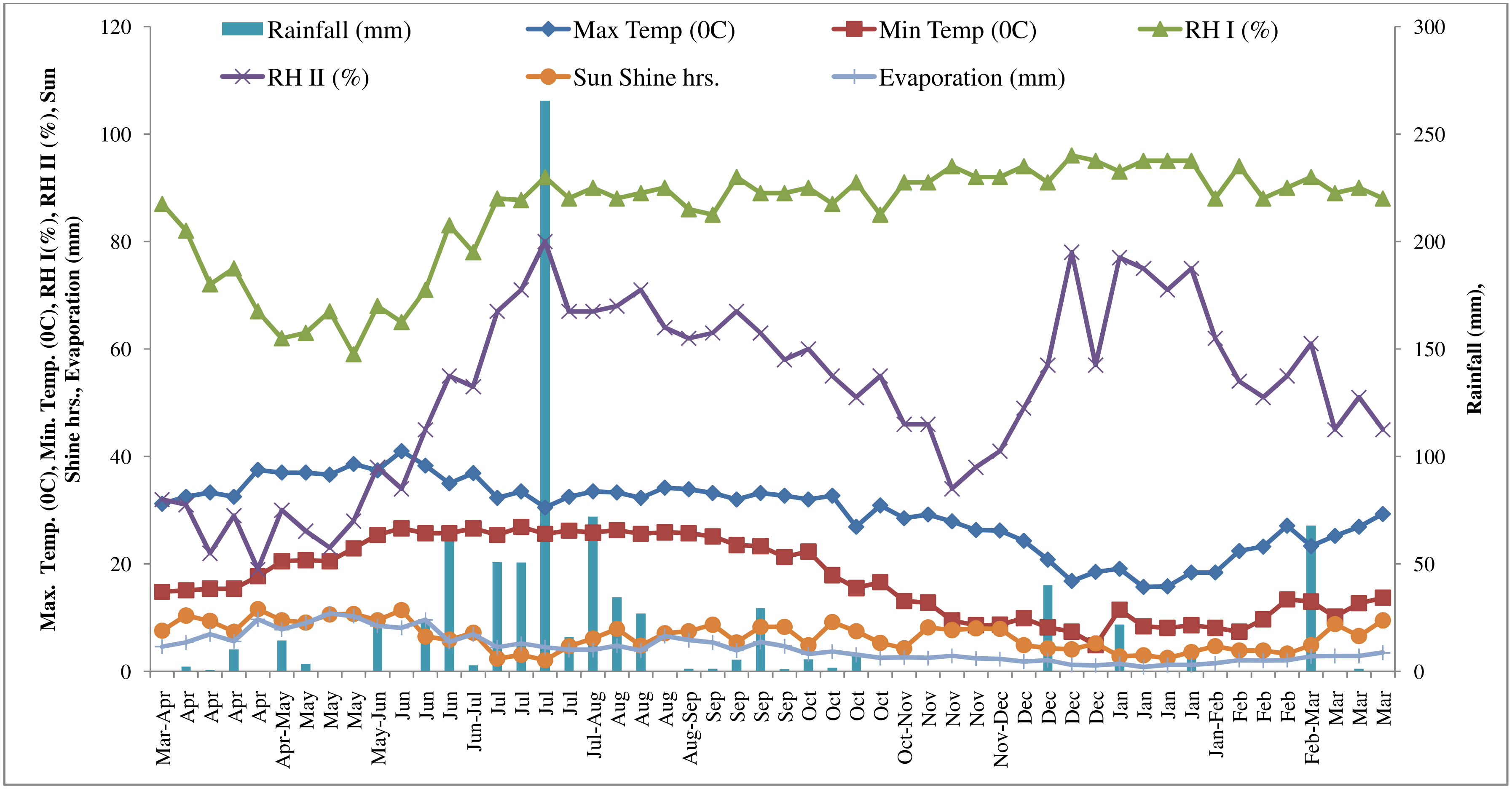

Fig 3.2: Weather data during experimental period April 2014 – March 2015

Table 3.1: Physicochemical properties of the soil of experimental site

S. No.	Property	Value obtained	Method employed
1.	Textural analysis		Bouycos Hydrometer method (Black, 1965)
	Sand (%)	54.42	
	Silt (%)	33.76	
	Clay (%)	10.82	
	Textural class	Sandy loam	USDA textural triangle
2.	pH (1:2 soil water suspension)	6.75	Glass electrode pH meter (Jackson, 1958)
3.	Electrical conductivity (dSm^{-1})	0.21	Bower and Wilcox (1965)
4.	Organic carbon (%)	0.76	Walkley and Black method (1934)
5.	Available nitrogen (kg N ha^{-1})	150.44	Alkaline $KMnO_4$ method (Subbiah and Asija, 1956)
6.	Available phosphorus (kg P ha^{-1})	16.34	Olsen's extraction method (Olsen *et al.*, 1954)
7.	Available potassium (kg K ha^{-1})	135.48	Neutral 1 N NH_4OAc extraction method (Hanway and Hiedal, 1952)
8.	P fixing capacity (%)	81.26	Waugh and Fits (1996)
9.	K fixing capacity (%)	54.07	Waugh and Fits (1996)
10.	Zn (ppm)	0.57	DTPA (Lindsay and Norwell, 1978)
11.	B (ppm)	1.03	Hot water soluble Boron (Hatcher and Wilcox,1950)

Table 3.2: Characteristics of soil profile

Horizon	Depth (cm)	Characteristics
Ap	0-20	Very dark grayish brown 10 YR 3/2 (moist), 10 YR 5/2 grayish brown (dry), sandy loam, weak fine to medium granular structure, moist friable consistency, clear smooth boundary, abundant roots, effervescence nil, pH-6.7, EC-0.27, Org. C-0.65%, Available N-175.62 kg ha^{-1}, Available P-17.35 kg ha^{-1}, Available K-151.20 kg ha^{-1}.
A	20-35	Very dark grayish brown 10 YR 3/2 (moist), 10 YR 5/2 grayish brown (dry), sandy loam, weak coarse granular to weak fine sub-angular blocky structure, friable consistency, gradual smooth boundary, abundant roots, effervescence nil, pH-6.5, EC-0.26, Org. C-0.62%, Available N-137.98 kg ha^{-1}, Available P- 16.82 kg ha^{-1}, Available K- 137.76 kg ha^{-1}.
BA	35-45	Dark Brown 10 YR 3/3 (moist) and grayish brown 10 YR 5/2 (dry), gravelly sandy loam, weak medium to fine sub-angular blocky structure, friable consistency, gradual smooth boundary, common roots, effervescence nil, pH-6.3, EC-0.24, Org. C-0.60, Available N-125.55 kg ha^{-1}, Available P- 15.22 kg ha^{-1}, Available K-128.8 kg ha^{-1}.
B	45-72	Dark Brown 10 YR 3/3 (moist), brown10 YR 4/3 (dry), sandy loam, sub-angular blocky structure, friable consistency, weak medium to fine gradual smooth boundary, common roots, effervescence nil, pH-6.2, EC-0.22, Org. C-0.56, Available N-112.89 kg ha^{-1}, Available P-12.14 kg ha^{-1}, Available K-120.96 kg ha^{-1}.
BC1	72-105	Dark Brown 10 YR 3/3 (moist), brown 10 YR 4/3 (dry) light sandy loam, very weak, medium sub-angular blocky structure; very friable consistency, gradual smooth boundary, occasional roots, effervescence nil, pH-6.2, EC-0.20, Org. C-0.54, Available N-94.08 kg ha^{-1}, Available P- 10.25 kg ha^{-1}, Available K-112 kg ha^{-1} .
BC2	105-127	Dark Brown 10 YR 3/3 (moist), brown 10 YR 4/3 (dry), light sandy loam with few fine distinct light brownish gray mottles, very weak medium to fine sub-angular blocky structure, very friable consistency; clear smooth boundary, occasional roots, effervescence nil, pH-6.1, EC-0.18, Org. C-0.50, Available N-87.80 kg ha^{-1}, Available P- 9.4 kg ha^{-1}, Available K-89.6 kg ha^{-1}.
2C	127+	Dark grayish brown 10 YR 4/2 (moist) and dark brown 10 YR 4/3 (dry); loose sand and gravel with few fine distinct light brownish gray and dark brown to brown mottles, single grain, no roots, effervescence nil, pH-6.0, EC-0.16, Org. C-0.48, Available N-60.2 kg ha^{-1}, Available P- 8.0 kg ha^{-1}, Available K-56 kg ha^{-1}.

3.2 Methodology of Experiments

Soil Test Crop Response studies for balanced fertilization in turmeric based on Integrated Plant Nutrition System (STCR - IPNS) were conducted adopting the Inductive cum Targeted yield model, on a Mollisol in tarai region, India. This study comprised of three field experiments in three phases *viz.,* fertility gradient experiment with fodder oat var. (UPO-212) (Phase I) in year 2012-13, test crop experiment turmeric var. (Pant peetabh) (Phase II) in year 2013-14 and test verification trial with turmeric of same variety (Phase III) in year 2014-15. Before starting experiment composite soil sample from the experimental field was collected and analyzed for various physico-chemical properties, presented in table 3.1. The above experiments were conducted as per the technical programme and methodology of STCR to study the effect of balanced fertilization on growth, quality and yield of turmeric. The details of the field experiments carried out and methods of analysis of soil and plant samples and the methodology followed in the development of prescription equations are presented as follow:

Experiment-1

The field experiment was carried out in two phases *i.e.* fertility gradient stabilizing experiment (preparatory trial) and test crop experiment (main trial).

3.2.1 Soil Fertility gradient Experiment (First Phase)

In the soil fertility gradient experiment, operational range of variation in soil fertility was created deliberately. For this purpose, the experimental field was divided into three equal strips, the first strip received no fertilizer (N0P0K0), the second strips received 100:100:100 N, P_2O_5 and K_2O Kg ha^{-1} (N1P1K1) and third strip receive 200:200:200 N, P_2O_5 and K_2O Kg ha^{-1} (N2P2K2) and a exhaust crop of fodder oat (*var.*UPO-212) was grown during Rabi 2012 for successful conduct soil test crop response correlation study and to minimize the interference of other soil and management factors affecting crop yield. Pre-sowing and post-harvest soil samples were collected from each fertility strip and analyzed for alkaline $KMnO_4$-N (**Subbiah and Asija, 1956**), Olsen –P **(Olsen *et al.*, 1954)** and NH_4OAc-K **(Hanway and Hiedal, 1952)**. At harvest, forage yield recorded (q ha-1) in different strips. The layout is shown in figure 3.3.

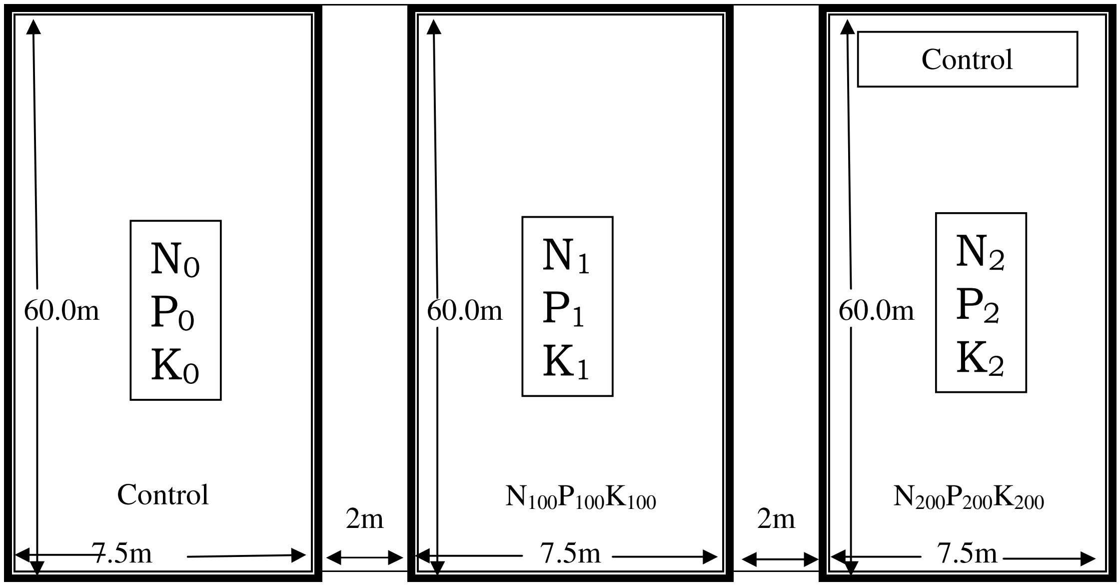

Fig. 3.3: Layout of the soil fertility gradient experiment

In the first phase, 2012, land was prepared in the month of November. For preparation of field one disc ploughing followed by two cross harrowing was done on November 27, 2012. The field was leveled with the help of tractor drawn leveler to give gentle slope for smooth drainage on the same day. Experimental site was divided into three equal strips (60.0m × 7.5 m) to apply three levels of nutrients, viz. 0, 1, 2 (*i.e.* $N_0P_0K_0$, $N_1P_1K_1$ and $N_2P_2K_2$) as given in table 3.3.

Nitrogen, phosphorus and potassium were applied as urea, single super phosphate and muriate of potash, respectively. Half dose of nitrogen and total dose of phosphorus and potassium were broadcasted on November 28, 2012 as basal. While remaining half dose of nitrogen was applied in two splitting dose as top dressing.

Table 3.3: Nutrient levels applied in fertility gradient experiment.

Strip (Symbol)	**Nutrient level (kg ha^{-1})**		
	N	**P_2O_5**	**K_2O**
I ($N_0P_0K_0$)	0	0	0
II ($N_1P_1K_1$)	100	100	100
III ($N_2P_2K_2$)	200	200	200

Sowing was done in deep furrows at 23 cm row to row distance on November 28, 2012. Seeds of variety UPO-212 were sowing at the rate of 100 kg ha^{-1}. Plant population was maintained by gap filling at improper germination sites after fifteen days of date after sowing. An attempt was made to keep crop free of weeds, insects, pests and diseases through recommended agronomic practices. Harvesting done At 50 % flowering stage of the crop on March 12, 2012. Photographic view of this experiment is presented in Plate 1.

Table 3.4: Strip wise forage yield of oat in fertility gradient experiment

Strip	Symbol	Fertilizer Dose (N,P_2O_5&K_2O)	Forage yield (q ha^{-1})
I	$N_0P_0K_0$	0,0,0	395.83
II	$N_1P_1K_1$	100,100,100	504.17
III	$N_2P_2K_2$	200,200,200	583.33

3.2.2 Test Crop Experiment (Second Phase):

After confirming the establishment of fertility gradients in the experimental field, in the second phase of the field experiment, each strip was divided into 24 plots, and initial soil samples were collected from each plot and analyzed for alkaline $KMnO_4$-N, Olsen's-P and NH_4OAc-K. The experiment was laid out in a fractional factorial design comprising twenty four treatments and the test crop experiment with turmeric was conducted with four levels each of N (0, 50, 100 and 150 kg ha^{-1}), P_2O_5 (0, 50, 100 and 150 kg ha^{-1}) and K_2O (0, 50, 100 and 150 kg ha^{-1}) and three levels of FYM (0, 10 and 20 t ha^{-1}). Turmeric variety *Pant peetabh* was developed through selection in germplasm lines. It was released by UPSVRC in 2001. It is an early maturing (210-215 days) variety with good rhizome yield of 250-260 q ha^{-1}. Plants are dwarf having a height of 130-140 cm at full grown stage along with 7-8 leaves per plant with a leaf area of 750-800 cm and light green colour. Fingers are very attractive and bright yellow. Average yield of primary rhizome is 200-340 g per plant and curing percentage is 18.75. The experiment was conducted as per the technical programme of AICRP-STCR.

In the second phase a test crop, Turmeric (var. Pant peetabh) was planted on the site of fertility gradient experiment during *summer,* 2013. Land was prepared in the month of April with one disc ploughing followed by four cross harrowing was done within each strip. The field was leveled with the help of leveler to furnish gentle slope for better drainage. During layout of experiment each strip (made in the fertility gradient stabilizing experiment in the previous season) was divided into twenty four plots (23 treated and one control) resulting in total seventy two (24×3) plots (4 m × 3 m size) plots. These treatments comprised of various selected combinations of nitrogen, phosphorus, potassium and farm yard manure (Table 3.5) and (Fig. 3.4).

Healthy disease free rhizome of turmeric (var. Pant peetabh) was used as sowing material collected from Vegetable Research Center, Pantnagar. The rhizomes were put at a depth of 15 cm in furrows opened with 40 cm row to row spacing and covered immediately with thin layer of soil on 16 April 2013.

Table 3.5: Levels of N, P_2O_5, K_2O and FYM used for the experiment on turmeric

Levels	**FYM (t ha^{-})**	**N (kg ha^{-1})**	**P_2O_5 (kg ha^{-1})**	**K_2O (kg ha^{-1})**
0	0	0	0	0
1	10	50	50	50
2	20	100	100	100
3	-	150	150	150

Half of nitrogen, total phosphorus, total potash and total dose of FYM were applied as basal on 15 April 2013. While remaining one half of nitrogen was applied as top dressing.

To keep crop free from of weeds, insects, pests and diseases, the recommended agronomic practices were followed during the crop season. Important dates for various operations during crop season are presented in the table 3.6.

Table 3.6: Important dates of different operations of turmeric (test crop)

Operations	**Date**
Harrowing, leveling, and layout	09.04.2013
Date of initial soil sample collection	12.04.2013
Application of fertilizers & FYM	22.04.1013
Date of seed treatment	22.04.2013
Planting	23.04.2013
Top dressing of half dose of urea	15.06.2013
Date of plant sample collection (Haulm)	23.12.2013
Date of plant sample collection (Rhizome)	11.03.2014
Date of digging (Rhizome)	15.03.2014
Date of Post-digging soil sample collection	24.03.2014

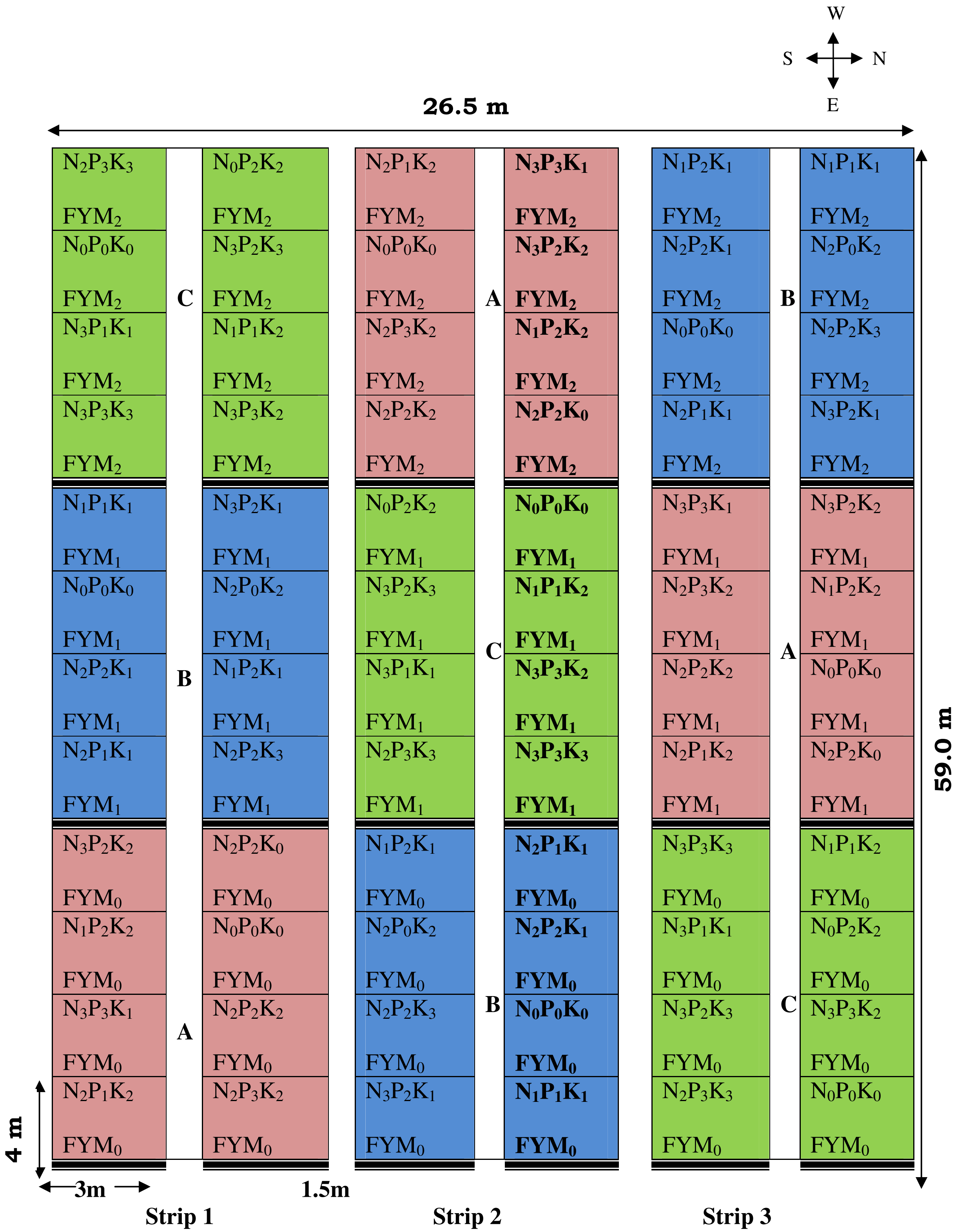

Fig. 3.4: Layout and treatment combinations of the test crop experiment

3.3 Observations

3.3.1 Collection of Soil Samples

Soil samples were collected during different phases of the experiments. First phase experiment soil samples were taken after selection of experimental field, here samples were randomly collected from 5-6 places at 0-15 cm depth to second phase experiment soil sample. Before start of the main experiment, 72 samples were collected at 0-15 cm depth from each plot as per the layout plan. Soil samples were also collected after digging of crop, i.e. turmeric. Soil samples, after air dried under shade, were ground and passed through 2 mm sieve before analysis. Soil samples were also collected for conducting follow-up experiment during 2014-15 i.e. third phase of experiment.

3.3.2 Collection of Plant Samples

Plant samples (haulm) were taken from each plot. Five plants were selected from each plot and samples of haulm were taken and fresh weight was recorded. The plant samples were first air dried and subsequently samples were kept in paper bags and oven dried at 60°C for 48 hours and dry matter content and dry matter yield was recorded. In the same way rhizome samples were collected from each plot and dry matter content & dry matter yields were also recorded.

$$\text{Dry matter content (per cent)} = \frac{\text{Weight of oven dried sample (g)}}{\text{Weight of fresh sample (g)}} \times 100$$

Dry matter yield (q ha^{-1}) = Fresh head yield (q ha^{-1}) × Dry matter content (%)

3.3.3 Yield

3.3.3.1 Rhizome yield

After digging of the rhizome from each plot, the rhizome yield was recorded and reported as q ha^{-1}. Rhizome samples were also collected from each plot for nutrient uptake and quality parameters determination.

3.3.3.2 Haulm yield

Haulm yield per plot was obtained by harvesting of haulm from each plot and reported as q ha-1.Haulm samples were also taken for N,P and K analysis.

3.4 Chemical analysis of Soil Samples

3.4.1 Availability indices of Nitrogen

a) Organic carbon was determined by modified **(Walkley and Black, 1934)** method as described by **(Jackson, 1967).** The values were reported in percent.

b) Nitrogen was determined by Alkaline $KMnO_4$ method as described by **(Subbiah and Asija, 1956).** The values were recorded in kg $ha^{-1.}$

3.4.2 Availability indices of Phosphorus

Phosphorus was determined by two methods:

(a) Olsen method : Phosphorus was determined by 0.5 M $NaHCO_3$ (pH 8.5) extraction method (**Olsen *et al.,* 1954**) followed by colour development by ascorbic acid method (**Murphy and Riley, 1962**) and the available phosphorus concentration in soil samples was recorded with the help of spectrophotometer at 730 nm wavelength. Final values of P in soil were reported in kg ha^{-1}.

(b) AB-DTPA method : By using AB-DTPA (1M NH_4HCO_3 +0.005M DTPA at pH 7.6) as extractant (**Soltanpour and Schwab, 1977)** followed by colour development by ascorbic acid method **(Murphy and Riley, 1962)** and the available phosphorus concentration in soil samples was recorded with the help of spectrophotometer at 820 nm wavelength. Finally the values were recorded in kg ha^{-1}.

(c) Mehlich I method: By using Mehlich I (Double acid) (0.05*N* HCl and 0.025 *N* H_2SO_4) as extractant **(Korcak and Fanning,1978)** followed by colour development by ascorbic acid method **(Murphy and Riley, 1962)** and the available phosphorus concentration in soil samples was recorded with the help of spectrophotometer at 730 nm wavelength. Finally the values were recorded in kg ha^{-1}.

3.4.3 Availability indices of Potassium

(a) Neutral ammonium acetate method: Potassium was determined by using neutral ammonium acetate as extractant **(Hanway and Hiedal, 1952).**

Potassium concentrations in the extracts were read by using flame photometer. Final values in soil were reported in kg ha^{-1}.

(b) **AB-DTPA method**: By using AB- DTPA (1M NH_4HCO_3+ 0.005M DTPA at pH 7.6) as extractant **(Soltanpour and Schwab, 1977).** Final values in soil were reported in kg ha^{-1}.

(c) **Mehlich I method:** By using Mehlich I (Double acid) (0.05*N* HCl and 0.025 *N* H_2SO_4) as extractant **(Korcak and Fanning, 1978).** Final values in soil were reported in kg ha^{-1}.

3.5 Chemical analysis of Plant Sample

Processed plant samples of haulm and rhizome were analyzed for N, P and K content. Oxidation of organic material and release of mineral elements was done by digestion of 0.5g plant sample, with di-acid mixture (9:4) of concentrated HNO_3 and 70 per cent perchloric acid **(Jackson, 1967).** The residue of digested material was dissolved in 6 N HCl. The volume was made up by glass distilled water in volumetric flask in the ratio of 1:100. Details of these analyses are given below.

3.5.1 Nitrogen

The nitrogen content was determined by modified micro-jeldahl method **(Jackson, 1967).** The digestion of dried plant sample (0.2 gm) is done with 10 ml of H_2SO_4 and 1 gm of catalyst mixture in a digestion tube. For pre-digestion overnight rest was taken. Further, the digestion is carried on digestion assembly till the digest becomes colourless. The digest material was distilled and ammonia liberated was absorbed in 4% Boric acid solution containing mixed indicator. Nitrogen content was estimated by titrating the distillate with N/20 H_2SO_4 solution. It was expressed in percentage on dry weight basis both haulm and rhizome.

3.5.2 Phosphorus

Phosphorus was determined by Vanadomolybdo-Phosphoric acid, yellow colour-method in acid system and the intensity of yellow colour was read by UV-VIS spectrophotometer at 420 nm wavelength as described by **(Chapman and Parker 1961).** The contents were expressed as percent in haulm and rhizome.

3.5.3 Potassium

The potassium content of the digested material was estimated by flame photometer. The contents were expressed as percent potassium in haulm and rhizome.

3.6 Total nutrient uptake

(a) Uptake by haulm (kg ha^{-1}) = Nutrient content (%) in haulm × dry matter yield of haulm (q ha^{-1})

(b) Uptake by rhizome (kg ha^{-1}) = Nutrient content (%) in rhizome × dry matter yield of rhizome (q ha^{-1})

(c) Total nutrient uptake by plant (kg ha^{-1}) = Uptake by haulm (kg ha^{-1}) + Uptake by rhizome (kg ha^{-1})

3.7 Basic data for Fertilizer Recommendation

Basic data were calculated with the help of soil & applied fertilizer nutrients, crop yield, nutrient uptake of rhizome and haulm yields.

3.7.1 Nutrient requirement for production of one quintal of economic produce (rhizome)

The nutrient requirement was calculated as follows:

$$\text{Nutrient requirement (NR)} = \frac{\text{Total nutrient uptake (kg)}}{\text{Rhizome yield (q)}}$$

The values were reported as kg of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) required for producing one quintal of rhizome. These values were calculated separately for each plot and then averages were taken.

3.7.2 Contribution of nitrogen, phosphorus and potassium from soil (Cs)

In this method, the efficiency of soil nutrients was calculated from soil test values of unfertilized plots (control plots). The soil efficiency was calculated as a ratio of total uptake and soil test value of a nutrient for each control plot and makes their average. The soil contribution in each plot was determined by multiplying the soil test value of the plot with the average soil efficiency as determined from the unfertilized plots. The soil efficiency was calculated as follows:

Plate1: Photographic view of chemical analysis in the laboratory

Percent contribution of available nutrient from soil (Cs)

$$= \frac{\text{Total uptake of nutrient in contorl plot}}{\text{Soil test value of that nutrient in control plot}} \times 100$$

The mean of all control plots with respect to nutrient in question was calculated for each nutrient.

3.7.3 Contribution of concerned nutrient from fertilizer without FYM (Cf)

The fertilizer efficiency was calculated from treated plots after giving allowance for soil contribution. The fertilizer efficiency was calculated as a ratio of the difference between the total uptake and soil contribution and applied fertilizer dose in each treated plot.

$$\frac{\begin{array}{l}\text{Total uptake of nutrients}\\ \text{(kg/ha) in fertilizer and}\\ \text{FYM treated plots}\end{array} - \begin{array}{l}\text{Soil test values of nutrients}\\ \text{in fertilizer and FYM}\\ \text{treated plots} \times \text{CS} / 100\end{array} \begin{array}{l}\text{Nutrient added (kg/ha) X CFYM / 100}\\ \text{- through FYM}\\ \end{array}}{\text{Fertilizer dose (N/P/K) applied (kg/ha)}} \times 100$$

3.7.4 Contribution of nitrogen, phosphorus and potassium from FYM (Cfym)

FYM efficiency of any nutrient was calculated only from the FYM treated plots (6 plots). For calculating the efficiency of fertilizer in FYM treated plots, the value of nutrient uptake from that treatment be deducted from uptake of that nutrient supplied through soil and further divided by added nutrients by FYM respectively. The values were calculated as given in the following formula:

Percent contribution of nutrient from FYM =

$$\frac{\begin{array}{l}\text{Total uptake of nutreints (kg/ha)}\\ \text{in only organic manure treated plots}\end{array} - \begin{array}{l}\text{Soil test values of nutrients}\\ \text{in only organic plots} \times \text{CS} /100\end{array}}{\text{organic manure nutrients dose (N/P/K) applied (kg/ha)}} \times 100$$

3.7.5. Contribution of concerned nutrient from fertilizer with FYM (Cf*)

The fertilizer efficiency of nutrient with FYM was calculated from treated plots after giving allowance for soil and FYM contribution. The fertilizer efficiency was calculated as a ratio of the difference between the total uptake and soil & FYM contribution and applied fertilizer dose in each treated plot.

Per cent contribution of nutrients from fertilizer with FYM (CF %) =

$$\frac{\text{Total uptake of nutrients (kg/ha) in fertilizer and FYM treated plots} - \text{Soil test values of nutrients in fertilizer and FYM treated plots} \times CS/100}{\text{Fertilizer dose (N/P/K) applied (kg/ha)}} \times 100$$

3.8 Fertilizer requirement for targeted yield

Equations for fertilizer requirement of nitrogen, phosphorus and potassium for targeted yield were worked out as follows:

3.8.1 Fertilizer requirement of nitrogen, phosphorus and potassium for targeted yields were worked out as follows:

Without FYM

FN= (NR/Cf) ×100T-(Cs/Cf) ×SN

FP_2O_5= (NR/Cf) ×100T - (Cs/Cf) × 2.29 x SP

FK_2O= (NR/Cf) ×100T – (Cs/Cf) × 1.21 SK

Fertilizer requirement equations for nutrients through conjoint use of chemical fertilizer and FYM

With FYM

FN = (NR/Cf*) ×100 T – (CS/Cf*) × SN – (Cfym/Cf*) × M

FP_2O_5 = (NR/Cf*) × 100 T – (CS/Cf*) × 2.29 x SP – (Cfym/Cf*) ×2.29 x M

FK_2O = (NR/Cf*) × 100 T – (CS/Cf*) ×× 1.21SK – (Cfym/Cf*) ×× 1.21 M

Where,

FN = Fertilizer nitrogen (kg N ha^{-1})

F P_2O_5 = Fertilizer phosphorus (kg P_2O_5 ha^{-1})

FK_2O = Fertilizer potassium (kg K_2O ha^{-1})

NR =Nutrient requirement of nitrogen, phosphorus and potassium

Cf = Percent contribution of concerned nutrient from fertilizer without FYM

Cf* = Percent contribution of concerned nutrient from fertilizer with FYM.

CS = Percent contribution of concerned nutrient from soil

Cfym = Percent contribution of concerned nutrient from FYM

T = Targeted yield (q ha^{-1})

SN = Soil test value for available nitrogen (kg ha^{-1})

SP = Soil test value for available phosphorus (kg ha^{-1})

SK = Soil test value for available potassium (kg ha^{-1})

M = Concerned nutrient content in organic matter

3.9. Multiple regression for maximum and economic yield

Multiple regression approach is used to calculate the dose of nutrient (S) required obtaining the maximum yield of crops under given set of experimental conditions. It can further be used to calculate the economic dose of fertilizer nutrients by incorporating a constant factor, i.e. per unit cost of produce divided by per unit cost of input (fertilizer) in the original equation. In this approach yield is regressed with soil nutrients, fertilizer nutrients, their quadratic terms and the interaction term of soil and fertilizer nutrients as given below:

$$Y= A \pm b1\ SN \pm b2\ SN2 \pm b3\ SP \pm b4 + SP2 \pm b5\ SK \pm b6\ SK2 \pm b7\ FN \pm b8\ FN2 \pm b9\ FP \pm b10\ FP2 \pm b11\ FK \pm b12\ FK2 \pm b13\ FNSN \pm b14\ FPSP \pm b15\ FKSK$$

Where

Y = Crop yield (kg ha^{-1})

A = Intercept (kg ha^{-1})

bi = Regression coefficients (kg ha^{-1})

SN, SP, SK = Available soil nitrogen, phosphorus and potassium (kg ha^{-1}), respectively.

FN, FP, FK = Fertilizer nitrogen, phosphorus and potassium (kg ha^{-1}), respectively.

3.10 Nutrient requirement for maximum and economic yields

Multiple regression analysis and fertility gradient approach, evolved at IARI has provided the basis for quantitative fertilizer adjustments based on soil test for maximum yield per hectare, maximum profit per hectare and maximum return per rupee spent on fertilizer (**Ramamoorthy, 1974**). These equations were derived as below:

The ideal equation for the partial function of fertilizer nutrient is as follows:

$Y = a + b\,x + c\,x^2 - dx$

$$\frac{dy}{dx} = b - 2cx - dz$$

$$X_{(max)} = \frac{b - dz}{2c}$$

$$X_{(eco)} = \frac{b - (q/p) - dz}{2c}$$

Where,

a = constant independent of x and z

b & c = regression coefficient of linear and quadratic terms of X

z = soil test value of nutrient in question

x = fertilizer dose (kg ha^{-1})

3.11. Quality parameters of turmeric:

To judge the quality of rhizome following parameters were determined:

3.11.1 Curing percent

After harvesting, 500 g cleaned fresh rhizomes were filled in a receptacle and a measured quantity of 0.1% sodium bicarbonate was added until the water level stood about 5 to 7.5 cm above the level of rhizomes and boiling was commenced above a direct fire, till the froth and white fumes appeared, it took about 3/4 hour for proper rhizome cooking. The cooked rhizomes were moved from receptacle and then dried. After curing, the curing percentage was calculated by using the following formula given by **Krishnamurthy *et al.* (1975)**.

Curing percentage = (Cured yield of rhizomes /Fresh rhizomes yield)x 100

3.11.2 Curcumin content

Curcumin content **Krishnamurthy *et al* (1975)** modified the ASTA (American Spice Trade Association) method the modified method followed in this investigation.

3.11.2.1 Preparation of sample extract for curcumin estimation

For estimation of curcumin content in turmeric rhizome finely ground turmeric powder amples (1 g) were extraxcted by refluxing over a water cooled condenser with 100 ml of distilled alcohal (methenol) for 2and half hours. The extracts was transferred to a 100 ml volumetric flask and volume was made to 100 ml with alcohal (methenol). It was then filtered and an aliquat of 2 ml was transferred to a 25 ml volumetric flask and made to 25 ml volume, mixed well and the absorbance of this solution was measered at 425 nm wavelength against blank made of alcohal **(Manjunath *et al.,* 1991).**

3.11.2.2 Preparation of standard solution

First of all 25 mg purified curcumin (Eastman Kodak Co. New York) was weighed and dissolved with 95% ethanol in 100 ml volumetric flak and the volume made up to mark. One ml of this solution was taken with the pipette and diluted to 100 ml. in a volumetric flask with ethanol. The absorbance was measured by spectrophotometer at 425 nm wave length.

$$\text{Curcumin} = \frac{\text{Absorbance of extract}}{a \times w} \times 125$$

Where,

a = Value of standard curve graph

and w = Weight of sample in (g).

3.13 Protein content (%)

Protein content in rhizomes was estimated by multiplying the nitrogen content with 6.25 factors **(Singh and Dixit, 2010).**

3.14 Verification trials

The adjustment equations generated from basic data were utilized for validation of equations obtained in the test crop experiments. The verification trial on turmeric was conducted in next year, i.e. in summer 2014-15. In this trial ten treatments with three replications were studied under RBD. The treatments were as following:

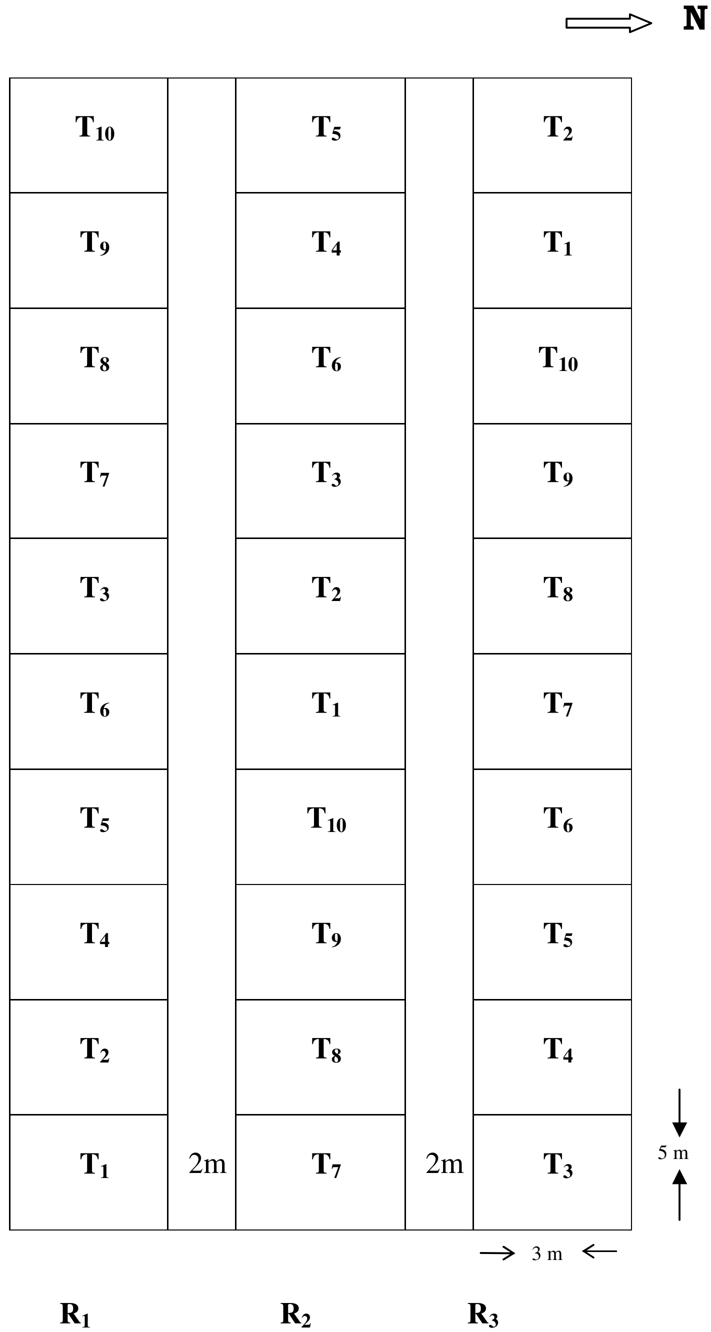

Fig. 3.5: Layout of verification experiment

Table 3.7: Fertilizers and FYM treatments in verification trial of Turmeric

Treatments	Notation
Control	T1
General recommendation Dose	T2
Yield Target 250 q ha^{-1}	T3
Yield Target 250 q ha^{-1}+ FYM 10t ha^{-1}	T4
Yield Target 250 q ha^{-1}+ FYM 20t ha^{-1}	T5
Yield Target 300 q ha^{-1}	T6
Yield Target 300 q ha^{-1}+ FYM 10t ha^{-1}	T7
Yield Target 300 q ha^{-1}+ FYM 20t ha^{-1}	T8
Yield Target 250 q ha^{-1} + Zn (1.0 %)	T9
Yield Target 250 q ha^{-1} + B (1.0 %)	T10

The yield obtained from this experiment was recorded. The information generated from this experiment was used for calculation of economics for the test crop.

3.15 Statistical analysis

The data of fertilizer requirement and nutrient use efficiency experiments were analyzed by the method of fitting up of simple as well as multiple regression equations **(Panse and Sukhatame, 1962 and Snedecor and Cochran, 1967)** and also as per standard design of AICRP on ‘Soil Test Crop Response Correlation Project’.

Results and Discussion

Results of the present investigation entitled "Soil Test Crop Response Studies for Balanced Fertilization of Turmeric (*Curcuma longa* L.) in Mollisol of Uttarakhand." are presented with the help of suitable tables and figures. The trend observed compared with the work of other scientists and explained proper reasoning of experimental results. Attempt has been made to discuss results of the experiments and give explanations in the light of experimental evidences. It has also been tried to understand the cause and effect relationship to cull out information of practical value particularly for the farmers of Uttarakhand and the country as a whole.

4.1 Soil analysis

4.1.1 Fertility gradient experiment

A field experiment was conducted as per the technical programme of soil test crop response correlation studies. To evaluate a meaningful regression between soil test values of the various plots and crop response to fertilizer, possible large variations in the fertility levels (soil test values) of different strips of selected field was created. The experimental success is entirely depends on the creation of the artificial gradient of soil fertility. In principle strip III should be richest in fertility status followed by strip II and strip I with poorest fertility. Because highest amount of fertilizer nitrogen, phosphorus and potash was applied in strip III followed by strip II while no fertilizer was applied in strip I. Before conducting main experiment on turmeric in the preceding crop season preparatory trial had conducted by growing exhaust crop oat (var. UPO-212). Experimental soil was Sandy loam classified as *Aquic Hapludoll* having pH 6.75, EC 0.21 (dSm^{-1}), Organic carbon 0.76%, Alkaline $KMnO_4$- N 150.44, Olsen's-P 16.34 and Ammonium Acetate- K 135.48 kg ha^{-1} (Table 3.1)

4.1.2 Soil test values: Main experiment

Strip wise range and average of soil test values obtained by different soil test methods for nitrogen, phosphorus and potassium are given in table 4.1. Soil test values of individual plots are given in appendix III.

pH

The pH of experimental field varied from 6.37 to 7.40 with a average of 6.93. pH in strip I ranged from 6.37-7.40 with a average of 6.97. While in strip II, the pH ranged from 6.53 to 7.21 with a average of 6.93. Range of pH in strip III varied from 6.54 to 7.14 with a average of 6.90. The average value of pH was lowest in strip II and the highest in strip I.

Electrical conductivity (EC)

The EC of experimental field varied from 0.12 to 0.32 dSm^{-1} with an average of 0.21 dSm^{-1}. EC in strip I ranged from 0.12 to 0.26 $dSm^{-1}$with an average of 0.16 dSm^{-1}. While in strip II, the EC ranged from 0.15 to 0.27 dSm^{-1} with an average of 0.21 dSm^{-1}. Range of EC in strip III varied from 0.19 to 0.32 dSm^{-1} with an average of 0.25 dSm^{-1}. The average value of EC was lowest in strip I and the highest in strip III.

Organic carbon

Organic carbon content of entire experimental field varied from 0.58-1.05 percent with a average of 0.76 per cent. Organic carbon content in strip I ranged from 0.58-0.98 percent with a average of 0.73 percent. While in strip II, the organic carbon content ranged from 0.58-1.05 percent with a average of 0.77 percent. Range of organic carbon content in strip III varied from 0.64-1.05 percent with an average of 0.78 percent. The average value of organic carbon content was lowest in strip I and the highest in strip III.

Nitrogen

Available Nitrogen extracted by alkaline-$KMnO_4$ method of the entire experimental field varied from 112.90 to 263.42 kg N ha^{-1} with average value of 144.95 kg N ha^{-1}. Strip wise values ranged from 112.90 to 200.70 with a average of 140.60 in strip I, 112.90 to 263.42 with a average of 144.26 in strip II and 112.90 to 213.25 with a average of 150.01 kg N ha^{-1} in strip III. The average value of Nitrogen was lowest in strip I and the highest in strip III.

Phosphorus

Available Phosphorus content of the entire experimental field ranged from 16.97 to 29.27 kg P ha^{-1} with a average value of 24.56 kg P ha^{-1}. Strip wise range varied from 18.24 to 26.30 with a average value of 21.99 kg ha^{-1} in strip I, 22.48 to

28.85 with a average value of 25.84 kg P ha^{-1} in strip II and 16.97 to 29.27 with a average of 25.86 kg P ha^{-1} in Strip III. The average value of Phosphorus was lowest in strip I and the highest in strip III.

Potassium

Available Potassium extracted by neutral normal NH_4OAC method ranged from 58.24 to 189.28 kg ha^{-1} with a average of 108.16 kg K ha^{-1} for the entire experimental field. Values ranged from 58.24 to 126.56 in strip I with a average value of 81.71 kg K ha^{-1}, 58.24 to 189.28 in strip II with a average value of 113.17 kg K ha^{-1} and 84.00 to 189.28 kg K ha^{-1} in strip III with a average value of 129.59 kg K ha^{-1}. The average value of Potassium was lowest in strip I and the highest in strip III.

Table 4.1: Range and average of the soil test values under different strips

Sl. No.	Particulars	Strip I	Strip II	Strip III	Whole field
1.	pH (1:2 soil water suspension)	6.37-7.40 (6.97)	6.53-7.21 (6.93)	6.54-7.14 (6.90)	6.37-7.40 (6.93)
2.	Electrical conductivity (dSm^{-1})	0.12-0.26 (0.16)	0.15-0.27 (0.21)	0.19-0.32 (0.25)	0.12-0.32 (0.21)
3.	Organic carbon (%)	0.58-0.98 (0.73)	0.58-1.05 (0.77)	0.64-1.05 (0.78)	0.58-1.05 (0.76)
4.	Available nitrogen (kg N ha^{-1})	112.90-200.70 (140.60)	112.90-263.42 (144.26)	112.90-213.25 (150.01)	112.90-263.42 (144.95)
5.	Available phosphorus (kg P ha^{-1})	18.24-26.30 (21.99)	22.48-28.85 (25.84)	16.97-29.27 (25.86)	16.97-29.27 (24.56)
6.	Available potassium (kg K ha^{-1})	58.24-126.56 (81.71)	58.24-189.28 (113.17)	84.00-189.28 (129.59)	58.24-189.28 (108.16)

Note: Value given in parenthesis Indicate average.

4.1.3 Statistical verification of proper creation of fertility gradient

Analysis of variance was carried out by using the soil nutrients, soil Nitrogen (SN), soil Phosphorous (SP) and soil Potassium (SK) separately as dependent variables. The results obtained are given in table 4.2.

Table 4.2: Significance, R square and average of soil test values of whole plots

Dependent Variable	P level	R Square	Average	CV%
SN	<0.01**	0.789	144.95	17.60
SP	<0.01**	0.674	24.56	11.96
SK	<0.01**	0.827	108.16	30.48

It is seen (table 4.2) that in case of SN, SP or SK as dependent variable the effect of the strip is highly significant. This indicates that the fertility gradient was created in respect of N, P and K. These fertility ranges with respect to N, P and K soil test values were mainly due to differential application of fertilizers and manure in the preceding crop season. However, local heterogeneity in the soil also contributed partly to this range of variations in the soil fertility. Therefore, it can be concluded from above results that the Organic carbon, alkaline $KMnO_4$-N, Olsen's-P and neutral normal NH_4OAc-K content of soil increased in the order of strip I < strip II < strip III of the experimental field which represents that there was proper creation of fertility gradient with the application of graded doses of nitrogen, phosphorus and potassium. It is also statistically proved that there was proper creation of fertility gradient and it is significant in respect of N, P, K and FYM levels. On the basis of statistical verification of fertility gradient it can be concluded that the experimental field is suitable for soil test crop response studies for the next season crop. In principle strip III should be richest in fertility status followed by strip II and strip I with poorest fertility. Because highest amount of fertilizer nitrogen, phosphorus and potash was applied in strip III followed by strip II while no fertilizer was applied in strip I. The possible reason of above trend may be inherent variation in field as well as applied nutrients in different strips, such trend has been utilized for successful conduction of experiment. Similar types of findings were also reported by **Pande (2010) and Rawat (2014)** in the Mollisol of Uttarakhand.

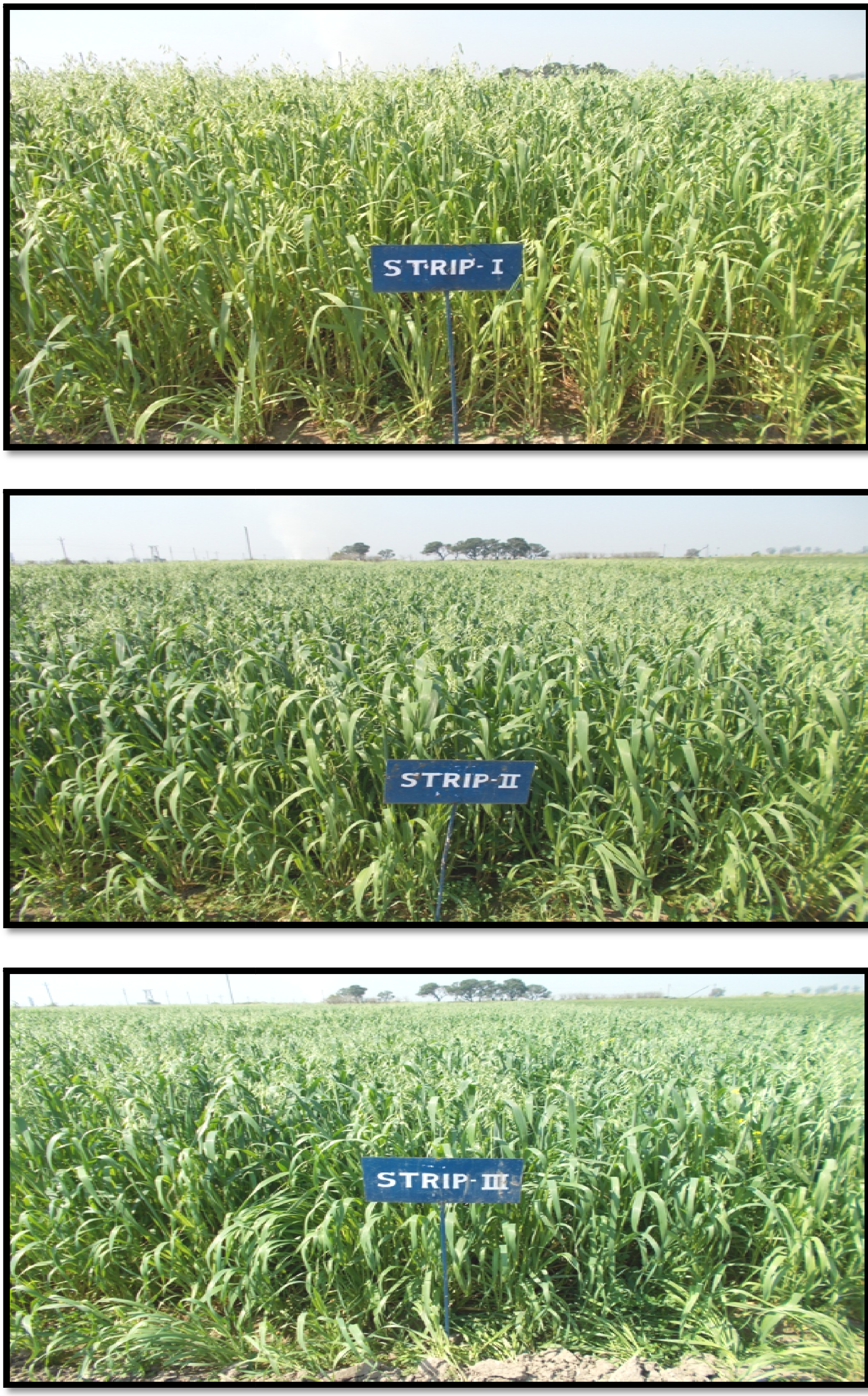

Plate 2: Photographic view of exhaust crop-Oat (var. UPO-212)

4.2 Availability indices of Nitrogen, Phosphorus and Potassium.

Availability indices of N, P and K in present investigation evaluated from all (seventy two) plot soil test value of N, P and K by different methods, the relative suitability of different soil test methods for a given nutrient was judged from comparison of the magnitude of R^2 values of the regression equations obtained by including alternatively one method each time keeping the methods of other nutrients constant. Generally, the R^2 values above 0.66 are taken as indication of good fit, 0.45 to 0.65 as moderate fit, and below 0.45 as poor fit of the equation **(ICAR, 1974)**. Data were analyzed to find out multiple regression equation for different functions with selected soil test methods i.e. organic carbon or alkaline $KMnO_4$, Olsen's, AB-DTPA or Mehlich-1 method and neutral normal NH_4OA_C, AB-DTPA or Mehlich-1 method to determine, available nitrogen, phosphorus and potassium in soil, respectively. Availability indices of N, P and K were determined by regression equations using rhizome yield as dependent and soil test values, fertilizer doses as independent variables.

4.2.1 Availability indices of Nitrogen

The different chemical extractants have been tried from time to time to measure the available N in soils. In view of the diverse soil and climatic conditions no single index for available N has universal acceptance. In Soil Testing laboratories these methods are not being used as they are cumbersome with lengthy procedures and a large number of samples cannot be handled in a short time. An ideal soil test method is one which is simple, rapid, reliable, less expensive and easily adaptable to situations.

Nitrogen was determined by alkaline $KMnO_4$ and organic carbon method as index of available Nitrogen. Equations showing the relationship by these methods are given below:

I) Organic carbon (%)

$$YIELD = 330.2684^* - 123.8972\ OC - 7.2069\ SP^* + 0.7731\ SK - 0.1462\ FN - 5.4983\ FP^* + 1.5608\ FK^* - 0.0023\ FN^2 + 0.0084\ FP^2 - 0.0023\ FK^2 + 1.2186\ FNOC + 0.2201\ FPSP^* - 0.0073\ FKSK \quad \text{…eq (I)}$$

$R^2 = 0.672$

II) Alkaline $KMnO_4N$

$$YIELD = 290.9058^* - 0.5586\ SN - 5.6318\ SP^* + 0.5941\ SK - 0.6164\ FN - 4.4757\ FP^* + 1.5466\ FK^* - 0.0016\ FN^2 + 0.0035\ FP^2 - 0.0026\ FK^2 + 0.0085\ FNSN + 0.2007\ FPSP^* - 0.0065\ FKSK \quad \text{…eq(II)}$$

$R^2 = 0.687$

4.2.2 Availability indices of Phosphorus

Evaluation of P fertility status of soil is necessary to make a sound P fertilizer recommendation for optimizing crop yield. To determine the available P status various methods are employed by different scientists in most of the soil testing laboratories. The rate and quantity of P that can be solubilized by a particular extractants depends on the soil and chemical nature of the extractants used. Following multiple regression equation developed for the evaluation of available Phosphorus.

I. Olsen's P

YIELD = 290.9058* - 0.5586 SN - 5.6318 SP* + 0.5941 SK - 0.6164 FN - 4.4757 FP* + 1.5466 FK* - 0.0016 FN^2 + 0.0035 FP^2 - 0.0026 FK^2 + 0.0085 FNSN + 0.2007 FPSP* - 0.0065 FKSK …eq(III)

R^2= 0.687

II. AB-DTPA P

YIELD = 339.2264* - 0.4761SN - 8.8852 SP* + 0.6126 SK - 0.5626 FN - 4.7802 FP* + 1.4122 FK* - 0.0014 FN^2 - 0.0024 FP^2 - 0.0023 FK^2 + 0.0078 FNSN + 0.2486 FPSP* - 0.0060 FKSK …eq (IV)

R^2 = 0.675

III. Mehlich- P

YIELD = 247.5221* - 0.6374SN - 3.4206SP + 0.5944SK - 0.6767FN - 2.8099FP + 1.4872FK* - 0.0012 FN^2 + 0.0029FP^2 - 0.0030FK^2 + 0.0084FNSN + 0.1378 FPSP - 0.0055 FKSK ...eq (V)

R^2 = 0.652

4.2.3 Availability indices of Potassium

Evaluation of K fertility of soil is necessary for optimizing fertilizer use and making K fertilizer recommendation of the crop. Numerous methods have been advocated by several workers to measure the available K status of the soils but none of these has been found to be universally applicable. The K availability depends upon their amount in the soil, soil characteristics, temperature and organic matter content. Following multiple regression equation developed for the evaluation of available Potassium.

I) Neutral Ammonium Acetate

$$YIELD = 290.9058^* - 0.5586\ SN - 5.6318\ SP^* + 0.5941\ SK - 0.6164\ FN - 4.4757\ FP^* + 1.5466\ FK^* - 0.0016\ FN^2 + 0.0035\ FP^2 - 0.0026\ FK^2 + 0.0085\ FNSN + 0.2007\ FPSP^* - 0.0065\ FKSK \quad \text{...eq (VI)}$$

$R^2 = 0.687$

II) AB- DTPA K

$$YIELD = 287.9835^* - 0.5496\ SN - 5.7812\ SP^* + 0.6318\ SK - 0.5998\ FN - 4.5108\ FP^* + 1.5944\ FK^* - 0.0017\ FN^2 + 0.0036\ FP^2 - 0.0027\ FK^2 + 0.0084\ FNSN + 0.2018\ FPSP^* - 0.0068\ FKSK \quad \text{...eq (VII)}$$

R2 = 0.688

III) Mehlich K

$$YIELD = 289.6805^* - 0.5558\ SN - 5.5331\ SP^* + 0.5964\ SK - 0.6173\ FN - 4.3915\ FP + 1.5220\ FK^* - 0.0016\ FN^2 + 0.0035\ FP^2 - 0.0027\ FK^2 + 0.0084\ FNSN + 0.1969\ FPSP^* - 0.0064\ FKSK \quad \text{...eq (VII)}$$

R2 = 0.686

Various combinations of different availability indices of N, P and K are given in Table 4.3 and appendix IV. It is very useful to choose best combination of availability indices of different method for N, P and K in soil.

Various soil test methods were evaluated for their suitability under field conditions by **Velayutham *et al.* (1985).** Suitability of soil test methods is useful in selecting the most appropriate testing procedure suited for particular crop in a given region. Among chemical methods, available nitrogen extracted by alkaline $KMnO_4$ was found suitable for predicting its availability as reported by **Bhaskar Rao *et al.* (2002).**

The suitability of soil test methods are needed for success of soil testing lab to develop all those methods, which are capable of extracting the amount of nutrient that can significantly predict yield response. The various soil test methods were evaluated by taking values of soil test value of N, P and K of the experiment in different plots. Quadratic regression equations were developed and values of regression coefficient compare to evaluate suitability of different methods. In the present investigation an approach of quadratic multiple regression of the yield with different combination of soil test method along with fertilizer dose was used. Similar study was also conducted

Table 4.3: Combination of different availability indices of nitrogen, phosphorus and potassium.

Equation	R2	Parameter
YIELD = 330.2684* - 123.8972 OC - 7.2069 SP* + 0.7731 SK - 0.1462 FN - 5.4983 FP* + 1.5608 FK* - 0.0023 FN² + 0.0084 FP² - 0.0023 FK² + 1.2186 FNOC + 0.2201 FPSP* - 0.0073 FKSK	0.672	OC% Olsen's P NH_4OAc- K
YIELD = 328.7519 - 125.0891 * O C - 7.3776 * SP + 0.8179 * SK - 0.1569 * FN - 5.5327 * FP + 1.6178 * FK - 0.0023 * FN² + 0.0084 * FP² - 0.0024 * FK² + 1.2372 * FNOC + 0.2217 * FPSP - 0.0077 * FKSK	0.673	OC% Olsen's P ABDTPA- K
YIELD = 328.1773 - 123.3371 * O C - 7.0347 * SP + 0.7711 * SK - 0.1387 * FN - 5.3760 * FP + 1.5284 * FK - 0.0022 * FN² + 0.0085 * FP² - 0.0024 * FK² + 1.1962 * FNOC + 0.2149 * FPSP - 0.0071 * FKSK	0.671	OC% Olsen's P Mehlich- K
YIELD = 339.4124 - 63.6124 * O C - 9.6879 * SP + 0.6545 * SK + 0.2309 * FN - 5.3121 * FP + 1.3159 * FK - 0.0019 * FN² + 0.0033 * FP² - 0.0023 * FK² + 0.6248 * FNOC + 0.2468 * FPSP - 0.0055 * FKSK	0.655	OC% ABDTPA-P NH_4OAc- K
YIELD = 338.0826 - 63.5774 * O C - 9.8523 * SP + 0.6870 * SK + 0.2276 * FN - 5.3355 * FP + 1.3525 * FK - 0.0019 * FN² + 0.0032 * FP² - 0.0023 * FK² + 0.6313 * FNOC + 0.2481 * FPSP - 0.0057 * FKSK	0.655	OC% ABDTPA-P ABDTPA- K
YIELD = 341.4146 - 66.8098 * O C - 9.6897 * SP + 0.6754 * SK + 0.2105 * FN - 5.2667 * FP + 1.3069 * FK - 0.0019 * FN² + 0.0034 * FP² - 0.0024 * FK² + 0.6513 * FNOC + 0.2444 * FPSP - 0.0055 * FKSK	0.655	OC% ABDTPA-P Mehlich- K
YIELD = 244.5239 - 63.8426 * O C - 4.8173 * SP + 0.6175 * SK + 0.3069 * FN - 3.8503 * FP + 1.3133 * FK - 0.0018 * FN² + 0.0084 * FP² - 0.0026 * FK² + 0.5060 * FNOC + 0.1574 * FPSP - 0.0051 * FKSK	0.635	OC% Mehlich-P NH_4OAc- K
YIELD = 241.0464 - 62.3090 * O C - 4.8418 * SP + 0.6333 * SK + 0.3154 * FN - 3.8268 * FP + 1.3344 * FK - 0.0018 * FN² + 0.0083 * FP² - 0.0026 * FK² + 0.4916 * FNOC + 0.1567 * FPSP - 0.0052 * FKSK	0.636	OC% Mehlich-P ABDTPA- K
YIELD = 242.8005 - 64.1397 * O C - 4.6384 * SP + 0.6128 * SK + 0.3087 * FN - 3.7220 * FP + 1.2797 * FK - 0.0018 * FN² + 0.0085 * FP² - 0.0027 * FK² + 0.4960 * FNOC + 0.1518 * FPSP - 0.0049 * FKSK	0.635	OC% Mehlich-P Mehlich- K
YIELD = 290.9058* - 0.5586 SN - 5.6318 SP* + 0.5941 SK - 0.6164 FN - 4.4757 FP* + 1.5466 FK* - 0.0016 FN² + 0.0035 FP² - 0.0026 FK² + 0.0085 FNSN + 0.2007 FPSP* - 0.0065 FKSK	0.687	Alkaline $KMnO_4N$ Olsen's P NH_4OAc- K
YIELD = 287.9835 - 0.5496 * SN - 5.7812 * SP + 0.6318 * SK - 0.5998 * FN - 4.5108 * FP + 1.5944 * FK - 0.0017 * FN² + 0.0036 * FP² - 0.0027 * FK² + 0.0084 * FNSN + 0.2018 * FPSP - 0.0068 * FKSK	0.688	Alkaline $KMnO_4N$ Olsen's P ABDTPA- K
YIELD = 289.6805 - 0.5558 * SN - 5.5331 * SP + 0.5964 * SK - 0.6173 * FN - 4.3915 * FP + 1.5220 * FK - 0.0016 * FN² + 0.0035 * FP² - 0.0027 * FK² + 0.0084 * FNSN + 0.1969 * FPSP - 0.0064 * FKSK	0.686	Alkaline $KMnO_4N$ Olsen's P Mehlich- K
YIELD = 339.0685 - 0.4764 * SN - 8.8763 * SP + 0.6126 * SK - 0.5630 * FN - 4.7763 * FP + 1.4124 * FK - 0.0014 * FN² - 0.0024 * FP² - 0.0023 * FK² + 0.0078 * FNSN + 0.2484 * FPSP - 0.0060 * FKSK	0.675	Alkaline $KMnO_4N$ ABDTPA-P NH_4OAc- K
YIELD = 337.5393 - 0.4764 * SN - 9.0312 * SP + 0.6461 * SK - 0.5592 * FN - 4.8053 * FP + 1.4558 * FK - 0.0014 * FN² - 0.0023 * FP² - 0.0024 * FK² + 0.0078 * FNSN + 0.2498 * FPSP - 0.0062 * FKSK	0.676	Alkaline $KMnO_4N$ ABDTPA-P ABDTPA- K
YIELD = 338.7932 - 0.4735 * SN - 8.8902 * SP + 0.6306 * SK - 0.5575 * FN - 4.7423 * FP + 1.4020 * FK - 0.0014 * FN² - 0.0021 * FP² - 0.0024 * FK² + 0.0077 * FNSN + 0.2463 * FPSP - 0.0059 * FKSK	0.675	Alkaline $KMnO_4N$ ABDTPA-P Mehlich- K
YIELD = 247.4948 - 0.6373 * SN - 3.4194 * SP + 0.5943 * SK - 0.6767 * FN - 2.8095 * FP + 1.4872 * FK - 0.0012 * FN² + 0.0029 * FP² - 0.0030 * FK² + 0.0084 * FNSN + 0.1377 * FPSP - 0.0055 * FKSK	0.652	Alkaline $KMnO_4N$ Mehlich-P NH_4OAc- K
YIELD = 244.9651 - 0.6356 * SN - 3.4708 * SP + 0.6160 * SK - 0.6757 * FN - 2.8052 * FP + 1.5168 * FK - 0.0012 * FN² + 0.0028 * FP² - 0.0031 * FK² + 0.0084 * FNSN + 0.1377 * FPSP - 0.0057 * FKSK	0.652	Alkaline $KMnO_4N$ Mehlich-P ABDTPA- K
YIELD = 245.4208 - 0.6360 * SN - 3.2726 * SP + 0.5957 * SK - 0.6805 * FN - 2.7007 * FP + 1.4595 * FK - 0.0012 * FN² + 0.0029 * FP² - 0.0031 * FK² + 0.0083 * FNSN + 0.1329 * FPSP - 0.0054 * FKSK	0.651	Alkaline $KMnO_4N$ Mehlich-P Mehlich- K

by **Bordoloi (2013)** in maize in acid soil**.** As presented above the magnitude of R^2 was 0.672 for organic carbon and 0.687 for alkaline $KMnO_4$ N. While R^2 was 0.687 for Olsen's P, 0.675 for AB-DTPA P and 0.652 for Mehlich P . The value of R^2 was 0.687 for Ammonium acetate K, 0.688 for AB-DTPA K and 0.686 for Mehlich K. Above equation clearly showed that alkaline $KMnO_4$ N, Olsen's P and AB-DTPA K are the better method to determine over all for turmeric grown in Mollisol of *Tarai* region of Uttarakhand.

Ghanei (2004) found that the amount of extractable P decreases in the order: 0.01 *M* $CaCl_2$ <Pi2<AB-DTPA<Pil< Olsen< colwell< Mehlich-1<0.1*M* HCl. However, Mehlich-3 method extracted the largest amount of P (14.54 - 67.35 mg·kg−1) while Olsen extracted the smallest amount (3.25 - 32.77 mg·kg−1). The average extractable P in soils was found to be in the order of Olsen < Kelowna < Bray & Kurtz-1 < Mehlich-3. Although the four methods extracted different amounts of P from soil, values of P extracted by the different methods were strongly correlated among themselves (R2 = 0.87 to 0.95) reported by **Sarkar *et al.,* (2014)** .

Neutral normal ammonium acetate method of potassium extraction worked well for sorghum crop. Potassium extracted with N NH_4OAc pH 7.0 gave the best indication of dry matter yields reported by **Affinnih *et al.,* (2014)**. Similar finding were observed by **Shanwal and Singh (2004)** and **Ghanei and Hosseinpur, (2004)** in his experiment showed that the amount of extractable P decreases in the order: 0.01 M $CaCl_2$< Pi-2< AB-DTPA< Pi-1 < Olsen < Colwell< Mehlich-1< 0.1 M HCl.

From the above result and discussion, it can be suggested Alkaline $KMnO_4$ method for soil available nitrogen, Olsen's P for soil available phosphorus but for easily estimate of AB-DTPA P and AB-DTPA K method for soil available potassium in laboratory use due to multi extractants, can be taken as indices for determining N, P and K in Mollisol of Uttarakhand particularly for turmeric and other crops in general.

4.3 Yield and nutrient content of turmeric

Strip wise and plot wise fresh and dry matter yield with N, P and K content of rhizome given in appendix V & VI while range and average of experimental field is given in table 4.4.

4.3.1 Fresh yield

Rhizome fresh yield (q ha^{-1}) of experimental field ranged from 113.33 to 354.17 with an average of 235.22. Average rhizome yield recorded in strip III (257.36

q ha^{-1}) was followed by strip II (227.11 q ha^{-1}) and in strip I (221.21 q ha^{-1}). Haulm yield (q ha^{-1}) of experimental field ranged from 9.33 to 45.00 with an average of 25.97 q ha^{-1}. Average haulm yield recorded in strip III (30.25 q ha^{-1}) was followed by strip I (23.89 q ha^{-1}) and in strip II (23.78 q ha^{-1}).

4.3.2 Dry matter yield

Dry matter yield of rhizome (q ha^{-1}) in experimental field varied from 58.77 to 183.67 with an average 121.99 q ha^{-1}. Average Dry matter yield of rhizome recorded in order of strip III (133.46 q ha^{-1}) was followed by strip II (117.78 q ha^{-1}) and strip I (114.72 q ha^{-1}). However, dry matter yield of haulm (q ha^{-1}) in experimental field varied from 6.39 to 30.83 with an average 17.19 q ha^{-1}. Average dry matter yield of haulm recorded in order of strip III (20.72 q ha^{-1}) was followed by strip I (16.37 q ha^{-1}) and strip II (16.29 q ha^{-1}). Similar results also reported by **Manhas and Gill (2010).**

Table 4.4. Range and average fresh and dry matter yield and nutrient content of turmeric

Particulars		Strip I	Strip II	Strip III	Whole field
Rhizome	**Fresh yield (q ha^{-1})**	113.33-286.88 (221.21)	123.95-340.00 (227.11)	134.58-354.17 (257.36)	113.33-354.17 (235.22)
	Dry matter yield (q ha^{-1})	58.77-148.77 (114.72)	64.28-176.32 (117.78)	69.79-183.67 (133.46)	58.77-183.67 (121.99)
	N content (%)	1.12-1.96 (1.61)	1.12-2.03 (1.59)	1.05-2.03 (1.54)	1.05-2.03 (1.58)
	P content (%)	0.23-0.28 (0.25)	0.24-0.29 (0.26)	0.22-0.28 (0.25)	0.22-0.29 (0.26)
	K content (%)	1.05-2.90 (1.83)	1.20-2.50 (1.88)	1.40-2.90 (1.92)	1.05-2.90 (1.88)
Haulm	**Fresh yield (q ha^{-1})**	**10.83-37.50 (23.89)**	**12.33-35.83 (23.78)**	**9.33-45.00 (30.25)**	**9.33-45.00 (25.97)**
	Dry matter yield (q ha^{-1})	7.42-25.69 (16.37)	8.45-24.55 (16.29)	6.39-30.83 (20.72)	6.39-30.83 (17.79)
	N content (%)	0.42-1.54 (1.10)	0.84-1.61 (1.19)	0.91-1.61 (1.22)	0.42-1.61 (1.17)
	P content (%)	0.12-0.19 (0.16)	0.13-0.19 (0.16)	0.13-0.18 (0.16)	0.12-0.19 (0.16)
	K content (%)	0.27-0.46 (0.36)	0.23-0.66 (0.42)	0.25-0.77 (0.42)	0.23-0.77 (0.40)

4.3.3 Nitrogen content

Nitrogen content of rhizome (%) in experimental field varied from 1.05 to 2.03 with an average 1.58%. Average N content of rhizome recorded in order of strip I (1.61%) was followed by strip II (1.59%) and strip III(1.54%). However, N content of haulm (%) in experimental field varied from 0.42 to 1.61 with an average 1.17%. Average N content of haulm recorded in order of strip III (1.22%) was followed by strip II (1.19%) and strip I (1.10%). Similar results also reported by **Karthikeyan *et al.*, (2009).**

4.3.4 Phosphorus content

Phosphorus content of rhizome (%) in experimental field varied from 0.22 to 0.29 with an average 0.26%. Average P content of rhizome recorded in order of strip II (0.26%) was followed by strip I & III (0.25%). However, P content of haulm (%) in experimental field varied from 0.12 to 0.19 with an average 1.16%. Average P content of haulm recorded in each strip (0.16%). Similar results also reported by **Karthikeyan *et al.*, (2009).**

4.3.5 Potassium content

Potassium content of rhizome (%) in experimental field varied from 1.05 to 2.90 with an average 1.88%. Average K content of rhizome recorded in order of strip III (1.92%) was followed by strip II (1.88%) and strip I (1.83%). However, K content of haulm (%) in experimental field varied from 0.23 to 0.77 with an average 0.40%. Average K content of haulm recorded in order of strip III & II (0.42%) was followed by strip I (0.36%). Similar results also reported by **Karthikeyan *et al.* (2009).**

Average rhizome and haulm yields followed the following trend among the strips:

Strip III > Strip II > Strip I and Strip III > Strip I > Strip II, respectively.

Rhizome yield of turmeric under same strip with varying levels of FYM (F0= 0, F1= 10 and F2= 20 t ha^{-1}) of control $N_0P_0K_0$ plots showed the following trend:

Strip I: $F_2 > F_1 > F_0$

Strip II: $F_2 > F_1 > F_0$

Strip III: $F_2 > F_1 > F_0$

The above trend followed the expected trend of soil fertility. Higher rhizome yield was obtained due to application of higher dose of nitrogen, phosphorus and potassium. The plants grown with N, NP, NK or NPK remained green much longer, which contributed to longer photosynthesis and resulted in a higher shoot biomass of turmeric reported by **Akamine *et al.* (2007). Behura (2001)** also reported that chemical fertilizer of N and K applied in a certain ratio showed higher efficacy on turmeric yield. However, it is assumed that ratio may differ with the soil nutrient status. While, organic fertilizer improved soil productivity and fertility, which improved yield and quality of such long duration crop like turmeric **(Hossain & Ishimine, 2007; Velmurugan *et al.,* 2007; Mohapatra & Das 2009; Roy *et al.,* 2010; Dinesh *et al.,* 2010). Manhas & Gill (2010)** also found that application of FYM increased the growth, dry matter accumulation, yield and quality of turmeric. **Kamal and Yousuf (2012)** also recorded that highest estimated fresh rhizome yield & cured rhizomes yield 294.8 q ha^{-1} 5.59 q ha^{-1}, respectively.

4.4 Nutrient uptake by turmeric

Strip wise and plot wise nitrogen, phosphorus and potassium uptake of turmeric given in appendix VII while range and average of experimental field is given in table 4.5.

4.4.1 Nitrogen Uptake

Nitrogen uptake (kg ha^{-1}) by the rhizome in experimental field varied from 65.83 to 342.0 with an average 194.06 kg ha^{-1}. Average nitrogen uptake recorded in order of strip III (207.84 kg ha^{-1}) followed by strip II (188.70 kg ha^{-1}) and strip I (185.65 kg ha^{-1}). However, nitrogen uptake (kg ha^{-1}) by the haulm in experimental field varied from 3.14 to 45.95 with an average 21.25 kg ha^{-1}. Average nitrogen uptake by the haulm recorded in order of strip III (25.60 kg ha^{-1}) followed by strip II (19.70 kg ha^{-1}) and strip I (18.45 kg ha^{-1}). Therefore, total nitrogen uptake (kg ha^{-1}) by the crop in experimental field varied from 68.96 to 371.83 with an average 215.31 kg ha^{-1}. Average nitrogen uptake recorded in order of strip III (233.44 kg ha^{-1}) followed by strip II (208.39 kg ha^{-1}) and strip I (204.11 kg ha^{-1}).

The lower uptake of N in control plots may be due to lower yield obtained in these plots. Addition of N significantly enhanced its uptake over control. These results corroborate the finding of **Singh *et al.* (2005),** who have reported that an increase in the levels of nutrients increased the uptake of nutrients due to increase in growth attributing characters like plant height, leaves number, finger weight, finger size and turmeric yield were influenced by N application. It was also found that with the increment of N levels, all the yield contributing parameters increased progressively reported by **Haque *et al.,* (2007).**

Table 4.5: Range and average nutrient uptake of turmeric under different strips.

Particulars	Uptake (kg ha^{-1})	Strip I	Strip II	Strip III	Whole field
Rhizome	**Nitrogen**	65.83-246.47 (185.65)	76.49-297.51 (188.70)	97.71-342.0 (207.84)	65.83-342.0 (194.06)
	Phosphorus	13.40-38.79 (29.29)	15.17-46.20 (30.52)	15.08-49.59 (33.54)	13.40-49.59 (31.12)
	Potassium	67.59-383.50 (214.87)	89.99-396.73 (225.50)	97.71-479.38 (259.07)	67.59-479.38 (233.14)
Haulm	**Nitrogen**	3.14-37.76 (18.45)	7.10-38.60 (19.70)	5.82-45.95 (25.60)	3.14-45.95 (21.25)
	Phosphorus	0.91-4.03 (2.56)	1.08-4.57 (2.61)	0.83-4.97 (3.30)	0.83-4.97 (2.82)
	Potassium	2.64-10.34 (5.91)	1.93-14.58 (7.12)	1.57-16.66 (9.04)	1.57-16.66 (7.36)
Total (Rhizome + Haulm)	**Nitrogen**	68.96 – 263.40 (204.11)	83.59 – 323.40 (208.39)	103.53 – 371.88 (233.44)	68.96-371.88 (215.31)
	Phosphorus	14.31 – 42.05 (31.85)	16.25 – 48.78 (33.13)	15.91 – 54.56 (36.84)	14.31-54.56 (33.94)
	Potassium	70.23 – 389.48 (220.78)	91.92 – 407.59 (232.62)	99.29 – 489.23 (268.11)	70.23-489.23 (240.50)

4.4.2 Phosphorus uptake

Phosphorus uptake (kg ha^{-1}) by the rhizome in whole field varied from 13.40-49.59 with an average 31.12 kg ha^{-1}. Average phosphorus uptake recorded in order of strip III (33.54 kg ha^{-1}) followed by strip II (30.52 kg ha^{-1}) and strip I (29.29 kg ha^{-1}). However, phosphorus uptake (kg ha^{-1}) by the haulm in experimental field varied from 0.83 to 4.97 with an average 2.82 kg ha^{-1}. Average phosphorus uptake by the haulm recorded in order of strip III (3.30 kg ha^{-1}) followed by strip II (2.61 kg ha^{-1}) and strip I (2.56 kg ha^{-1}). Therefore, total phosphorus uptake (kg ha^{-1}) by the crop in experimental field varied from 14.31 to 54.56 with an average 33.94 kg ha^{-1}. Average phosphorus uptake recorded in order of strip III (36.84 kg ha^{-1}) was followed by strip II (33.13 kg ha^{-1}) and strip I (31.85 kg ha^{-1}).

Greater nutrient uptake by the crop in the applied inorganic nutrients with FYM indicated good synchrony between nutrient release and crop requirement during the active vegetative growth stage. Similar results finding by **Srinivasan *et al.* (2016).**

4.4.3 Potassium uptake

Potassium uptake (kg ha^{-1}) by the rhizome in whole field varied from 67.59 to 479.38 with an average 233.14 kg ha^{-1}. Average potassium uptake recorded in order of strip III (259.07 kg ha^{-1}) followed by strip II (225.50 kg ha^{-1}) and strip I (214.87 kg ha^{-1}). However, potassium uptake (kg ha^{-1}) by the haulm in experimental field varied from 1.57 to 16.66 with an average 7.36 kg ha^{-1}. Average potassium uptake by the haulm recorded in order of strip III (9.04 kg ha^{-1}) followed by strip II (7.12 kg ha^{-1}) and strip I (5.91 kg ha^{-1}). Therefore, total potassium, uptake (kg ha^{-1}) by the crop in experimental field varied from 70.23 to 489.23 with an average 240.50 kg ha^{-1}. The order of average potassium uptake recorded in order of strip III (268.11 kg ha^{-1}) > strip II (232.62 kg ha^{-1}) > strip I (220.78 kg ha^{-1}).

The beneficial effect of K application on rhizome K content is in agreement with the findings of **Subramanian *et al*., (2001).** Since both dry weight yields of the rhizomes and their respective nutrient contents were considerably increased by K application, the effect of K fertilization in increasing uptake of N, P and K as the products of dry matter and nutrient content was even greater. **Karthikeyan *et al*., (2009)** also reported similar result.

In general, the amount of nutrient uptake in turmeric was in the order of phosphorus < potassium< nitrogen, with slight variations in the values of nitrogen and potassium uptake.

Ranges and averages of uptake of N, P and K with varying levels of FYM for turmeric are presented in table 4.6.

Average nutrient uptake of N, P and K followed the following trend among the strips: Strip III > Strip II > Strip I.

Uptake of N, P and K with varying levels of FYM showed the following trend in $N_0P_0K_0$ plots (table 4.5):

Nitrogen	Phosphorus	Potassium
Strip I: $F_2 > F_1 > F_0$	Strip I: $F_2 > F_1 > F_0$	Strip I: $F_2 > F_1 > F_0$
Strip II: $F_2 > F_1 > F_0$	Strip II: $F_2 > F_1 > F_0$	Strip II: $F_1 > F_2 > F_0$
Strip III: $F_2 > F_1 > F_0$	Strip III: $F_2 > F_1 > F_0$	Strip III: $F_2 > F_1 > F_0$

Table 4.6: Uptake of N, P and K with varying levels of FYM in control plots.

Plot No	Treatment	Strip I uptake (kg ha^{-1})			Plot No	Strip II uptake (kg ha^{-1})			Plot No	Strip III uptake (kg ha^{-1})		
		N	P	K		N	P	K		N	P	K
11	$N_0P_0K_0OM_2$	128.37	26.68	185.82	35	129.06	31.2	143.69	58	139.2	26.6	187.23
7	$N_0P_0K_0OM_1$	148.13	24.99	102.68	41	159.39	26.9	218.66	67	161.9	29.0	179.81
22	$N_0P_0K_0OM_0$	68.96	14.31	70.23	47	83.59	16.2	91.92	72	103.5	15.9	99.29

The above trend shows that uptake of nutrients by the crop followed the trend accordance with the yield of the crop and expected fertility of the strip resulted from the addition of fertilizers in gradient stabilizing experiment. The growth and yield of crop plants are also determined by the presence of sufficient quantities of nutrients in the soil in available form for their uptake. Uptake of nutrients is associated with the concentration and the distribution of ions in the external medium. Application of organic manures increased the concentration of nutrient ions in the soil solution.

Increase in the uptake of NPK in turmeric might be due to similar increases in NPK contents in rhizomes as well as increased rhizome yields. The highest fertility level resulted in maximum uptake of N, P and K. The positive influence of N and K fertilizers on root-shoot growth, yield attributes, yield and nutrients uptake might be due to increased number of leaves and their size development, increased photosynthates and their effective translocation towards developing reproductive organs (rhizomes). The present findings corroborate with those of other workers

(**Reddy *et al.,* 2008, Chaurasa *et al*., 2009** and **Pandey *et al.,* 2012). Ahirwar *et al.,* (2015)** also reported that the maximum uptake of N (158.6 kg ha^{-1}), P (51.9 kg ha^{-1}) and K (107.8 kg ha^{-1}).

From above results it can be interpreted that combined use of inorganic fertilizer with FYM in most of the cases increased uptake of nutrients by the crops. Increase in nitrogen uptake might be due to increased supply of nutrients directly through organic (FYM) and fast decomposition of crop resides and inorganic sources to the crops as well as indirectly through checking the loss of nutrients from soil solution which resulted in better growth. In presence of FYM may be increase in microbial population which favors soil environment. In FYM treated plots with chemical fertilizer, uptake of nitrogen increased due to growth promoting harmones, which ultimately increased nitrogen uptake.

In case of increase in uptake of phosphorus with the use of FYM is might be due to that FYM not only supplied phosphorus by its own but also solubilized it with organic acids produced from the decomposition of organic matter and also provides favorable soil conditions for the microorganisms. The probable reason for increase in potassium uptake is due to good content of potassium in organic sources (FYM) and mineralization of potassium from organic matter. Similar results were also found by **Shri *et al.* (2004).**

4.5 Basic data to calculate fertilizer dose for targeted yields of turmeric (*Curcuma longa* L.)

Experimental data of rhizome yield, nutrient uptake, available nutrients in initial soil samples, applied dosed of N, P and K nutrients through fertilizers and farmyard manure were used to compute basic parameters viz., the nutrient equirement for producing one quintal of turmeric rhizome (NR), the percent contribution of nutrients from soil (C_S), fertilizers (C_F) and FYM (C_{FYM}). These basic parameters required for formulating the fertilizers prescription equation with or without FYM for targeted yield of turmeric are presented in table 4.7.

The nutrient requirement for the production of one-quintal turmeric rhizome was 0.91 kg of Nitrogen, 0.32 kg of Phosphorus (P_2O_5) and 1.02 kg of Potassium (K_2O) presented in (Table 4.7). Percent contribution of nitrogen, Phosphorus and Potassium from soil was 61.45, 56.13 and 69.35, respectively. Contribution from fertilizer as percentage of its nutrient content was 119.29, 45.13 and 201.96 without FYM and 143.67, 53.94 and 265.11 with FYM for Nitrogen, Phosphorus and Potassium, respectively. Contribution from farmyard manure as percentage of its nutrient content was 46.31, 10.3 and 74.91 for Nitrogen, Phosphorus and Potassium, respectively.

Table 4.7: Basic data for calculating fertilizer dose with and without FYM for targeted yield of turmeric

S. No	Particulars	Without FYM			With FYM		
		N	P	K	N	P	K
1.	*Nutrient requirement (kg q^{-1})	0.91	0.32	1.02	0.91	0.32	1.02
2.	Contribution of available nutrient from soil (%)	61.45	56.13	69.35	61.45	56.13	69.35
3.	Contribution from applied fertilizer (%)	119.29	45.13	201.96	143.67	53.94	265.11
4.	Nutrients contribution from applied FYM (%)	-	-	-	46.31	10.3	74.91

*Nutrient requirement : N, P_2O_5, K_2O

4.6. Fertilizer adjustment equations:

Soil test based fertilizer recommendation equations for nitrogen, phosphorus and potassium were developed for desired target yields of turmeric with and without FYM using the basic parameters presented in table 4.8.

Table 4.8. Soil test based fertilizer adjustment equations for targeted yield of turmeric

Fertilizer dose (kg ha^{-1})	N, P_2O_5, K_2O with FYM	N, P_2O_5, K_2O without FYM
Nitrogen	FN= 0.63T- 0.42 SN-0.32 ON	FN= 0.76 T–0.52 SN
Phosphorus	FP_2O_5= 0.59T-2.38 SP- 0.43 OP	FP_2O_5 = 0.71 T–2.85 SP
Potassium	FK_2O= 0.38 T-0.31 SK-0.34 OK	FK_2O = 0.51 T – 0.41 SK

T= yield target (q ha^{-1}), SN= Alkaline $KMnO_4$-N, SP= Olsen's- P (kg ha^{-1}), SK= Amm. Ac. -K (kg ha^{-1}),ON =Amount of N applied through FYM (kg ha^{-1}), OP= Amount of P applied through FYM (kg ha^{-1}) and OK= Amount of K applied through FYM (kg ha^{-1}), FN= Fertilizer dose of nitrogen (kg ha^{-1}), FP_2O_5= Fertilizer dose of phosphorus (kg ha^{-1}), FK_2O=Fertilizer dose of potassium (kg ha^{-1}), respectively.

4.7 N, P_2O_5 and K_2O requirements for different yield targets of turmeric with and without combination of FYM

Fertilizer adjustment equations for calculating nutrient requirement with and without FYM are given in table 4.9, 4.10 & 4.11. These equations were developed with the help of basic data.

4.7.1 Without using FYM

Nutrient requirements for different yield targets were calculated with the help of targeted yield equations. Ready reckoners of N, P_2O_5 and K_2O requirement are given in table 4.9 and also presenting in the form of bar diagram i.e. fig (4.1 to 4.3).

Since rhizome yield in the present investigation varied from 113.33 to 354.17 with an average of 235.22. Therefore, 200, 275 and 350 q ha^{-1} yield targets were selected for nutrient requirement calculations. The soil test value ranged of nitrogen range from 112.90 to 263.42, for phosphorus 16.97 to 29.27 and for potassium 58.24 to 189.28. Therefore, soil test values considered within these ranges to calculate nutrient requirement for targeted yield of turmeric.

To achieve 200 q ha^{-1} yield target, 74.00 kg Nitrogen ha^{-1} was needed at the soil test value of 150 kg N ha^{-1} Nitrogen, whereas for the same yield target at 200 kg soil test value for alkaline N ha^{-1}, only 48.00 kg of Nitrogen as fertilizer was required. Further, if the soil test value of Nitrogen reaches to 250 kg ha^{-1} then to reach the same yield target only 22.00 kg N ha^{-1} needed (table 4.9).

Similarly, fertilizer Phosphorus requirement for targeted yield of 200 q ha^{-1}at lower soil test value i.e. 15 kg ha^{-1} of Olsen's Phosphorus requirement follow was 99.3 kg ha^{-1}. At the soil test, value of 20 kg of P ha^{-1} to achieve same yield target (200 q ha^{-1}), the requirement of fertilizer Phosphorus was 85.0 kg ha^{-1}. Further, if soil test value reaches 25 kg Olsen's P ha^{-1}, the fertilizer Phosphorus needed would be 70.8 kg ha^{-1} to meet the same yield target of 200 q ha^{-1} (table 4.9).

Potassium fertilizer requirement for targeted yield of 200 q ha^{-1} where soil test value of Potassium was 75 kg ha^{-1} NH_4OAC-K, was 71.3 kg fertilizer Potassium. While at 125 kg ha^{-1} and 175 kg ha^{-1} soil test values of Potassium, need of potasic fertilizer for same yield target were 50.8 and 30.3 kg ha^{-1}, respectively as given in table 4.9.

Table 4.9: N, P_2O_5, K_2O requirements for different yield targets of turmeric without using FYM

Soil test values (kg/ha)	Yield targets of turmeric (q ha^{-1})		
	200	**275**	**350**
Alkaline $KMnO_4$ N	**N requirements (kg ha^{-1})**		
150	74.0	131.0	188.0
200	48.0	105.0	162.0
250	22.0	79.0	136.0
Olsen's P	**P_2O_5 requirements (kg ha^{-1})**		
15	99.3	152.5	205.8
20	85.0	138.3	191.5
25	70.8	124.0	177.3
Amm. Ac.-K	**K_2O requirements (kg ha^{-1})**		
75	71.3	109.5	147.8
125	50.8	89.0	127.3
175	30.3	68.5	106.8

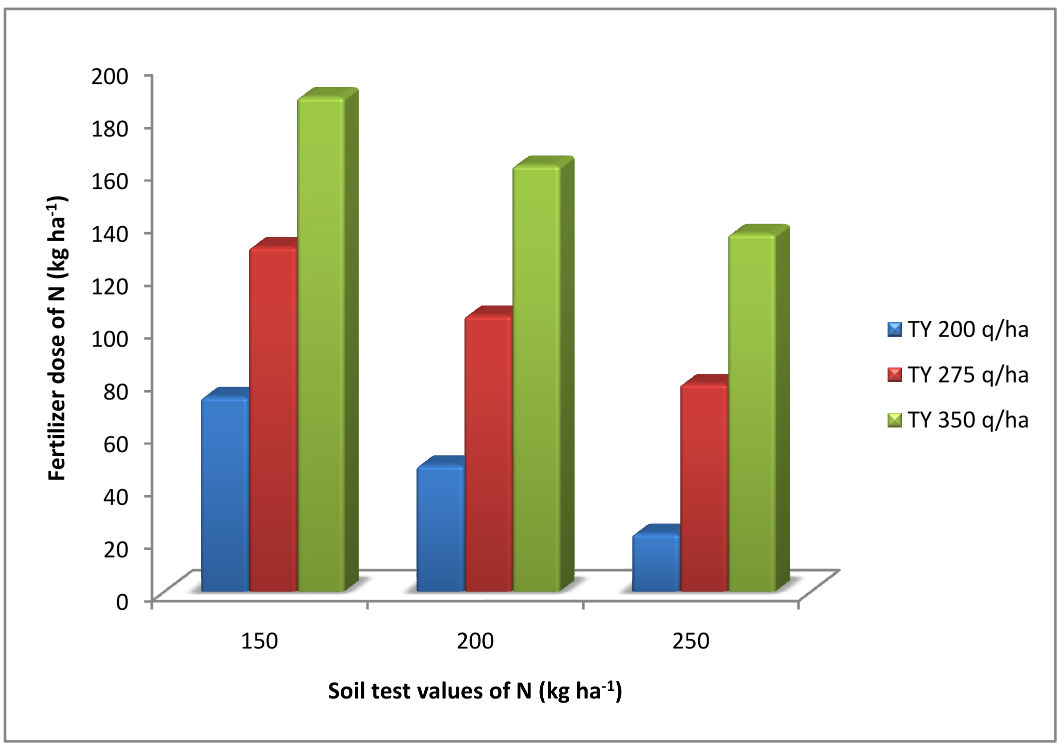

Fig. 4.1: N requirements of turmeric at different soil test values and yield targets

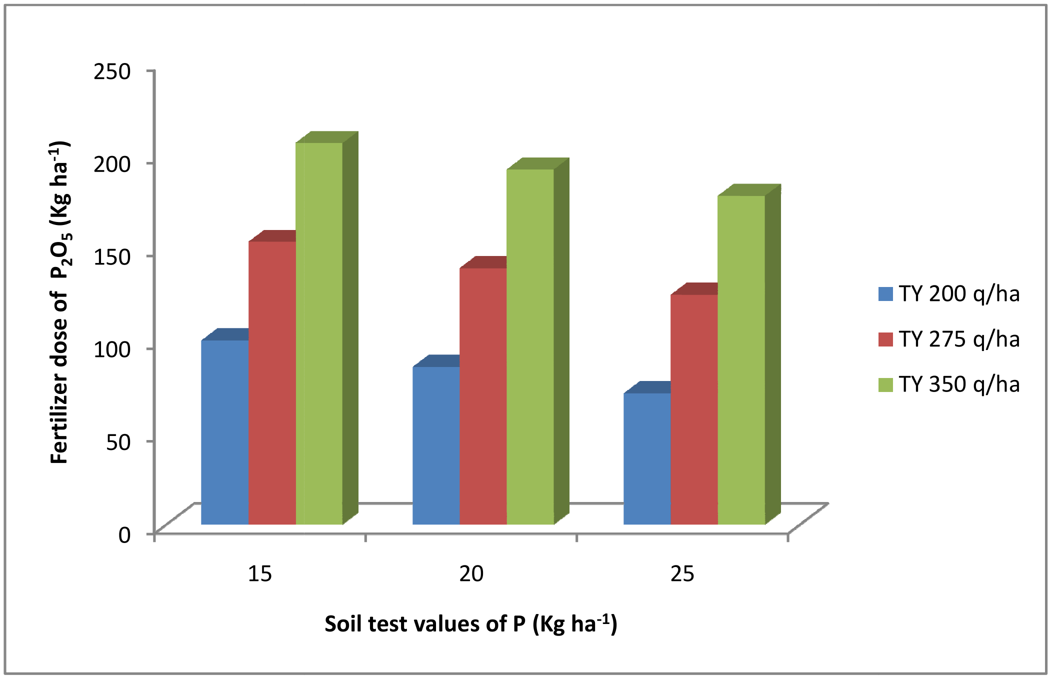

Fig. 4.2: P_2O_5 requirements of turmeric at different soil test values and yield targets

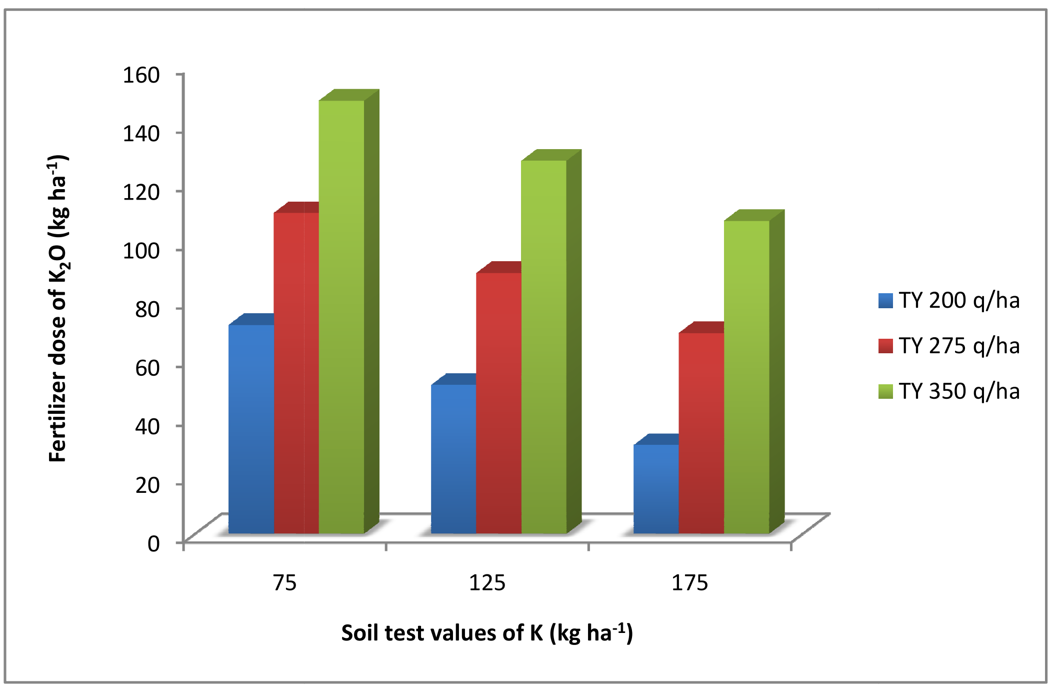

Fig. 4.3: K_2O requirements of turmeric at different soil test values and yield targets

4.7.2 Fertilizer requirement with conjoint use of FYM

4.7.2.1 Fertilizer requirement with 10 t FYM

Nutrient requirements for different yield targets were calculated with the help of targeted yield equations. The ready reckoners of N, P_2O_5 and K_2O requirements are given in table 4.10 and also presenting in the form of bar diagram i.e. fig (4.4 to 4.6).

Since fertilizer requirements basically depends on yield and soil test value in a given agro climatic region. Therefore fertilizer doses observed with changing soil test value and yield. Rhizome yield ranged from 113.33 to 354.17 q ha^{-1} therefore 200, 275 and 350 q ha^{-1} yield were selected to calculate nutrient requirement for target yield of turmeric with conjoint use of FYM (10 tonnes). The soil test value ranged for nitrogen as 112.90 to 263.42, for phosphorus 16.97 to 29.27 and for potassium 58.24 to 189.28 kg ha^{-1}, therefore, soil test value considered within these range to calculate nutrient requirement for targeted yield with conjoint use of FYM (10 tonnes).

Achieve 200 q ha^{-1} yield targets, 44.76 kg Nitrogen ha^{-1} was needed at the soil test value of 150 kg N ha^{-1}, whereas for the same yield target at 200 kg soil test value for alkaline $KMnO_4$-N ha^{-1}, 23.76 kg of Nitrogen as fertilizer was required. Further, if the soils test value of Nitrogen reaches to 250 kg ha^{-1} then to reach the same yield target only 2.76 kg N ha^{-1} needed presented in (Table 4.10).

Similarly, fertilizer Phosphorus requirement for targeted yield of 200 q ha^{-1} at soil test value i.e. 15 kg ha^{-1} of Olsen's Phosphorus requirement was 68.54 kg ha^{-1}. At the soil test value of 20 kg of Olsen's P ha^{-1} to achieve same yield target (200 q ha^{-1}) requirement of fertilizer Phosphorus was 56.64 kg ha^{-1}. However, where soil test value reaches 25 kg Olsen's P ha^{-1}, the fertilizer Phosphorus was 44.74 kg ha^{-1} needed presented in (Table 4.10).

Potassium fertilizer requirement for targeted yield of 200 q ha^{-1} at soil test value of Potassium 75 kg ha^{-1} NH_4OAC-K, was 33.03 kg ha^{-1} fertilizer Potassium. While at 125 kg ha^{-1} and 175 kg ha^{-1} soil test values of Potassium, need of potasic fertilizer for same yield target were 17.53 and 10.5 kg ha^{-1}, respectively as given in table 4.10.

Table 4.10: N, P_2O_5 and K_2O requirements for different yield targets of turmeric using 10 t FYM

Soil test values (kg/ha)	Yield targets of turmeric (q ha^{-1})		
	200	**275**	**350**
Alkaline $KMnO_4$ N	N requirements (kg ha^{-1})		
150	44.76	92.01	139.26
200	23.76	71.01	118.26
250	2.76	50.01	97.26
Olsen's P	P_2O_5 requirements (kg ha^{-1})		
15	68.54	112.79	157.04
20	56.64	100.89	145.14
25	44.74	88.99	133.24
Amm. Ac.-K	K_2O requirements (kg ha^{-1})		
75	33.03	61.53	90.03
125	17.53	46.03	74.53
175	2.03	30.53	59.03

Note: In present study FYM contain 0.57%N, 0.32%P and 0.58%K

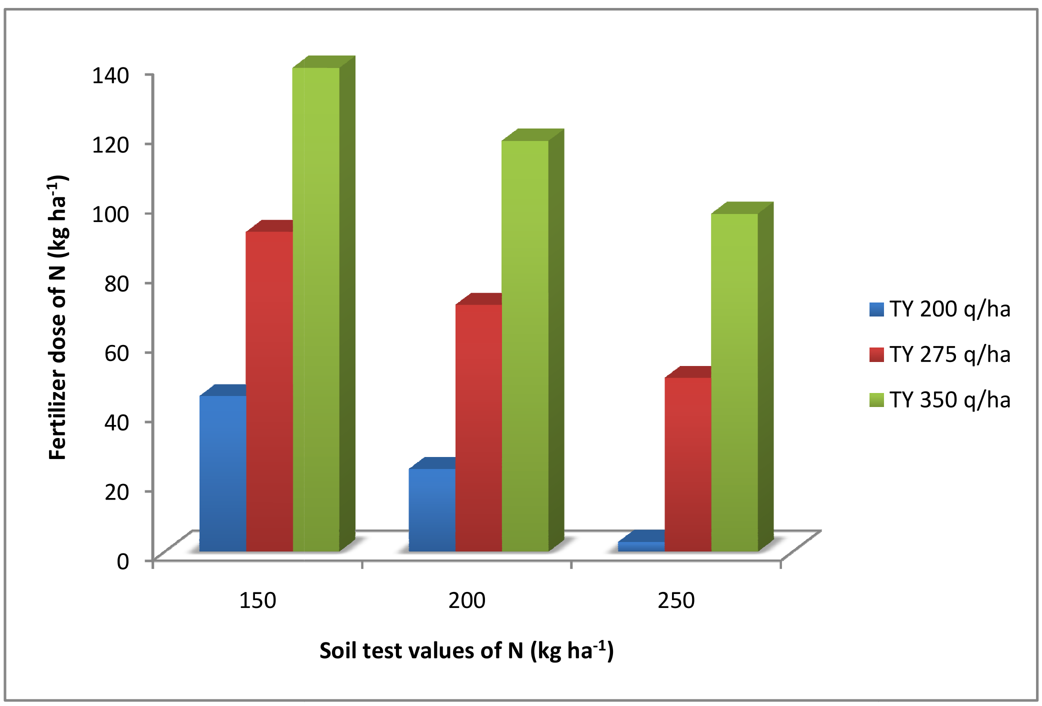

Fig. 4.4: N requirements of turmeric at different soil test values and yield targets with 10 t FYM

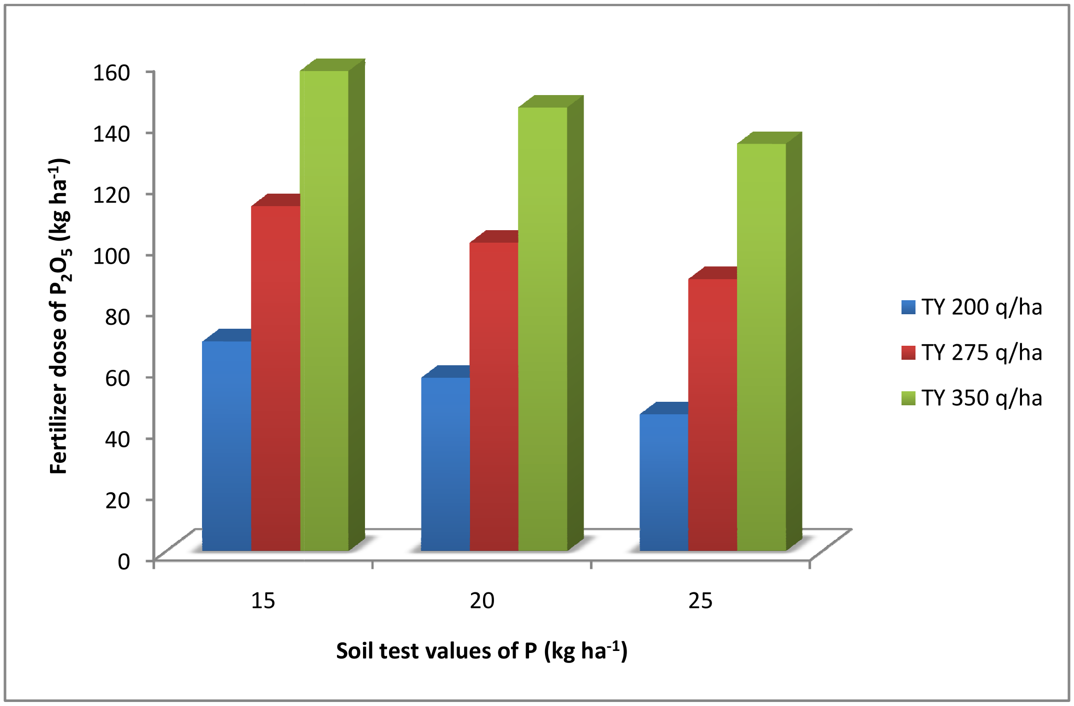

Fig. 4.5: P_2O_5 requirements of turmeric at different soil test values and yield targets with 10 t FYM

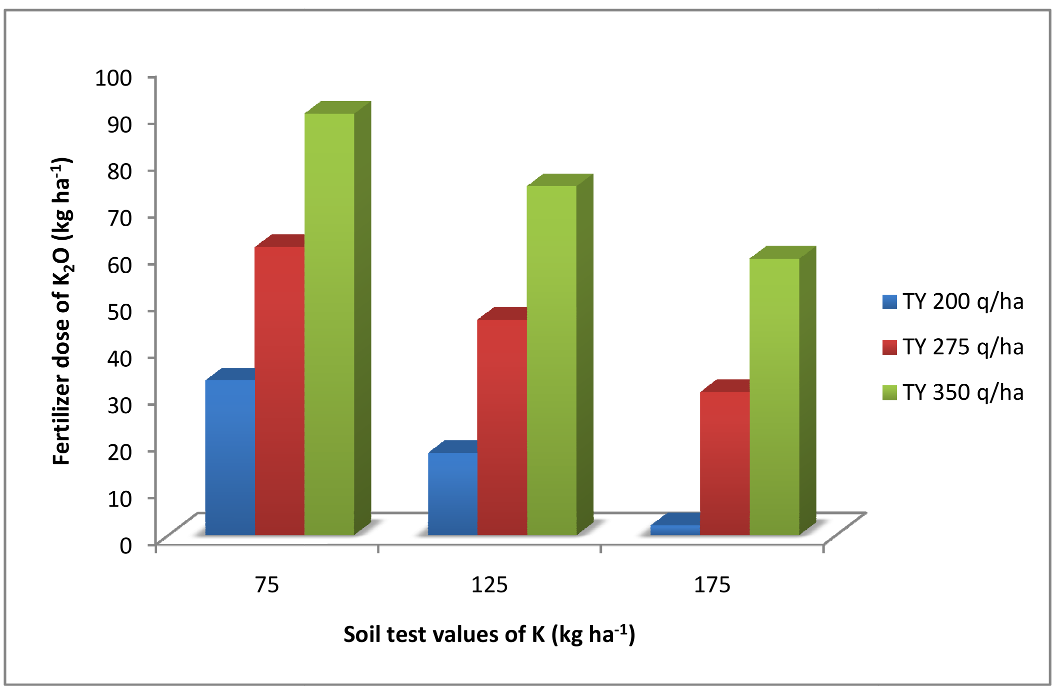

Fig. 4.6: K_2O requirements of turmeric at different soil test values and yield targets with 10 t FYM

4.7.2.2 Fertilizer with 20 t FYM

Nutrient requirements for different yield targets were calculated with the help of targeted yield equations. The ready reckoners of N, P_2O_5 and K_2O requirement are given in table 4.11 and also presenting in the form of bar diagram i.e. fig (4.7 to 4.9).

To achieve 200 q ha^{-1} yield target, 26.52 kg Nitrogen ha^{-1} was needed at the soil test value of 150 kg alkaline $KMnO_4$-N ha^{-1} Nitrogen, whereas for the same yield target at 200 kg N ha^{-1} soil test value, 5.52 kg ha^{-1} of Nitrogen as fertilizer was required. Further, if the soils test value of Nitrogen reaches to 250 kg ha^{-1} then no need of fertilizer to the same yield target presented in (Table 4.11 and fig 4.7 to 4.9).

Similarly, fertilizer Phosphorus requirement for targeted yield of 200 q ha^{-1} at soil test value 15 kg ha^{-1} of Olsen's Phosphorus requirement was 54.78 kg ha^{-1}. At the soil test value of 20 kg of Olsen's P ha^{-1} to achieve same yield target (200 q ha^{-1}) requirement of fertilizer Phosphorus was 42.88 kg ha^{-1}. However, where soil test value reaches 25 kg Olsen's P ha^{-1}, the fertilizer Phosphorus was 30.98 kg ha^{-1} needed presented in (Table 4.11).

Potassium fertilizer requirement for targeted yield of 200 q ha^{-1} where soil test value of Potassium was 75 kg ha^{-1} NH_4OAc-K, 13.31 kg ha^{-1} fertilizer Potassium was required. However, at 125 and 175 kg ha^{-1} soil test values of Potassium then no need of potasic fertilizer for same yield target.

Thus data presented in table no 4.9, 4.10 and 4.11 clearly indicate that N, P and K requirement increase with increasing the yield target of turmeric. However, it decreases with increasing soil test value. Similar finding were reported by **Bera *et al.*, (2006)** and **Regar and Singh (2014).** There was a higher response under NPK with FYM as compared to NPK alone. These could be achieved by integrated use of FYM with NPK fertilizers. The role of FYM is multidimensional ranging from building up of organic matter, maintaining favorable soil physical & biological properties and balanced supply of nutrients as reported by **Katharine *et al.* (2013).**

Table 4.11: N, P_2O_5 and K_2O requirements for different yield targets of turmeric using 20 t FYM

Soil test values (kg/ha)	Yield targets of turmeric (q ha^{-1})		
	200	275	350
Alkaline $KMnO_4$ N	N requirements (kg ha^{-1})		
150	26.52	73.77	121.02
200	5.52	52.77	100.02
250	-	31.77	79.02
Olsen's P	P_2O_5 requirements (kg ha^{-1})		
15	54.78	99.03	143.28
20	42.88	87.13	131.38
25	30.98	75.23	119.48
Amm. Ac.-K	K_2O requirements (kg ha^{-1})		
75	13.31	41.81	70.31
125	-	26.31	54.81
175	-	10.81	39.31

Note: In present study FYM contain 0.57%N, 0.32%P and 0.58%K

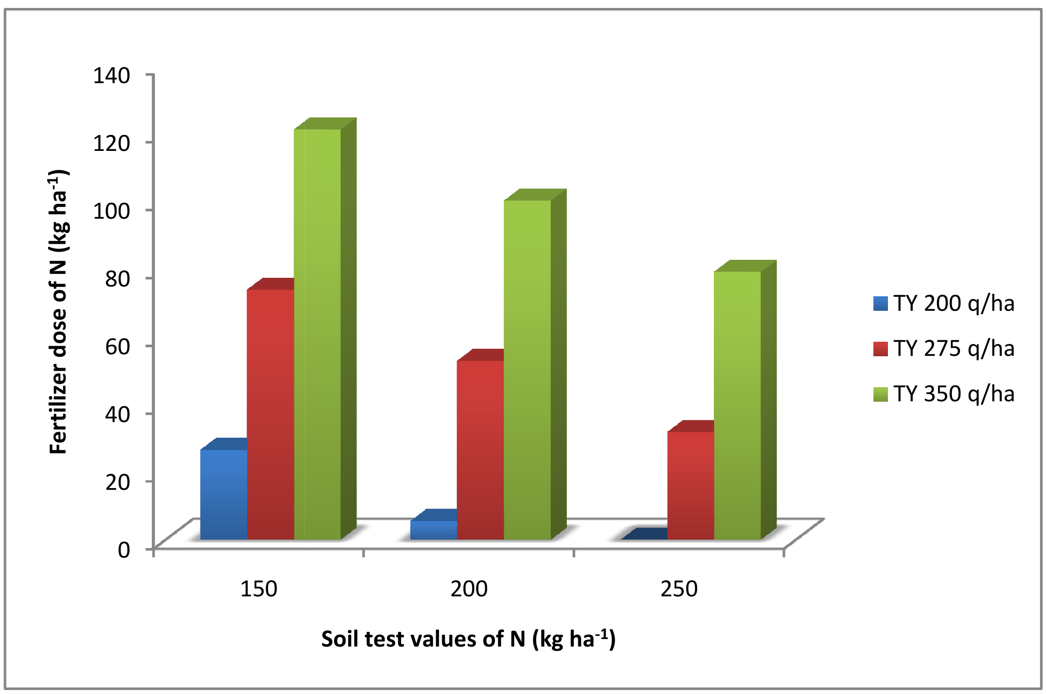

Fig. 4.7: N requirements of turmeric at different soil test values and yield targets with 20 t FYM

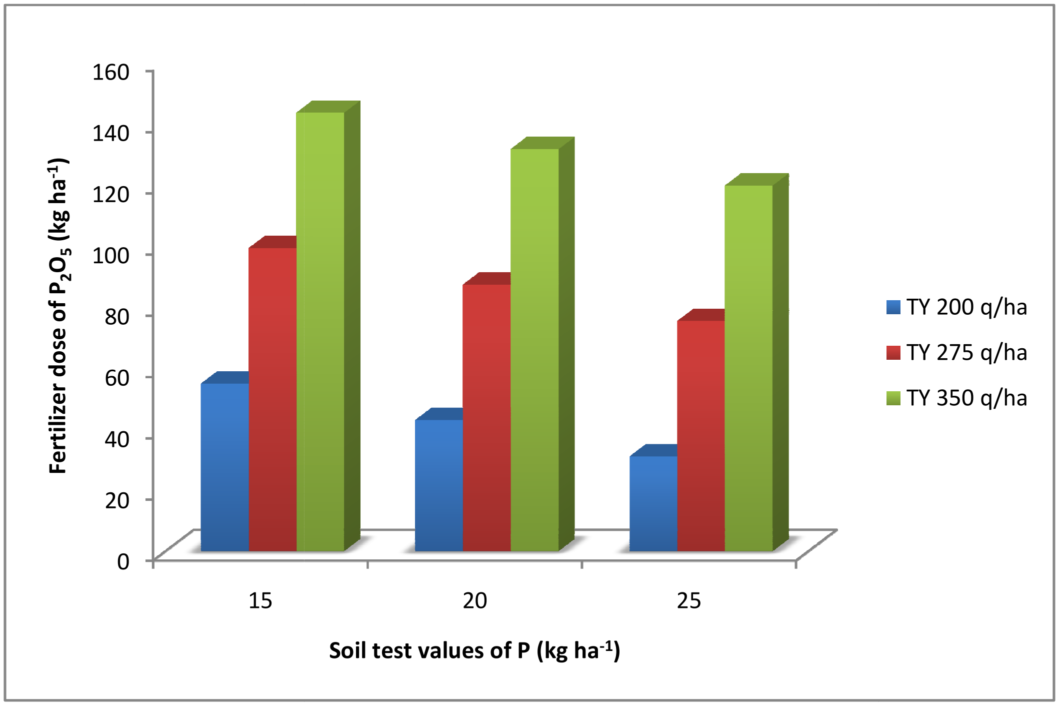

Fig. 4.8: P requirements of turmeric at different soil test values and yield targets with 20 t FYM

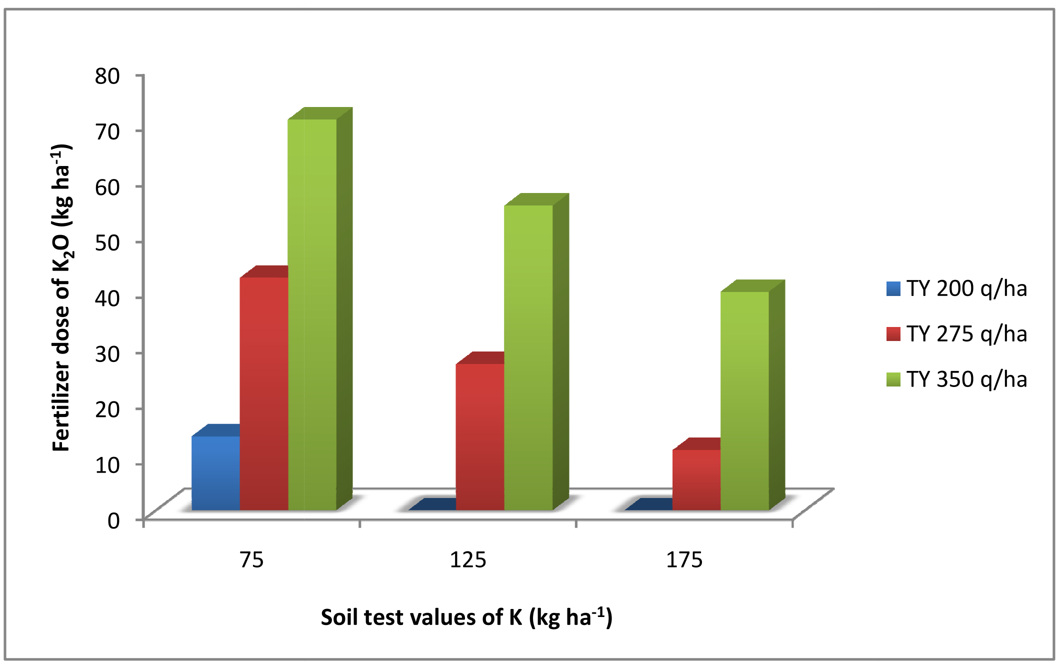

Fig. 4.9: K requirements of turmeric at different soil test values and yield targets with 20 t FYM.

4.8 Fertilizer equivalence of FYM for turmeric

Fertilizer equivalence of FYM in the present investigation was calculated by taking differences in fertilizer requirement of nutrient in question with and without FYM at a particular soil test value and target yield. The average saving of fertilizer by 10.0 tonnes FYM were 33.99 kg ha^{-1} N, 37.36 kg ha^{-1} P and 42.97 kg ha^{-1} K along with the experimental soil test value and yield targets (Table 4.12).

Data presented in table 4.12 and 4.13 clearly shows that FYM equivalence decreases with increases soil test value and similar it has also increase with increasing yield targets. It is clear that the effect of FYM is crop specific and it also varies with level of soil fertility and yield target that ultimately helps in saving fertilizer. FYM in combination with chemical fertilizers increased the available nutrient status of the soil. Further by taking 20 tonnes of FYM the average saving of fertilizer were 50.51 kg ha^{-1} N, 51.12 kg ha^{-1} P and 60.48 kg ha^{-1} K along within the experimental soil test values and yield targets. Fertilizer equivalence of FYM depending on composition of FYM and its amount added. As soil test values increases, fertilizer equivalence of FYM decreases, however, it increases with increasing in yield targets for nitrogen, phosphorus and potassium added through FYM (Fertilizer equivalence of FYM). Similarly result use also reported by **Rawat *et al.,* (2015)** when FYM used in combination of fertilizer. The average value of N, P_2O_5 and K_2O fertilizer equivalences from one tone of FYM used, were 3.39, 3.73 and 4.29 kg ha^{-1} respectively, however, average value of FYM equivalence of N, P_2O_5 and K_2O ranged from 2.89 to 3.89 kg ha^{-1} for N, 3.50 to 3.97 kg ha^{-1} for P_2O_5 and 3.79 to 4.79 kg ha^{-1} for K_2O, respectively, when use by 10 t FYM ha^{-1} (Table 4.12). However, value of N, P_2O_5 and K_2O fertilizer equivalences from one tone FYM were 2.52, 2.56 and 3.02 kg ha^{-1} respectively, however, average value of FYM equivalence of N, P_2O_5 and K_2O ranged from 2.10 to 2.86 for N, 2.44 to 2.67 for P_2O_5 and 2.59 to 3.38 for K_2O, respectively, when use by 20 t FYM ha^{-1}(Table 4.13). The overall average was calculated for per tone FYM from contribution both under 10 & 20 tonne FYM application. Thus, for one tone FYM equivalent, the values were 2.95, 3.14 and 3.65, respectively for N, P_2O_5 and K_2O. Applied FYM doses were doubled but fertilizer equivalences were not doubled due to slow immobilization rate of FYM. Fertilizers saving by use of FYM reported by **Yanthan *et al.,* (2010)** and **Ahirwar *et al.,* (2015)** in turmeric.

Table 4.12: Fertilizer equivalence of FYM (10 t ha^{-1}) under different yield targets and soil test value of turmeric.

Soil test values (kg/ha)	Fertilizer equivalence of 10 t FYM (kg ha^{-1})				Fertilizer equivalence of one t FYM (kg ha^{-1})
	200	275	350	Average	
Alkaline $KMnO_4$ N	N fertilizer equivalence (kg ha^{-1})				
150	29.24	38.99	48.74	38.99	**3.89**
200	24.24	33.99	43.74	33.99	**3.39**
250	19.24	28.99	38.74	28.99	**2.89**
Average	24.24	33.99	43.74	33.99	**3.39**
Olsen's P	P_2O_5 fertilizer equivalence (kg ha^{-1})				
15	30.71	39.71	48.71	39.71	**3.97**
20	28.36	37.36	46.36	37.36	**3.73**
25	26.01	35.01	44.01	35.01	**3.50**
Average	28.36	37.36	46.36	37.36	**3.73**
Amm. Ac.-K	K_2O fertilizer equivalence (kg ha^{-1})				
75	38.22	47.97	57.72	47.97	**4.79**
125	33.22	42.97	52.72	42.97	**4.29**
175	28.22	37.97	47.72	37.97	**3.79**
Average	33.22	42.97	52.72	42.97	**4.29**

Table 4.13: Fertilizer equivalence of FYM (20 t ha^{-1}) under different yield targets and fertility level of turmeric.

Soil test values (kg/ha)	Fertilizer equivalence of 20 t FYM (kg ha^{-1})				Fertilizer equivalence of 1 t FYM (kg ha^{-1})	Overall Fertilizer equivalence of 1 t FYM (kg ha^{-1})
	15	**20**	**25**	Average		
Alkaline $KMnO_4$ N	N fertilizer equivalence (kg ha^{-1})					
150	47.48	57.23	66.98	57.23	**2.86**	**3.37**
200	42.48	52.23	61.98	52.23	**2.61**	**3.00**
250	22.00	47.23	56.98	42.07	**2.10**	**2.49**
Average	37.32	52.23	61.98	50.51	**2.52**	**2.95**
Olsen's P	P_2O_5 fertilizer equivalence (kg ha^{-1})					
15	44.47	53.47	62.47	53.47	**2.67**	**3.32**
20	42.12	51.12	60.12	51.12	**2.56**	**3.14**
25	39.77	48.77	57.77	48.77	**2.44**	**2.97**
Average	42.12	51.12	60.12	51.12	**2.56**	**3.14**
Amm. Ac.-K	K_2O fertilizer equivalence (kg ha^{-1})					
75	57.94	67.69	77.44	67.69	**3.38**	**4.08**
125	50.75	62.69	72.44	61.96	**3.09**	**3.69**
175	30.25	57.69	67.44	51.79	**2.59**	**3.19**
Average	46.31	62.69	72.44	60.48	**3.02**	**3.65**

4.9 Rhizome yield response

Response of a particular applied nutrient at middle doses of other nutrients had been worked out. Rhizome yield (q ha^{-1}) at different doses of nitrogen and FYM with constant level of P and K (middle or recommended) were taken and then averaged. Response to N at middle doses of P and K (kg ha^{-1}) is shown in table 4.14 (Fig 4.10) and similarly response of P and K were also worked out.

4.9.1 Response to N at middle doses of P_2O_5 and K_2O (kg ha^{-1})

The response of 50, 100 and 150 kg of nitrogen application over control was found to be 97, 119 and 52 kg kg^{-1}, respectively. It was increasing upto 100 kg N ha^{-1} applied but decreasing at 150 kg N ha^{-1} application. Considering over successive doses, for 0 to 50 kg *i.e.* increment of 50 kg N resulted in increasing of yield to the amount of 48.40 q ha^{-1}. So the increment was 97 kg kg^{-1} of over successive dose of N. Similarly for 50 to 100 kg *i.e.* increment of 50 kg N resulted in increasing of yield to the amount of 70.84 q ha^{-1}. So the Increment was 142 kg kg^{-1} of over successive dose of N. Decreasing of yield was 41.25 q ha^{-1} yield per kg of N application for 100 to 150 kg range. Hence, increment of N application from 50 to 100 kg showed highest response at middle doses of P and K. The highest yield was obtained from the turmeric grown with NPK followed by NK, because the plants with these treatments remained green longer and they had higher shoot biomass, which ultimately contributed to higher yield. Similar studies revealed by **Hossain and Ishimine (2005) and Akamine *et al.,* (2007).**

4.12.2 Response to P_2O_5 at middle doses of N and K_2O (kg ha^{-1})

The response of 50, 100 and 150 kg of phosphorus application over control was found to be 7, 74 and 25 kg kg^{-1}, respectively. It was increasing upto 100 kg P_2O_5 ha^{-1} applied but decreasing at 150 kg P_2O_5 ha^{-1} application. Considering over successive doses, for 0 to 50 kg *i.e.* increment of 50 kg P_2O_5 resulted in increasing of yield to the amount of 3.54 q ha^{-1}. So the increment was 7 kg ha^{-1} yield per kg of over successive dose of P_2O_5. Similarly for 50 to 100 kg *i.e.* increment of 50 kg P_2O_5 resulted in increasing of yield to the amount of 70.84 q ha^{-1}. So the Increment was 142 kg ha^{-1} yield per kg of over successive dose of P_2O_5. Decreasing of yield was 36.60 q ha^{-1} yields per kg of P_2O_5 application for 100 to 150 kg range. Hence, increment of

P_2O_5 application from 50 to 100 kg showed highest response at middle doses of N and K. Application of PK showed antagonistic effect on turmeric yield. It was assumed that PK without N created a nutrient imbalance in the plants or formed toxic ions **(Akamine *et al.,* 2007).**

Table 4.14: Response of Nitrogen, Phosphorus and Potassium on rhizome yield of turmeric.

fertilizer dose kg/ha	Rhizome yield (q/ha)				Response kg per kg	
	FYM 0	FYM 10	FYM 20	Average	Over N 0	Over successive dose
N0	191.25	177.08	198.33	**188.89**	0.00	0.00
N50	201.88	283.33	226.67	**237.29**	97	97
N100	255.00	354.17	315.21	**308.13**	119	142
N150	230.21	230.42	340.00	**266.88**	52	-83
AVERAGE	**219.59**	**261.25**	**270.05**			
P0	233.75	251.46	216.04	**233.75**	0.00	0.00
P50	283.33	219.58	208.96	**237.29**	7	7
P100	255.00	354.17	315.21	**308.13**	74	142
P150	251.46	286.88	276.25	**271.53**	25	-73
AVERAGE	**255.89**	**278.02**	**254.12**			
K0	187.71	247.92	187.71	**207.78**	0.00	0.00
K50	194.79	226.67	297.50	**239.65**	64	64
K100	255.00	354.17	315.21	**308.13**	100	201
K150	223.13	223.13	318.75	**255.00**	31	-94
AVERAGE	**215.16**	**262.97**	**279.79**			

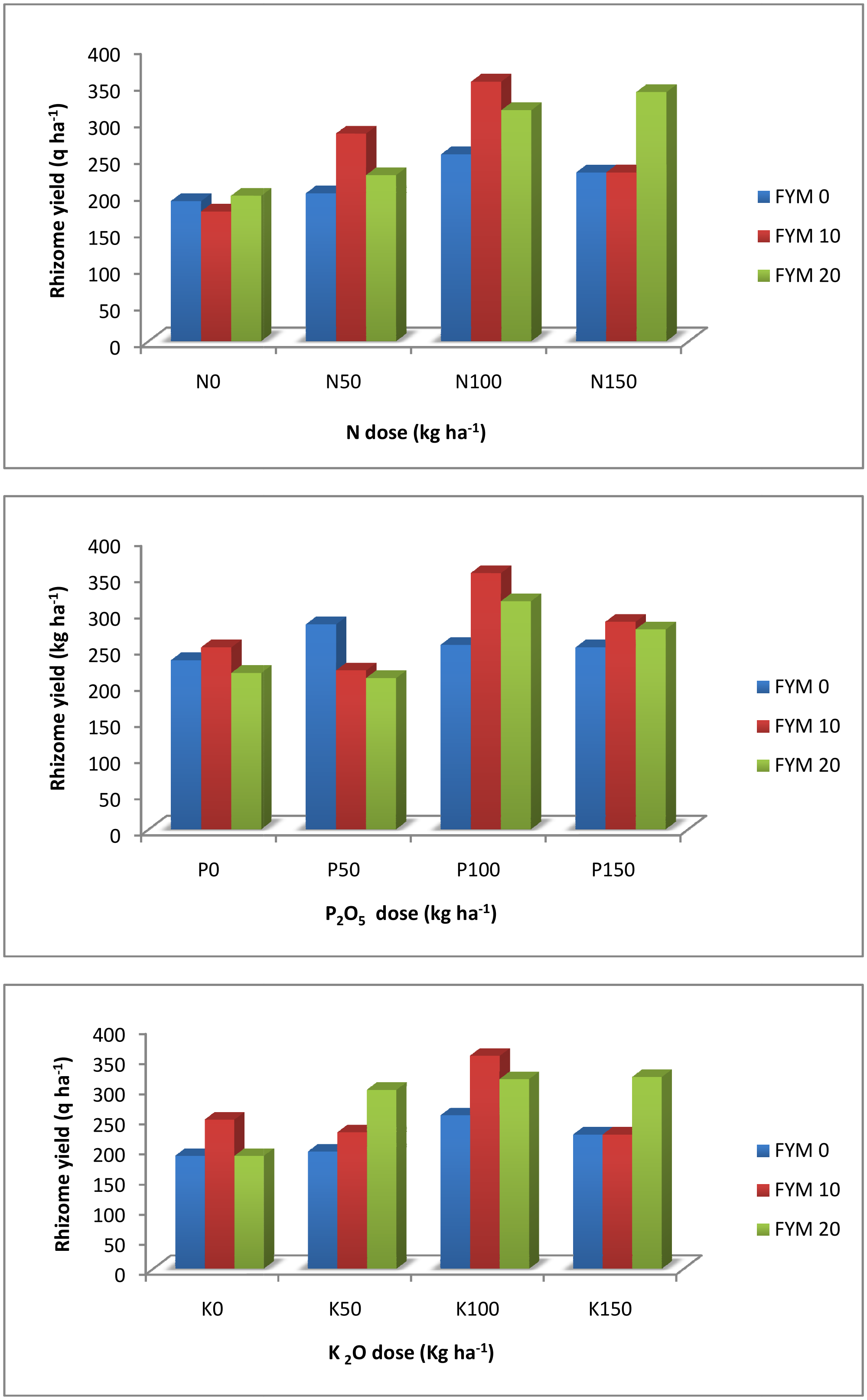

Fig. 4.10: Response of N, P_2O_5 and K_2O on total rhizome yield of turmeric.

Plate 3: Photographic view of turmeric (var. Pant Peetabh) main experiment

4.9.3 Response to K_2O at middle doses of N and P_2O_5 (kg ha^{-1})

The response of 50, 100 and 150 kg of potassium application over control was found to be 64, 100 and 31 kg kg^{-1}, respectively. It was increasing upto 100 kg K_2O ha^{-1} applied but decreasing at 150 kg K_2O ha^{-1} application. Considering over successive doses, for 0 to 50 kg *i.e.* increment of 50 kg K_2O resulted in increasing of yield to the amount of 31.87 q ha^{-1}. So the increment was 64 kg yield per kg of over successive dose of K_2O. Similarly for 50 to 100 kg *i.e.* increment of 50 kg K_2O resulted in increasing of yield to the amount of 68.48 q ha^{-1}. So the Increment was 201 kg yield per kg of over successive dose of K_2O. Decreasing of yield was 53.13 q ha^{-1} yield per kg of K_2O application for 100 to 150 kg range. Hence, increment of K_2O application from 50 to 100 kg ha^{-1} showed highest response at middle doses of N and K. **Behura (2001)** also reported that chemical fertilizer of N and K applied in a cerlain ratio showed higher efficacy on turmeric yield. However, it is assumed the ratio may differ with the soil nutrient status. Similar response of N, P and K on cotton was reported by **Katharine *et al.,* (2013).**

4.10 Multiple regressions for different functions

The multiple regression equation represent a relationship between rhizome yield, as dependent variable and the soil test values, fertilizer doses, nutrient uptake, interaction between soil test values, fertilizer doses and among fertilizer nutrients as independent variables was established through a multiple regression equation of quadratic type.

Location specific fertilizer recommendations are possible for soils of varying fertility, resource conditions of farmers and levels of targeted yield for similar soil classes and environment **(Ahmed *et al*., 2002). S**oil test values used for this equations were alkaline $KMnO_4$-N Olsen-P and normal ammonium acetate-K kg ha^{-1} as recommended soil test method for Mollisol of Uttarakhand (**Sachan *et al.,* 1982**). Fertilizer dose used in the form of nutrient N, P_2O_5 and K_2O kg ha^{-1}

The following regression equations have been worked out by using quadratic equation as given below:

$$\text{YIELD} = 290.9058^* - 0.5586\ SN - 5.6318\ SP^* + 0.5941\ SK - 0.6164\ FN - 4.4757\ FP^* + 1.5466\ FK^* - 0.0016\ FN^2 + 0.0035\ FP^2 - 0.0026\ FK^2 + 0.0085\ FNSN + 0.2007\ FPSP^* - 0.0065\ FKSK$$

$(R^2 = 0.687)$

Where,

Y	=	Rhizome yield (q ha^{-1})
FN	=	Nitrogen through fertilizer (kg ha^{-1})
FP	=	Phosphorus (P_2O_5) through fertilizer (kg ha^{-1})
FK	=	Potassium (K_2O) through fertilizer (kg ha^{-1})
SN	=	Soil test value for Nitrogen (N), alkaline $KMnO_4$-N as an index (kg ha^{-1})
SP	=	Soil test value for Phosphorus (P) by Olsen's as an index (kg ha^{-1})
SK	=	Soil test value for Potassium (K) neutral normal NH_4OAc-K as an index (kg ha^{-1}).

** Significant at 1% level.

* Significant at 5% level.

The value of coefficient of predictability (R^2) obtained in multiple regression equation is 0.687** is highly significant and model fit to the data according to STCR norms, indicating 68.7 per cent variation in yield can be predicted by complete set of available soil N, P, & K and applied fertilizer doses of N, P & K and their interaction.

4.11 Type of fertilizer response

It is generally at a given soil test value the yield will increase up to a limit with increasing dose of fertilizer and beyond that the yield will not increase but decrease, following the "Law of diminishing return". The fertilizer dose, at which maximum yield increase occurs, decreases with increasing soil test value of the nutrient in question. Eight different types of responses are possible or there are eight ways in which the algebraic symbols (+) and (-) of the linear, quadratic and interaction terms of regression co-efficient could be arranged **(STCR coordinator's report, 1972-73).**

Types of responses identified in the present investigation were: (--+), (-++) and (+--) for N, P and K, respectively, and presented in table 4.15.

Table 4.15: Response type obtained by regression equation

R^2 value	Nutrient	Response Type
0.687**	Nitrogen	--+
	Phosphorus	-++
	Potassium	+--

Nitrogen showed the '– –+' type response to fertilizer occurs only when soil has a minimum critical soil test value. There is a continuous depression in yield with increasing the fertilizer dose but at higher soil test values, the depression gradually decreases.

Phosphorus showed the response type '- + +' will occur when there is positive response to applied fertilizer up to a limit and decrease beyond that level. Further there will be positive correlation between soil and fertilizer nutrients.

Potassium showed the response type '+ - -' is characterized by positive and decreasing response of applied fertilizer nutrients. There is negative correlation between soil and fertilizer nutrients. The law diminishing return is said to be operate in this case. It is the ideal response type (+ - -) for linear, quadratic and interaction term was found only for one nutrient i.e. for Potassium.

4.12 Potassium requirement for maximum and economic yields

Multiple regression analysis and fertility gradient approach provided the basis for quantitative nutrient adjustment, based on soil test for maximum yield per hectare, maximum profit per hectare and maximum return per rupee spent on nutrient (Ramamoorthy, 1974). The ideal equation for the partial function of fertilizer nutrient is as follows:

$$Y = a + bx - cx^2 - dxz$$

Where,

a	=	constant independent of x and z
b & c	=	regression coefficient of linear and quadratic terms of x
z	=	soil test values of nutrient in question
x	=	fertilizer doses (kg ha^{-1})

Examining the sign of linear quadratic and interaction terms of fertilizer potassium in above equation. On differentiating the above equation, the following mathematical expression emerged.

$$\frac{dy}{dx} = b - 2\,xc - dz$$

Since $\frac{dy}{dx} = 0$ under condition of maximum yield

$$X_{(max)} = \frac{b - dz}{2c} \quad \ldots (1)$$

Where,

$X_{(max)}$ = dose of fertilizer for maximum yield at soil test values z

Substituting the values b, c and d of regression equation ---, where response type '+ – –' was obtained on the need of fertilizer for maximum yield was calculated. For economic dose, the consequences of 'law of diminishing return' have to be taken care of under such conditions where marginal return just equals the last rupee invested on fertilizer nutrient, that is output/input ratio become unity.

Mathematically, it may be expressed as :

$$px\Delta Y = qx\Delta X$$

$$\text{or} \quad \frac{dy}{dx} = \frac{q}{p}$$

where,

p = Price of 1 kg of turmeric rhizome in rupees

q = Price of 1 kg of nutrient in rupees

y = Yield in q ha^{-1}

From above equations it can be inferred as:

$$B - 2\,cx - dx = q/p$$

$$\text{Or } X_{(eco)} = \frac{b - (q/p) - dz}{2c} \qquad \dots (2)$$

Putting the value of b, c and d from regression equation (+ – –) response type economic rider while deciding nutrient dose, that as 'desired marginal return'. This becomes specially important when limited money could be put for different alternative purposes return per last rupee of investment becomes the only, criteria, guiding the investment policy, under such conditions.

$$p \times y = DR\ X\ qx$$

where,

DR = desired marginal return on investment in fertilizer

and therefore,

$$\frac{dy}{dx} = DR\,\frac{q}{p}$$

From the above equations it could be deduced to

$$b - 2cx - dx = DR\ X\ q/p$$

$$X_{(eco)}\ DR = \frac{b - (DR \times q/p) - dz}{2c}$$

By putting the values of b, c and d the economic doses can be calculated at a particular level of desired marginal return (DR), ratio (q/p) and soil test value (z)

Fertilizer dose for maximum and economic yield for varying soil test values can be derived from multiple regression equation under following conditions

(i) The coefficient of determination (R^2) is significant and above 67 per cent.

(ii) The response type obtained ‘ + - -’.

(iii) The regression coefficient of linear term, quadratic term and interaction of particular nutrients are significant at least 5 per cent of level of significance **(STCR manual, 1985)**.

Since + - - type of response only observed in case of potassium, therefore fertilizer doses of maximum and economic yield can be calculated with the help of above equation as described by **Singh (1996)**.

$FK_{(max)} = 279.42 - 1.25\ SK$

$FK_{(econ)} = 279.42 - 1.25\ SK - 26.60 \times R \times DR$

Where,

SK = Soil test value of potassium (kg ha^{-1})

FK = Fertilizer potassium (kg ha^{-1})

PR (Price ratio) = q/p = price of 1 kg nutrient in question/price of 1 kg dry matter of turmeric.

The response type, obtained for potassium for turmeric can be seen from the regression equation (R^2=0.687) was signified by sign ‘+ - -’. The positive response will decrease with increasing soil test values for given fertilizer dose.

Potassium requirement for maximum and economic yields were calculated with the above equation. The data in table 4.16 clearly shows that fertilizer dose decrease as soil test value increased. Similarly economic dose of potassium under the desired marginal return of 1, 2 and 3 rupee per last rupee invested in fertilizer, at various soil test values and price ratios were calculated. Fertilizer potassium doses decreased with increasing price ratio (price of nutrient per price of turmeric) and desired return, at any particular soil test value. Similarly, with increasing soil test value at particular price ratio and desired return, the economic fertilizer doses decreased. Similar results also found by **Singh *et al.*, (1996), Singh *et al.*, (1997), Yanthan *et al.*, (2010) and Ahirwar *et al.*, (2015).**

Table 4.16: Potassium requirement of turmeric for maximum and economic yield

Soil test value (NH_4OAc-K)	Max. yield	For economic yield								
		Price ratio (R) = Price of one kg K / Price of one kg dry matter of turmeric								
		1			2			3		
		Desired return (DR)			Desired return (DR)			Desired return (DR)		
		1	2	3	1	2	3	1	2	3
75	203.67	177.07	150.47	123.87	150.47	97.27	44.07	123.87	44.07	-
100	172.42	145.82	119.22	92.62	119.22	66.02	12.82	92.62	12.82	-
125	141.17	114.57	87.97	61.37	87.97	34.77	-	61.37	-	-
150	109.92	83.32	56.72	30.12	56.72	3.52	-	30.12	-	-
175	78.67	52.07	25.47	-	25.47	-	-	-	-	-
200	47.42	20.82	-	-	-	-	-	-	-	-
225	16.17	-	-	-	-	-	-	-	-	-

Price of one kg dry matter of turmeric = Rs. 200.00, Price of one kg potassium fertilizer = Rs. 27.67

4.13 Correlation between rhizome yield and various parameters of turmeric

Various correlation worked out in present investigation is presented in table 4.17. The rhizome yield of turmeric significantly correlated with haulm yield (0.587**), applied N (0.464**), P (0.599**) and K (0.636**). Similarly yield was also significantly correlated with uptake of N (0.883**), P (0.975**) and K (0.852**). Haulm yield is significantly correlated with soil phosphorus (0.283*) and soil potassium (0.377**). Haulm yield is also significantly correlated with applied N (0.357**), P (0.306) & K (0.460**). Haulm yield also shows positive and significant correlation with uptake of N (0.629**), P (0.603**) & (0.481**). Similar results found by **Ahirwar *et al.,* (2015).** Soil nitrogen content found positively and significantly correlated with organic carbon (0.258*). Soil phosphorus contents show positive and significant correlation with soil potassium content (0.532**).

The quality parameter i.e. protein%, curing% and curcuma% of turmeric were highly significantly with uptake of nutrients and yield of rhizome and haulm. Protein content showed significantly correlated with applied soil nitrogen (0.239**).

Uptake of N found positively and significantly correlated with uptake of P (0.865**), uptake of K (0.712**). Uptake of P shows positive and significant correlation with uptake of K (0.840**). **Shashidhar *et al.,* (1997)** also found that there was a positive correlation between the uptake of nitrogen and potassium and dry matter accumulation in crop.

4.14. Effect of soil fertility and fertilizer on quality of turmeric

It is well known that quality of turmeric was affected by soil fertility and applied fertilizer. Therefore, following quality parameters were studied for this purpose.

4.14.1. Curing (%)

Curing percentage of experimental field ranged from 11.45 to 24.42 % with an average of 17.84 %. Curing percentage in strip I ranged from 11.45 to 21.04 % with an average of 16.63 %. While in strip II the curing percentage ranged from 12.12 to 23.42 % with an average of 17.80 %. Range of curing percentage in strip III varied from 12.50 to 24.42 % with an average of 19.09 %. The average value of curing percentage was highest in strip III followed by strip II and strip I, respectively, (table 4.18). The relationship between curing%, soil and applied N,P and K was as follows:

Table 4.17:- Correlation of turmeric rhizome yield and various parameter of turmeric.

	YIELD	HAULM	SN	SP	SK	OC	FN	FP	FK	UN	UP	UK	Protein%	Curing%	Curcumin%
YIELD	1	0.587**	NS	NS	NS	NS	0.646**	0.599**	0.636**	0.883**	0.975**	0.852**	0.265*	0.583**	0.610**
HAULM		1	NS	0.283*	0.377**	NS	0.357**	0.306**	0.460**	0.629**	0.603**	0.481**	NS	0.329**	0.413**
SN			1	NS	NS	0.258*	NS	NS	NS	NS	NS	NS	0.239*	NS	NS
SP				1	0.532**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SK					1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
OC						1	NS	NS	NS	NS	NS	NS	NS	NS	NS
FN							1	0.600**	0.466**	0.594**	0.588**	0.569**	NS	0.390**	0.589**
FP								1	0.543**	0.563**	0.567**	0.456**	0.286*	0.379**	0.430**
FK									1	0.584**	0.618**	0.554**	NS	0.491**	0.540**
UN										1	0.865**	0.712**	0.664**	0.522**	0.557**
UP											1	0.840**	0.265*	0.576**	0.564*
UK												1	NS	0.522**	0.573**
Protein%													1	NS	NS
Curing%														1	0.484**
Curcumin%															1

$$\text{Curing\%} = 22.1477^* - 0.0558\ SN - 0.0537\ SP - 0.0102\ SK - 0.0205\ FN - 0.0730\ FP + 0.1202\ FK^* - 0.0001\ FN^2 - 0.0013\ FP^2 - 0.0007\ FK^{2\,*} + 0.0003\ FNSN + 0.0070\ FPSP + 0.0001\ FKSK \ldots\ldots \quad R^2=0.534$$

Curing percentage is largely affected by factors such as moisture content and fertility status of the soil. **Jadho *et al.* (2005)** reported that curing percentage (19.18%) was acquired in the treatment combination of 120:60:60 kg of NPK ha^{-1}. Similar result also presented by **Gopalkrishna *et al.* (1997) and Singh and Dixit (2010).**

4.14.2. Curcumin%

Curcumin content of experimental field ranged from 2.31 to 4.63 % with a average of 3.40 %. Curcumin content in strip I ranged from 2.31 to 4.40 % with a average of 3.35 %. While in strip II the curcumin content ranged from 2.55 to 4.40 % with a average of 3.32 %. Range of curcumin content in strip III varied from 2.55 to 4.63 % with a average of 3.52 %. The average value of curcumin was highest in strip III followed by strip I and strip II, respectively, (table 4.18). The relationship between curcumin %, soil and applied N, P and K was as follows:

$$\textbf{Cucurmin\%} = 3.9612^* - 0.0048\ SN - 0.0483\ SP + 0.0045\ SK - 0.0099\ FN - 0.0047\ FP + 0.0084\ FK + 0.0000\ FN^2 - 0.0003\ FP^{2*} - 0.0000\ FK^2 + 0.0001\ FNSN + 0.0010\ FPSP - 0.0000\ FKSK \ldots\ldots \quad R^2=0.547$$

The quality of turmeric is often valued on the basis of the colour intensity of the rhizome which depends on the presence of curcumin content in the rhizome. The superiority of inorganic nutrients with FYM over alone inorganic nutrients and control might be due to improvement in the physical,, chemical and microbiological condition of the soil and adequate application of N, P and K at the time sowing and earthling up. Similar result also found by **Nandal (2000), Dixit and Bhardwaj (2006) and Singh and Dixit (2010).**

4.14.3. Protein content (%)

Protein content of experimental field ranged from 6.56 to 12.69 % with an average of 9.86 %. Protein content in strip I ranged from 7.00 to 12.25 % with an average of 10.04 %. While in strip II the protein content ranged from 7.00 to 12.69 % with an average of 9.92 %. Range of protein content in strip III varied from 6.56 to 12.69 % with an average of 9.61 %. The average value of protein content was highest in strip I followed by strip II and strip III, respectively, (table 4.18). The relationship between protein content (%,) soil and applied N, P and K was as follows:

Protein content (%) = 7.5449* + 0.0377 SN* - 0.2485 SP* + 0.0174 SK + 0.0446 FN + 0.0009 FP + 0.0054 FK - 0.0001 FN² - 0.0007 FP² + 0.0000 FK² - 0.0002 FNSN + 0.0025 FPSP - 0.0001 FKSK……………… R^2=0.303

The protein content increased considerably with all the nutrients applied either separately or in amalgamation viz. NP and K at different levels with nitrogen. Similar result also reported by **Singh & Dixit (2010) and Jaggi lal (2012).**

Table 4.18: Range and average of the quality parameter of turmeric under different strips

S.No.	Particulars	Strip I	Strip II	Strip III	Whole field
1.	Protein Content (%)	7.00-12.25 (10.04)	7.00-12.69 (9.92)	6.56-12.69 (9.61)	6.56-12.69 (9.86)
2.	Curing (%)	11.45-21.04 (16.63)	12.12-23.42 (17.80)	12.50-24.42 (19.09)	11.45-24.42 (17.84)
3.	Curcumin (%)	2.31-4.40 (3.35)	2.55-4.40 (3.32)	2.55-4.63 (3.52)	2.31-4.63 (3.40)

4.15 Post harvest Soil test values and apparent nutrient balance

Treatment and strip wise post harvest values are given in appendix V and strip wise range and average of post harvest soil test values for nitrogen, phosphorus and potassium given in table 4.19.

Table 4.19: Range and average of the soil test values (post harvest) under different strips

Sl No	Particulars	Strip I	Strip II	Strip III	Whole field
1.	Organic carbon (%)	0.53-0.86 (0.68)	0.56-0.95 (0.77)	0.64-0.90 (0.76)	0.53-0.95 (0.74)
2.	Available nitrogen (kg N ha^{-1})	100.35-200.70 (147.91)	112.90-238.34 (155.75)	112.90-225.79 (162.55)	100.35-238.34 (155.41)
3.	Available phosphorus (kg P ha^{-1})	15.80-24.29 (19.05)	21.99-26.40 (24.45)	19.16-28.52 (25.09)	15.80-28.52 (22.86)
4.	Available potassium (kg K ha^{-1})	69.44-115.36 (92.35)	73.92-170.24 (101.97)	71.68-171.48 (103.37)	69.44-171.48 (99.23)

Organic carbon content of experimental field ranged from 0.53 to 0.95 percent with a average of 0.74 per cent. Organic carbon content in strip I ranged from 0.53 to 0.86 per cent with a average of 0.68 percent. While in strip II the organic carbon content ranged from 0.56 to 0.95 percent with a average of 0.77 percent. Range of organic carbon content in strip III varied from 0.64 to 0.90 percent with a average of 0.76 percent. The average value of organic carbon was highest in strip II followed by strip III and strip I, respectively.

Available Nitrogen extracted by alkaline- $KMnO_4$ method of the experimental field varied from 100.35 to 238.34 kg N ha^{-1} with a average 155.41 kg N ha^{-1}. Strip wise variation ranged from 100.35 to 200.70 with a average of 147.91 in strip I, 112.90 to 238.34 kg N ha^{-1} with a average of 155.75 kg N ha^{-1} in strip II and 112.90 to 225.79 with a average of 162.55 kg N ha^{-1} in strip III. The average value of Nitrogen was highest in strip III followed by strip II and strip I, respectively.

Available Phosphorus content of the entire experimental field ranged from 15.80 to 28.52 kg P ha^{-1} with a average value of 22.86 kg P ha^{-1}. Strip wise range varied from 15.80 to 24.29 with a average value of 19.05 kg P ha^{-1} in strip I, 21.99 to 26.40 with a average value of 24.45 kg P ha^{-1} in strip II and 19.16 to 28.52 kg P ha^{-1} with a average value of 25.09 kg P ha^{-1} in strip III. The average value of Phosphorus was highest in strip III followed by strip II and strip I, respectively.

Available Potassium extracted by neutral normal NH_4OAc method ranged from 69.44 to 171.48 kg K ha^{-1} with a average of 99.23 kg K ha^{-1} for the entire experimental field. Values ranged from 69.44 to 115.36 in strip I with a average value of 92.35 kg K ha^{-1}, 73.92 to 170.24 in strip II with a average value of 101.97 kg K ha^{-1} and 71.68 to 171.48 kg ha^{-1} in strip III with a average value of 103.37 kg K ha^{-1}. The average value of Potassium was highest in strip III followed by strip II and strip I, respectively.

These post harvest values used for fertilizer recommendation by targeted yield approach for next crop in the cropping system.

4.15.1 Apparent nutrient balance

Organic carbon content of experimental field changed from 0.76 to 0.74 percent initial to post soil test value. Average organic carbon content in strip I changed from 0.73 to 0.68 per cent. While in strip II the average organic carbon content changed from 0.77 to 0.77 percent and average organic carbon content in strip III changed from 0.78 to 0.76 per cent. Over all organic carbon content slightly decrease from initial to post soil test value (table 4.20).

Nitrogen of experimental field changed from 144.95 to 155.41 kg N ha^{-1} initial to post soil test value. Average Nitrogen in strip I changed from 140.60 to 147.91 kg N ha^{-1}. While in strip II the Nitrogen changed from 144.26 to 155.75 and average Nitrogen in strip III changed from 150.01 to 162.55 kg N ha^{-1}. Over all Nitrogen increase from initial to post soil test value. Increase in available nitrogen with 100% NPK and FYM may be due to the direct addition of nitrogen through inorganic sources and FYM to the available pool of the soil. The decomposition of organic matter is accompanied by the release of appreciable quantities of carbon dioxide which, when dissolved in water, forms carbonic acid which is capable of weathering certain primary minerals. The increase in available N due to organic materials application might be also attributed to the greater multiplication of microbes caused by the addition of organic materials for the conversion of organically bound N to inorganic form. The favourable soil conditions under FYM addition might have helped in the mineralization of soil N leading to build up of higher available N. Similar result also found by **Yanthan *et al.* (2010).**

Phosphorus of experimental field changed from 24.56 to 22.86 kg P ha^{-1} initial to post soil test value. Average Phosphorus in strip I changed from 21.99 to 19.05 kg P ha^{-1}. While in strip II the Phosphorus changed from 25.84 to 24.45 and average Phosphorus in strip III changed from 25.86 to 25.06 kg P ha^{-1}may be due to high P fixation capacity of particular site characteristics.

Potassium of experimental field changed from 108.16 to 99.23 kg K ha^{-1} initial to post soil test value. Average Potassium in strip I changed from 81.71 to 92.35 kg K ha^{-1}. While in strip II the Potassium changed from 113.17 to 101.97 and average Potassium in strip III changed from 129.59 to 103.37 kg K ha^{-1}. Over all Potassium decreased from initial to post soil test value due to large amount of uptake K by rhizome and higher potassium fixation capacity of particular site characteristics.

Table 4.20: Apparent nutrient balance during experiment

S.No	Particulars	Strip I		Strip II		Strip III		Whole field	
		Initial	Post	Initial	Post	Initial	Post	Initial	Post
1.	Organic carbon (%)	0.58-0.98 (0.73)	0.53-0.86 (0.68)	0.58-1.05 (0.77)	0.56-0.95 (0.77)	0.64-1.05 (0.78)	0.64-0.90 (0.76)	0.58-1.05 (0.76)	0.53-0.95 (0.74)
2.	Available nitrogen (kg N ha^{-1})	112.90-200.70 (140.60)	100.35-200.70 (147.91)	112.90-263.42 (144.26)	112.90-238.34 (155.75)	112.90-213.25 (150.01)	112.90-225.79 (162.55)	112.90-263.42 (144.95)	100.35-238.34 (155.41)
3.	Available phosphorus (kg P ha^{-1})	18.24-26.30 (21.99)	15.80-24.29 (19.05)	22.48-28.85 (25.84)	21.99-26.40 (24.45)	16.97-29.27 (25.86)	19.16-28.52 (25.09)	16.97-29.27 (24.56)	15.80-28.52 (22.86)
4.	Available potassium (kg K ha^{-1})	58.24-126.56 (81.71)	69.44-115.36 (92.35)	58.24-189.28 (113.17)	73.92-170.24 (101.97)	84.00-189.28 (129.59)	71.68-171.48 (103.37)	58.24-189.28 (108.16)	69.44-171.48 (99.23)

In case of Organic carbon, P and K, decreased from initial to post harvest soil test value because applied fertilizer is fully utilized by crops and some amount of P and K fix in the soil due to high P & K fixation capacity of particular soil but in case of Nitrogen slightly increased from initial to post harvest soil test value. On an average, well decomposed FYM contains 0.57% N, 0.32% P_2O_5 and 0.58%K_2O. When FYM is applied to soil about 100% of N, P_2O_5 and K_2O are available for the turmeric crop, depending upon the transformation of each nutrient element in the soil matrix. So that available nutrient in post harvest soil is fewer amounts.

The data on $KMnO_4$-N, Olsen-P and NH_4OAc-K indicated the build up and maintenance of soil fertility due to soil test based fertilizer recommendation under NPK with FYM. Despite higher removal of nutrients, the fertility status was maintained at higher level in NPK with FYM as compared to NPK alone. This might be attributed to the prevention of losses of nutrients under NPK with FYM, even after meeting the crop needs. The findings of **Pachauri and Vinay Singh (2001)** and **Santhi *et al.,* (2002)** also supported the results recorded in the present study.

4.16 Soil test value prediction

Nutrient availability in the soil after the harvest of a crop is much influenced by the initial soil nutrient status, the amount of fertilizer nutrients added crop yield and the nature of the crop raised. But recently, the monoculture is replaced by cropping sequence approach. To apply soil test based fertilizer recommendations, the soils are to be tested after each crop, which is not practicable.

The predicted values can be utilized for recommending the fertilizer doses for succeeding crop thus eliminating the need of soil test after each crop. This provides the way for giving the fertilizer recommendations for whole cropping sequence based on initial soil test values. Using a soil test based approach to nutrient management requires index measurement related to crop yield or the effective nutrient supply during the growth period, regular monitoring of soil test values and well developed service infrastructure with excellent quality control **(Dobermann *et al.*, 2003)** which is not feasible in farmer's point of view. So it has become necessary to predict the soil test values after the harvest of a crop. It is done by post-harvest soil test value predicting equations making use of the vital soil test values, applied fertilizer doses and the obtained nutrients uptake or yield. By using the soil test value of the post harvest samples as a dependent variable and initial soil test value, applied fertilizer doses and yield or uptake as independent variables the following linear polynomial equations were derived. The functional relationship is as follows:-

Table 4.21 Prediction equation of postharvest soil nutrient based on yield and uptake of turmeric

S,No.	Prediction equation	R^2 Value
1.	**Based on yield**	
	PHN = 67.3461* + 0.6744 SN* + 0.0626 FN* - 0.0562 Y*	0.825**
	PHP = - 0.5282 + 0.8379 SP* - 0.0036 FP + 0.0127 Y*	0.839**
	PHK = 53.1182* + 0.4492 SK* + 0.1399 FK* - 0.0487 Y*	0.987**
2.	**Based on uptake**	
	PHN = 61.8054* + 0.6752 SN* + 0.0464 FN - 0.0294 UN	0.817**
	PHP = - 0.6286 + 0.8393 SP* - 0.0030 FP + 0.0893 UP*	0.843**
	PHK = 47.5535* + 0.4496 SK* + 0.1223 FK* - 0.0199 UK*	0.979**

** Regression is significant at the 0.01 level (2-tailed)

* Regression is significant at the 0.05 level (2-tailed)

FN = Fertilizer Nitrogen, FP= Fertilizer Phosphorus, FK= Fertilizer Potassium

SN = Soil Nitrogen, SP=Soil Phosphorus. SK= Soil Potassium,

PHN = Post Harvest Soil Nitrogen, PHP= Post Harvest Soil Phosphorus

PHK = Post Harvest Soil Potassium, Y= Yield.

Based on above prediction equations strip wise observed and predicted post harvest soil test value ($KMnO_4$-N, Olsen-P and NH_4OAc-K kg ha^{-1}) can be calculated. The observed and predicted post harvest soil test values were compared by Paired t-Test. This test shows that that predicted and observed value were non-significant. Thus it can be concluded that predicted values may be used for fertilizer recommendation for next crop in the cropping system. Strip wise average observed and predicted soil test value on the basis of yield is given in appendix V, respectively. Range and average of observed and predicted post harvested soil test values are given in Table 4.22.

Table 4.22. Predicted and observed value of post harvest soil test value

S.No.	Particulars	Strip I		Strip II		Strip III	
		Observed	Predicted	Observed	Predicted	Observed	Predicted
1.	Available nitrogen (kg N ha^{-1})	147.91	155.35	155.75	157.48	162.55	159.66
2.	Available phosphorus (kg P ha^{-1})	19.05	20.58	24.45	23.88	25.09	24.28
3.	Available potassium (kg K ha^{-1})	92.35	88.04	101.97	101.89	103.37	108.04

Above prediction equation showed that the prediction equation of Potassium (R^2 = 0.987 & 0.979) is best than Phosphorus (R^2= 0.839 & 0.843) and Nitrogen (R^2= 0.825 & 0.817) on the basis of yield and uptake, respectively.

The predicting equations are highly significant for the major nutrient viz. N, P_2O_5 and K_2O in the study area (Table 4.21). The soil test values generated through this predicting equation may be utilized for soil test based fertilizer recommendation for the next crop in the crop rotation. Similar result also found by **Bera *et al.,* (2006).**

4.17. Verification trial (Phase III)

The verification trials are important since the calibration of results obtained on research farm are required to be tested for their validity. Verification trials have great demonstration value of showing the importance of soil testing for fertilizer recommendations to farmers and result in wider acceptability of soil testing to the farming community. The objective of these trials are (i) to test the validity of results obtained from the main experiment before recommendation to the extension agencies and (ii) to show the farmers the greater profitability of the soil test based fertilizer recommendation than general recommended dose.

Verification trial on turmeric was conducted during 2014-15 to verify the adjustment equations (Table 4.8) generated the test crop experiments during 2013-14. In this trial ten treatments with three replications were taken under RBD. The average rhizome yield of each treatment is given below in table 4.23 and also presented in Fig 4.11.

Table 4.23: Yield of Turmeric rhizome under various treatments

Treatments Details ($N:P_2O_5:K_2O$:FYM)	Yield (q ha^{-1})
T1= Control	173.61
T2= GRD (General Recommendation Dose)	211.11
T3= TY_1(250q ha^{-1}) (Target Yield)	228.22
T4= TY_1 (250q ha^{-1})+10t ha^{-1} FYM	237.50
T5= TY_1 (250q ha^{-1})+20t ha^{-1} FYM	238.89
T6= TY_2 (300q ha^{-1})	248.61
T7= TY_2 (300q ha^{-1})+10t ha^{-1} FYM	276.39
T8= TY_2 (300q ha^{-1})+20t ha^{-1} FYM	268.06
T9= TY_1 (250q ha^{-1})+Zn (1%)	201.39
T10= TY_1 (250q ha^{-1})+B (1%)	188.89
CD at 5%	53.33
CV	13.68

Result of this experiment (Table 4.23) indicated that treatment T_8 gave significantly higher yield followed by ($T_7 > T_6 > T_5 > T_4 > T_3$) as compared to control (T_1). Treatments (T_7) and (T_8) gave significantly higher yield as compared to general recommendation (T_2). Treatment (T_9) and Treatment (T_{10}) were not showing significantly difference as compare to treatments T_3 and T_4. Moreover these treatments were superior over T_3 and T_4, which indicate there was no effect of applied Zn and B to turmeric. This might be due sufficient availability of these two nutrients for optimum production of turmeric in the soil.

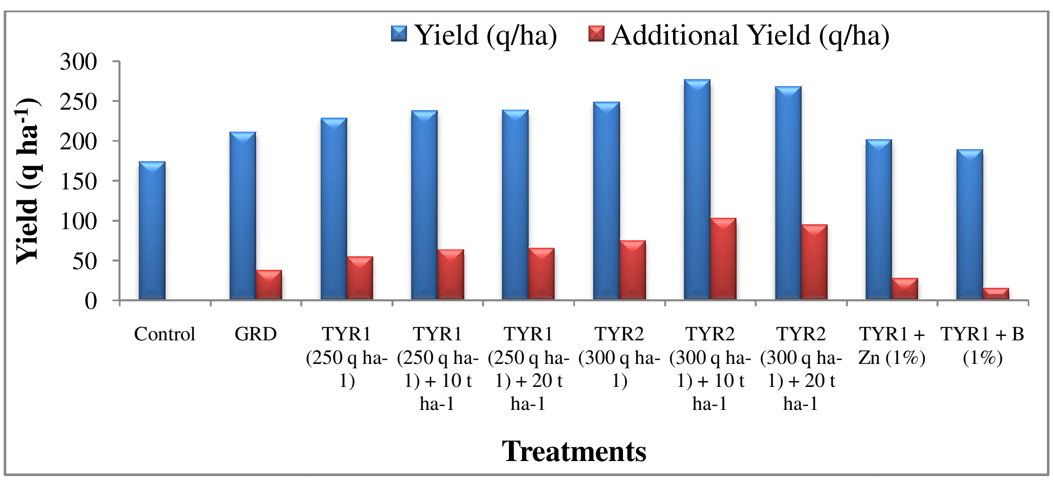

Fig. 4.11 Turmeric yield comparison between control, G.R.D and STCR based fertilizer recommendations

Among the two targets tried, target 250 t ha^{-1} recorded relatively higher RR than target 300 t ha^{-1} and it has also recorded significantly higher yields over GRD. This might be due to the better use efficiency of applied NPK fertilizers at low yield target levels. GRD recorded 12.5 RR which is lower than STCR treatments (table 4.24). The relatively higher RR recorded under STCR and IPNS treatments when compared to GRD, might be due to balanced supply of nutrients from fertilizer, efficient utilization of applied fertilizer nutrients in the presence of organic sources and the synergistic effect of the conjoint addition of organic sources of nutrients **(Rao and Srivastava 2000).** Response ratio increases with increasing dose of FYM at both the yield targets. Higher B:C ratio observed at higher target (300 q ha^{-1}) with10 tonne FYM indicating the 300 q ha^{-1} appropriate yield target for turmeric and it has also showed yield variation within the range of STCR experiment yield target (± 10%). Similar result was also reported by **Anonymus (2000), Kadam and Sonar (2006)** and **Yanthan *et al.,* (2010)**.

4.18 Generation of data base for online fertilizer recommendation

Over the years the research work in soil fertility has established that the fertility status of soil varies spatially. Soil survey provides information on spatial variability in soils that is related to soil fertility with the development of the concept that the soil fertility varies not only between regions but also within a field or plot.

Geographical Information System (GIS) is a computer based system that consists of data and software designed for spatial analysis of geographically referenced data. It helps in the integration of geographical data on soils, crops, weather and field history along with simulation models. Various data in a GIS system will have geographic reference and geographic position. These data sets can be converted to maps to illustrate their spatial variability within the field. It enable to translate the research finding into operational systems for use at farm level by providing a good platform for storage of base data, modelling, presentation of results, development of a user interface and helps to develop a Decision Support System (DSS) for site-specific nutrient management **(Maji *et al.,* 2005).**

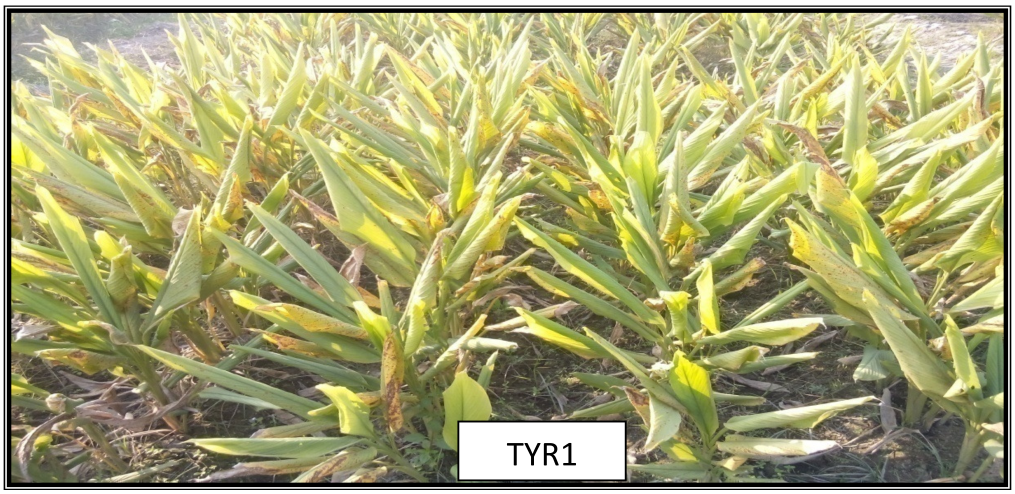

Plate 4: Photographic view of turmeric verification trial

Table 4.24: Economics of Verification Trial on Turmeric

Treatments	Fertilizer dose N-P-K (kg ha^{-1})	Actual Yield (kg ha^{-1})	Additional yield (kg ha^{-1})	Value of additional yield (Rs.)	Cost of fertilizer (Rs.)	Net benefit (Rs.)	B/C ratio	Response	Yield deviation
Control	0-0-0	17361	-	-	-	-	-	-	-
GRD	100-100-100	21111	3750	75000.00	9062.00	65938.00	7.28	12.5	-
TYR_1 (250 q ha^{-1})	92-122-69	22822	5461	109220.00	9200.00	100020.00	10.87	19.30	-8.7
TYR_1 (250 q ha^{-1}) + FYM 10 t ha^{-1}	60-87-31	23750	6389	127780.00	10985.00	116795.00	10.63	35.89	-5.0
TYR_1 (250 q ha^{-1}) + FYM 20 t ha^{-1}	42-74-12	23889	6528	130560.00	14575.00	115985.00	7.96	51.0	-4.4
TYR_2 (300 q ha^{-1})	130-157-95	24861	7500	150000.00	12161.00	137839.00	11.33	19.63	-17.13
TYR_2 (300 q ha^{-1}) + FYM 10 t ha^{-1}	92-117-50	27639	10278	205560.00	13425.00	192135.00	14.31	39.68	-7.87
TYR_2 (300 q ha^{-1}) + FYM 20 t ha^{-1}	74-103-31	26806	9445	188900.00	16966.00	171934.00	10.13	45.41	-10.64
TYR_1 (250 q ha^{-1}) + Zn (1%)	92-122-69	20139	2778	55560.00	10648.00	44912.00	4.22	9.82	-19.44
TYR_1 (250 q ha^{-1}) + B (1%)	92-122-69	18889	1528	30560.00	11083.00	19477.00	1.76	5.40	-24.44

Cost of Turmeric= 20 Rs./kg FYM cost= Rs.50/q N, P_2O_5 and K_20 cost (Rs./kg)=12.95, 50.00 and 27.67Rs./kg

Processing of fertility data and mapping in GIS

The soil fertility data on N, P and K index values in MS-Access at district level for different states of India is still under development. As far as district spatial layer is concerned, the state boundary maps, which consist of districts can be scanned in tiff format and imported to Arc GIS system. The ground control points (GCP's) may be identified for each state and based on them the individual state maps can be georeferenced. The state and district boundaries may be digitized to polyconic mode in chip format. After digitization, the necessary corrections can be done to clean the state and district layer for topology building. The individual district ids can be assigned in the layer to assign the attribute database. Through, cataloging the columns for N, P and K can be added in the layer to enter the attribute data.

As for as the attribute database in concerned, the N, P and K index values of each districts in state can be imported from MS-Access. The errors may be rectified in master state layer to generate different thematic maps on N, P and K index values of each state in GIS. From the attribute database, the different thematic layers have been reclassified to generate various thematic maps on N, P and K index values. The whole process can be explained by the flow chart.

In case of known fertility status one can give the known values of N, P and K and submit for calculation. This system provides real use of fertility maps to the users. It can be further narrow down to block/village level depending the information. The experiments conducted at different locations under STCR scheme suggest that a considerable amount of money can be saved if the fertilizers are prescribed using possible soil test values and yield target as per the economic conditions of the farmer.

In the present investigation, the data of the experiment i.e. yield, nutrient uptake, nutrient requirement, soil fertilizer and FYM efficiencies used for developing fertilizer adjustment equations. This information may work as a data base for online system of fertilizer prescription in the form of fertilizer recommendation. This information may be feed in link attributes as shown in the following flow chart (Fig 4.12).

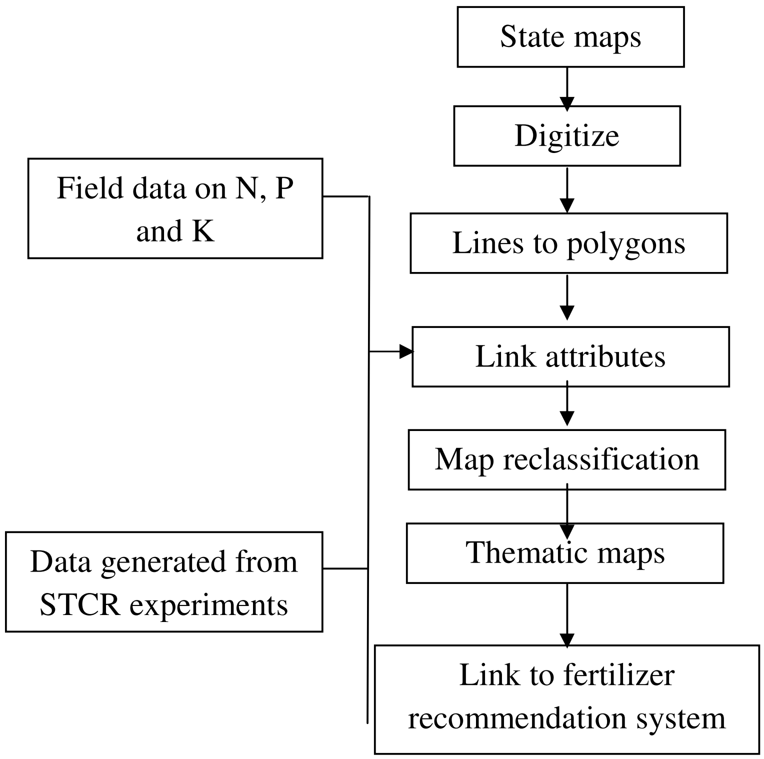

Fig. 4.12: Flow chart for online recommendation of fertilizer for turmeric

Summary and Conclusion

Chapter 5 SUMMARY AND CONCLUSIONS

The present investigation was conducted during the year 2013-14 and 2014-15 in an Aquic Hapludoll at D_7 block of Norman E. Borlogue Crop Research Centre of the G.B. Pant University of Agriculture and Technology, Pantnagar (29^0 N latitude and $79^0 29'$ E longitude). To fulfill the objectives of the present investigation, experiments were conducted in three phase in the years 2012-13, 2013-14 and 2014-15. The experiments were conducted as per the technical programme and methodology of AICRP on Soil Test Crop Response. The first experiment was conducted in two phases. In first phase soil fertility gradient was developed by dividing experimental field into three equal strips and applying graded doses of fertilizers in these strips and growing of exhaust crop fodder Oat. In the second phase i.e. next season test crop turmeric (var. *Pant peetabh*) was grown by dividing each strip into 24 plots having 21 treated and 3 controlled. Response to selected combinations of three levels of FYM (0, 10 and 20 t/ha), four levels of nitrogen (0, 50, 100 and 150 kg N ha^{-1}), four levels of phosphorus (0, 50, 100 and 150 kg P_2O_5 ha^{-1}) and four levels of potassium (0, 50, 100 and 150 kg K_2O ha^{-1}) at different fertility levels of turmeric was studied. Verification trial i.e. second experiment (III phase) was conducted during 2014-15 to validate the fertilizer adjustment equations developed in test experiment with ten treatments and three replications, having combinations of inorganic, organic and micronutrients.

Multiple regression type of equations were fitted to the data on the lines of the technical programme of All India Coordinate soil test crop response correlation Project (ICAR, 1972). The soil and plant analysis data were also utilized to develop basic data of fertilizer requirement for targeted production of turmeric. Salient experimental findings of the present investigation are summarized below:

1. It was possible to create difference in the soil fertility in one and same site by differentially fertilizing the strips and plots of the experiment field and growing exhaust crop in the preceding crop season. Soil per cent of organic carbon ranged from 0.58 to 1.05 per cent with a average of 0.76 per cent, Alkaline $KMnO_4$ extractable nitrogen ranged from 112.90 to 263.42 kg N ha^{-1} with average value of

144.95 kg N ha^{-1}, Olsen's phosphorus ranged from 16.97 to 29.27 kg P ha^{-1} with a average value of 24.56 kg P ha^{-1} and neutral normal NH_4OAc extractable potassium ranged from 58.24 to 189.28 kg K ha^{-1} with a average of 108.16 kg ha^{-1}.

2. The fresh rhizome yield of rhizome in experimental field varied from 113.33 to 354.17 q ha^{-1} with an average of 235.22 q ha^{-1}. Average rhizome yield of turmeric recorded in order of strip III (257.36 q ha^{-1}) followed by strip II (227.11 q ha^{-1}) and strip I (221.21 q ha^{-1}).

3. The dry matter yield of rhizome in experimental field varied from 58.77 to 183.67 q ha^{-1} with an average of 121.99 q ha^{-1}. Average dry matter yield of rhizome recorded in order of strip III (133.46 q ha^{-1}) was followed by strip II (117.78 q ha^{-1}) and strip I (114.72 q ha^{-1}).

4. The fresh yield of haulm in experimental field varied from 9.33 to 45.00 q ha^{-1} with an average of 25.97q ha^{-1}. Average haulm yield of turmeric recorded in order of strip III (30.25 q ha^{-1}) followed by strip I (23.89 q ha^{-1}) and strip II (23.78 q ha^{-1}).

5. Dry matter yield of haulm (q ha^{-1}) in experimental field varied from 6.39 to 30.83 with an average 17.19 q ha^{-1}. Average dry matter yield of haulm recorded in order of strip III (20.72 q ha^{-1}) was followed by strip I (16.37 q ha^{-1}) and strip II (16.29 q ha^{-1}).

6. The average N, P and K content of rhizome (%) were found 1.58, 0.26 and 1.88%, respectively. However, in haulm, the average N, P and K content were found 1.17, 0.16 and 0.40%, respectively.

7. The Nitrogen uptake of experimental field varied from 68.96 to 371.88 kg h^{a-1} with a average of 215.31 kg h^{a-1}. Average nitrogen uptake recorded highest in strip III (233.44 kg h^{a-1}), followed by strip II (208.39 kg h^{a-1}) and in strip I (204.11 kg h^{a-1}).

8. The Phosphorus uptake of experimental field varied from 14.31 to 54.56 kg ha^{-1} with a average of 33.94 kg ha^{-1}. Average phosphorus uptake recorded highest in strip III (36.84 kg ha^{-1}), followed by strip II (33.13 kg ha^{-1}) and in strip I (31.85 kg ha^{-1}).

9. Average Potassium uptake of experimental field varied from 70.23 to 489.23 kg ha^{-1} with a average of 240.50 kg ha^{-1}. Average potassium uptake recorded highest in strip III (268.11 kg ha^{-1}), followed by strip II (232.62 kg ha^{-1}) and in strip I (220.78 kg ha^{-1}).

10. With the help of above basic data parameters viz. nutrient requirement for the production of one quintal of turmeric rhizome (NR) and contribution of available nutrient from soil test value (CS), contributing of nutrient from added fertilizer (CF) and contribution of nutrient from applied FYM (CFYM) for N, P and K calculated.

11. For the production of one quintal rhizome yield, turmeric required 0.91 kg of nitrogen, 0.32 kg of phosphorus (P_2O_5) and 1.02 kg of potassium (K_2O).

12. The contribution of soil in supplying applying nitrogen, phosphorus and potassium of their soil test value for the crop was 61.45, 56.13 and 69.35 per cent, respectively.

13. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium were 46.31, 10.30 and 74.91, respectively.

14. Contribution from fertilizer as percentage was 143.67, 53.94 and 265.11, using with FYM and 119.29, 45.13 and 201.96 without FYM for nitrogen, phosphorus and potassium, respectively.

15. On the basis of basic data (NR, CS, CF and CFYM), fertilizer adjustment equations were developed and requirement of nitrogen, phosphorus and potassium was calculated for different yield targets of turmeric at different soil test values with the application of chemical fertilizer alone and with conjoint use of FYM.

16. For a particular yield target fertilizer doses decreased with increasing soil test values. However, for a particular soil test value fertilizer doses increased with increasing target of the yield.

17. The value of fertilizer equivalence found highest at higher yield target and the value of fertilizer equivalence decreased with increasing soil test values. The average saving of fertilizer by 1.0 tonne FYM were 2.95 kg ha^{-1} N, 3.14 kg P_2O_5 ha^{-1} and 3.65 kg K_2O ha^{-1} along with the experimental soil test value and yield targets.

18. Maximum yield response was observed i.e. 119 kg kg^{-1}, 74 kg kg^{-1}, 100 kg kg^{-1} for N, P_2O_5 and K_2O, respectively, with 100 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}.

19. From R^2 (0.687**) value, it can be observed that variation up to 68.7 per cent in turmeric rhizome yield can be explained by the variation in soil test value and fertilizer doses.

20. The ideal response type '+ - -' for quadratic interaction term was found only for potassium. Therefore, maximum and economic fertilizer requirements of calculated only for potassium.

21. From the present study, it can be concluded that Olsen's, AB-DTPA-P and MehlichI-P method for soil available phosphorus and neutral ammonium NH_4OA_C, AB-DTPA K and Mehlich I-K method for soil available potassium can be taken as indices for determining N, P and K in Mollisol of Uttarakhand. AB-DTPA and Mehlich-I as universal extractants can be adopted by soil testing laboratories for extraction as it can extract both P and K and various micronutrients too from the soil.

22. Fertilizer doses of potassium for maximum and economic yields decreased with increase in soil test value. Similarly, fertilizer doses for maximum profit decreased with increase in price ratio and desired return.

23. The rhizome yield of turmeric significantly correlated with haulm yield (0.587**), applied N (0.646**), P (0.599**) and K (0.636**). Similarly yield was also significantly correlated with uptake of N (0.883**), P (0.975**) and K (0.852**) and protein (0.265*), curing (0.583**) and curcumin% (0.610**).

24. The protein content of turmeric in experimental field varied from 6.56 to 12.69% with a average of 9.86%. Average protein content recorded highest in strip I (10.04%), followed by strip II (9.92%) and in strip III (9.61%).

25. The curing percentage of turmeric in experimental field varied from 11.45 to 24.42% with a average of 17.84%. Average curing percentage recorded highest in strip III (19.09%), followed by strip II (17.80%) and in strip III (16.63%).

26. The curcumin percentage of turmeric in experimental field varied from 2.31 o 4.63% with a average of 3.40%. Average curcumin percentage recorded highest in strip III (3.52%), followed by strip I (3.35%) and in strip II (3.32%).

27. For prediction the post harvest soil test values prediction equations were developed for available N, P and K and post harvest soil test values were calculated from these equations. No statistical difference was found between observed and predicted values.

28. Verification trial was conducted to test the validity of fertilizer adjustment equations. Results of this trial clearly indicate the superiority of targeted yield approach over general fertilizer recommendations.

From the findings which obtained in this investigation, following conclusion are clearly emerged.

In the region, Mollisol of Uttarakhand maximum yield response obtained at 100 Kg N ha^{-1}, 100 Kg P_2O_5 ha^{-1} and 100 Kg K_2O ha^{-1} in turmeric. Integrated fertilizer use on the basis of soil test value for the optimum target yield (300 q ha^{-1}) for combination of fertilizer dose consisting of 92 Kg N + 117 Kg P_2O_5 + 50 Kg K_2O ha^{-1} + 10tonne FYM and 74 Kg N + 103 Kg P_2O_5 + 31 Kg K_2O + 20 tonne ha^{-1} FYM proved significantly superior over general fertilizer recommendation,. The above INM combinations have also given higher B:C ratio and response ration over general fertilizer recommendation. Fertilizer prescription equations both under chemical and INM mode developed for turmeric at desired yield targets and fertility status used as per economic condition of farmers. Equations were also developed for prediction of post harvest soil test value for quick fertilizer recommendation to next crop in the cropping sequence. Prediction and observed values of available N, P & K were non-significant. AB-DTPA method for evaluating soil test value of P & K may be used for *tarai* region of Uttarakhand. Data generated from the present investigation is useful for online fertilizer recommendation as used by IISS, Bhopal and NIC, Pune.

Future Thrust

1. Since present study is site specific therefore, for wider applicability of equations, it is necessary to conduct large number of follow up trials in different region of the state at farmer's field in broader areas.

2. To overcome effect of season over the year there is need to develop model by including various factors, so that recommendation may become useful for changed scenario of climate, management and varieties.
3. There is need to develop method of estimating of soil efficiency, FYM efficiency and fertilizer efficiency from the same plot.
4. There is need to study long term effect of these recommendation on soil health and sustainability.

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Appendix

APPENDIX I

Weekly weather parameters during the course of experimentation 2013-14

Month	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)	Sun Shine (hrs.)	Evaporation (mm)
	Max	Min	0712 am	0712 pm			
Mar-Apr	30.5	14.5	88	38	0	8.5	4.7
Apr	33.3	14.8	79	24	0	10.3	7
Apr	36.9	17.9	68	23	0	9.4	8.6
Apr	34.7	18.2	61	29	8.4	9.4	7.8
Apr	35	19.5	64	30	0	9.1	7.7
Apr-May	38.9	19.1	60	23	0	10.1	11.4
May	38.7	19.7	56.7	26	1.2	7.9	9.6
May	38.4	23.8	60.4	31.6	0	8.8	9.1
May	39.2	29.1	70	44.4	0	4.3	9.6
May-Jun	37.9	25.8	67	41	0	7.8	8.8
Jun	35.2	27	75	56	23.6	4.2	7.1
Jun	33.6	25.2	80	66	119.8	3.9	6.1
Jun	31.3	25.2	87	70	173	3	3.9
Jun-Jul	31.1	25.2	91.6	71.6	287	2.4	3.6
Jul	32.3	25.3	90.6	73.1	154.8	2.5	5.2
Jul	32.4	26.3	87	70.7	37.2	6.2	4.6
Jul	31.3	25.5	90.7	77	97.8	2.6	3.9
Jul	32.4	25.6	85.4	68.6	95.8	4.5	4.7
Jul-Aug	33	26	87	68	44	6.1	4.3
Aug	32.1	25.3	91	74	175.6	5.2	4.5
Aug	31.5	24.5	88	73	187.8	4.9	5.1
Aug	33.6	25.9	87	65	12.4	7.3	3.9
Aug-Sep	31.2	25.2	93	73	43.8	2.4	3.3

Sep	32.1	23.6	91	69	5.2	6.4	4.1
Sep	33.4	23.6	85	62	34	7.9	4.1
Sep	32.8	23.8	81	65	5.4	8.7	3.7
Sep	33	24.1	89	62	33.2	6.6	3.7
Oct	30.3	23.1	82	67	6.8	4.2	3.6
Oct	31.2	22.1	90	61	79.6	6.7	2.8
Oct	30.4	20.1	91	63	0	5.5	2.3
Oct	30.2	16.8	88	55	0	8	2.7
Oct-Nov	30.2	18.8	85	53	6.8	5.5	3.6
Nov	27.9	16.2	90	56	0	3.9	2.3
Nov	27.1	9	93	38	0	1.9	2.2
Nov	26	9.9	93	42	0	2.1	2
Nov-Dec	26.4	9.5	92	49	0	4.6	1.6
Dec	25.7	8.2	94	42	0	8.7	2
Dec	23.2	7.4	93	49	0	6.6	1.3
Dec	21.6	8.5	92	59	0	2.7	1.4
Dec	18.9	6.1	94	65	10.2	4.6	1.6
Jan	17.1	5.9	97	74	1.6	3.1	1.3
Jan	16.1	7.5	96	79	3.6	2.6	1
Jan	17.4	9.3	94	73	105.8	3	1.9
Jan	17.5	9.2	94	79	1.4	1.6	1
Jan-Feb	16.2	9.4	96	72	0	2.2	0.8
Feb	22.5	8.9	92	60	2	5.6	2.1
Feb	20	7	95	58	93.2	6.7	2.2
Feb	22.2	10.2	91	55	0	6.3	2
Feb-Mar	23.4	11.2	90	48	81.4	6.2	3.5
Mar	24.9	10.3	88	46	0	7.6	2.6
Mar	27.8	14.1	87	46	12.8	9.1	3.2
Mar	28.7	14.2	83	39	0	7.9	2.9

APPENDIX II

Weekly weather parameters during the course of experimentation 2014-15

Month	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)	Sun Shine (hrs.)	Evaporation (mm)
	Max	Min	0712 am	712 pm			
Mar-Apr	31.2	14.8	87	32	0	7.6	4.6
Apr	32.5	15.1	82	31	2.2	10.4	5.4
Apr	33.3	15.4	72	22	0.6	9.4	6.9
Apr	32.5	15.4	75	29	10.2	7.4	5.6
Apr	37.5	17.7	67	19	0	11.6	9.7
Apr-May	37	20.5	62	30	14.4	9.5	7.8
May	37	20.7	63	26.1	3.4	9.1	9
May	36.6	20.5	67	23	0	10.6	10.8
May	38.6	22.9	59	28	0	10.7	10.3
May-Jun	37.4	25.4	68	38	21.2	9.5	8.5
Jun	41	26.6	65	34	0	11.4	8.1
Jun	38.3	25.7	71	45	23.6	6.5	9.6
Jun	35	25.7	83	55	67	5.9	5.5
Jun-Jul	36.9	26.6	78	53	2.8	7.2	6.9
Jul	32.3	25.4	88	67	50.8	2.4	4.5
Jul	33.5	26.9	87.7	71	50.6	3.1	5.2
Jul	30.5	25.6	92	80	265.6	2.1	4.5
Jul	32.5	26.2	88	67	15.8	4.7	4
Jul-Aug	33.5	25.8	90	67	72	6.1	4
Aug	33.3	26.3	88	68	34.4	7.9	4.8
Aug	32.3	25.6	89	71	27	4.8	3.9
Aug	34.2	25.9	90	64	0	7.1	6.6
Aug-Sep	33.9	25.7	86	62	1.2	7.5	5.8
Sep	33.2	25.1	85	63	1.2	8.7	5.4
Sep	32	23.5	92	67	5.4	5.4	3.9

Sep	33.2	23.3	89	63	29.4	8.3	5.5
Sep	32.7	21.3	89	58	1	8.3	4.7
Oct	32	22.3	90	60	5.6	4.9	3.2
Oct	32.7	17.9	87	55	1.6	9.2	3.7
Oct	26.9	15.5	91	51	8.2	7.5	3.1
Oct	30.9	16.6	85	55	0	5.3	2.5
Oct-Nov	28.5	13.1	91	46	0	4.3	2.6
Nov	29.2	12.8	91	46	0	8.2	2.5
Nov	27.9	9.5	94	34	0	7.7	2.9
Nov	26.3	8.6	92	38	0	8	2.4
Nov-Dec	26.2	8.7	92	41	0	7.9	2.3
Dec	24.3	9.9	94	49	0	4.9	1.8
Dec	20.8	8.2	91	57	40.1	4.3	2.1
Dec	16.8	7.4	96	78	0	4.1	1.2
Dec	18.5	4.9	95	57	0	5.2	1.1
Jan	19.1	11.5	93	77	21.8	2.8	1.4
Jan	15.7	8.4	95	75	0	3	0.8
Jan	15.8	8.1	95	71	0	2.5	1.2
Jan	18.4	8.6	95	75	11	3.6	1.2
Jan-Feb	18.4	8.1	88	62	0	4.7	1.5
Feb	22.4	7.4	94	54	0	3.9	2.1
Feb	23.2	9.7	88	51	0	3.9	2
Feb	27.1	13.4	90	55	0.2	3.3	2.1
Feb-Mar	23.3	13	92	61	67.9	4.9	2.8
Mar	25.2	10.2	89	45	0	8.8	2.9
Mar	26.9	12.7	90	51	1.2	6.6	2.9
Mar	29.3	13.7	88	45	0	9.5	3.5

APPENDIX III

Strip and plot wise initial soil test values of experimental field.

STRIP-I

Plot No.	Treatments	Alkaline $KMnO_4$-N (kg ha^{-1})	Olsen's P (kg ha^{-1})	NH_4OAC-K (kg ha^{-1})	Organic carbon (%)
1.	$N_2P_1K_2OM_0$	125.44	25.03	76.16	0.76
2.	$N_3P_3K_1OM_0$	150.53	19.09	73.92	0.94
3.	$N_1P_2K_2OM_0$	163.07	24.18	108.64	0.61
4.	$N_3P_2K_2OM_0$	112.90	23.76	71.68	0.82
5.	$N_2P_1K_1OM_1$	137.98	23.33	70.56	0.90
6.	$N_2P_2K_1OM_1$	150.53	19.09	60.48	0.97
7.	$N_0P_0K_0OM_1$	125.44	20.36	71.68	0.60
8.	$N_1P_1K_1OM_1$	137.98	22.48	66.08	0.64
9.	$N_3P_3K_3OM_2$	125.44	24.18	70.56	0.66
10.	$N_3P_1K_1OM_2$	125.44	19.52	98.56	0.61
11.	$N_0P_0K_0OM_2$	112.90	21.21	126.56	0.75
12.	$N_2P_3K_3OM_2$	137.98	19.52	87.36	0.61
13.	$N_0P_2K_2OM_2$	175.62	22.06	81.76	0.64
14.	$N_3P_2K_3OM_2$	137.98	18.24	58.24	0.58
15.	$N_1P_1K_2OM_2$	125.44	22.91	70.56	0.81
16.	$N_3P_3K_2OM_2$	163.07	22.06	62.72	0.73
17.	$N_3P_2K_1OM_1$	175.62	22.91	64.96	0.96
18.	$N_2P_0K_2OM_1$	200.70	22.48	84.00	0.64
19.	$N_1P_2K_1OM_1$	150.53	22.48	99.68	0.60
20.	$N_2P_2K_3OM_1$	125.44	22.06	98.56	0.64
21.	$N_2P_2K_0OM_0$	137.98	22.06	87.36	0.73
22.	$N_0P_0K_0OM_0$	125.44	26.30	110.88	0.72
23.	$N_2P_2K_2OM_0$	112.90	19.94	85.12	0.84
24.	$N_2P_3K_2OM_0$	137.98	22.48	75.04	0.99
Mean		140.60	21.99	81.71	0.73

Cont…….

SRIP-II

Plot No.	**Treatments**	**Alkaline $KMnO_4$-N ($kg\ ha^{-1}$)**	**Olsen's P ($kg\ ha^{-1}$)**	**NH_4OAC-K ($kg\ ha^{-1}$)**	**Organic carbon (%)**
1.	$N_3P_2K_1OM_0$	150.53	24.18	174.72	0.69
2.	$N_2P_2K_3OM_0$	163.07	28.00	189.28	0.99
3.	$N_2P_0K_2OM_0$	263.42	28.42	133.28	1.03
4.	$N_1P_2K_1OM_0$	137.98	26.73	127.68	1.01
5.	$N_2P_3K_3OM_1$	125.44	22.48	140.00	0.58
6.	$N_3P_1K_1OM_1$	125.44	27.15	134.40	0.64
7.	$N_3P_2K_3OM_1$	137.98	24.18	103.04	0.72
8.	$N_0P_2K_2OM_1$	163.07	26.30	99.68	0.84
9.	$N_2P_2K_2OM_2$	125.44	22.91	100.80	0.76
10.	$N_2P_3K_2OM_2$	137.98	24.61	58.24	0.69
11.	$N_0P_0K_0OM_2$	112.90	22.91	88.48	0.67
12.	$N_2P_1K_2OM_2$	125.44	25.88	88.48	0.64
13.	$N_3P_3K_1OM_2$	150.53	23.76	69.44	0.84
14.	$N_3P_2K_2OM_2$	150.53	25.03	71.68	0.70
15.	$N_1P_2K_2OM_2$	188.16	28.00	87.36	0.78
16.	$N_2P_2K_0OM_2$	137.98	26.30	78.40	0.79
17.	$N_0P_0K_0OM_1$	125.44	22.91	112.00	0.76
18.	$N_1P_1K_2OM_1$	125.44	27.15	115.36	0.61
19.	$N_3P_3K_2OM_1$	125.44	26.30	123.20	0.88
20.	$N_3P_3K_3OM_1$	125.44	25.45	115.36	0.73
21.	$N_2P_1K_1OM_0$	150.53	27.15	129.92	0.76
22.	$N_2P_2K_1OM_0$	125.44	27.15	117.60	1.05
23.	$N_0P_0K_0OM_0$	137.98	28.42	126.56	0.76
24.	$N_1P_1K_1OM_0$	150.53	28.85	131.04	0.81
Mean		144.26	25.84	113.17	0.77

Cont…….

STRIP-III

Plot no.	Treatments	Alkaline $KMnO_4$-N (kg ha^{-1})	Olsen's P (kg ha^{-1})	NH_4OAC-K (kg ha^{-1})	Organic carbon (%)
1.	$N_2P_3K_3OM_0$	125.44	28.42	142.24	0.67
2.	$N_3P_2K_3OM_0$	175.62	22.91	173.60	0.70
3.	$N_3P_1K_1OM_0$	137.98	28.85	180.32	0.70
4.	$N_3P_3K_3OM_0$	137.98	29.27	172.48	0.64
5.	$N_2P_1K_2OM_1$	125.44	28.00	160.16	0.73
6.	$N_2P_2K_2OM_1$	150.53	27.58	137.76	0.70
7.	$N_2P_3K_2OM_1$	137.98	28.00	117.60	0.73
8.	$N_3P_3K_1OM_1$	150.53	25.88	92.96	0.91
9.	$N_2P_1K_1OM_2$	163.07	20.79	84.00	1.06
10.	$N_0P_0K_0OM_2$	112.90	16.97	124.32	0.94
11.	$N_2P_2K_1OM_2$	163.07	27.58	115.36	0.99
12.	$N_1P_2K_1OM_2$	112.90	21.64	91.84	0.75
13.	$N_1P_1K_1OM_2$	137.98	26.30	110.88	0.73
14.	$N_2P_0K_2OM_2$	163.07	27.58	114.24	0.84
15.	$N_2P_2K_3OM_2$	175.62	26.73	99.68	0.78
16.	$N_3P_2K_1OM_2$	175.62	25.03	132.16	0.76
17.	$N_3P_2K_2OM_1$	150.53	24.18	105.28	0.79
18.	$N_1P_2K_2OM_1$	213.25	25.88	113.12	0.76
19.	$N_0P_0K_0OM_1$	125.44	26.30	122.08	0.73
20.	$N_2P_2K_0OM_1$	150.53	27.15	115.36	0.79
21.	$N_1P_1K_2OM_0$	150.53	25.03	189.28	0.85
22.	$N_0P_2K_2OM_0$	175.62	25.88	137.76	0.88
23.	$N_3P_3K_2OM_0$	137.98	26.73	140.00	0.75
24.	$N_0P_0K_0OM_0$	150.53	28.00	137.76	0.75
Mean		150.01	25.86	129.59	0.78

APPENDIX IV

P and K Soil test value extracted by different methods

Strip I

S.No.	Treatments	AB-DTPA P	Mehlich-I P	AB-DTPA K	Mehlich-I K
1	$N_2P_1K_2OM_0$	22.00	25.25	79.52	75.04
2	$N_3P_3K_1OM_0$	20.12	19.75	75.04	72.8
3	$N_1P_2K_2OM_0$	23.34	24.28	110.88	107.52
4	$N_3P_2K_2OM_0$	22.53	24.60	72.80	69.44
5	$N_2P_1K_1OM_1$	22.27	24.92	72.80	68.32
6	$N_2P_2K_1OM_1$	20.39	20.07	63.84	58.24
7	$N_0P_0K_0OM_1$	19.58	19.10	75.04	70.56
8	$N_1P_1K_1OM_1$	22.00	20.07	70.56	64.96
9	$N_3P_3K_3OM_2$	22.80	21.04	71.68	70.56
10	$N_3P_1K_1OM_2$	19.31	22.34	98.56	97.44
11	$N_0P_0K_0OM_2$	20.12	21.69	125.44	124.32
12	$N_2P_3K_3OM_2$	19.58	21.04	88.48	84
13	$N_0P_2K_2OM_2$	20.12	21.69	84.00	79.52
14	$N_3P_2K_3OM_2$	19.05	18.77	60.48	59.36
15	$N_1P_1K_2OM_2$	19.85	23.95	72.80	71.68
16	$N_3P_3K_2OM_2$	20.12	24.28	64.96	62.72
17	$N_3P_2K_1OM_1$	20.39	24.60	66.08	62.72
18	$N_2P_0K_2OM_1$	19.85	23.63	86.24	81.76
19	$N_1P_2K_1OM_1$	19.58	23.95	105.28	96.32
20	$N_2P_2K_3OM_1$	19.58	23.63	98.56	94.08
21	$N_2P_2K_0OM_0$	19.85	22.98	87.36	86.24
22	$N_0P_0K_0OM_0$	22.53	24.28	113.12	106.4
23	$N_2P_2K_2OM_0$	21.73	19.10	82.88	80.64
24	$N_2P_3K_2OM_0$	21.46	20.07	76.16	72.8
Mean		**20.76**	**22.29**	**83.44**	**79.89**

Cont…….

Strip II

S.No.	Treatments	AB-DTPA P	Mehlich-I P	AB-DTPA K	Mehlich-I K
1	$N_3P_2K_1OM_0$	22.27	20.39	172.48	169.12
2	$N_2P_2K_3OM_0$	23.34	24.92	184.80	178.08
3	$N_2P_0K_2OM_0$	23.88	25.25	138.88	128.8
4	$N_1P_2K_1OM_0$	23.34	25.25	128.80	125.44
5	$N_2P_3K_3OM_1$	23.88	24.28	140.00	133.28
6	$N_3P_1K_1OM_1$	23.61	23.63	137.76	133.28
7	$N_3P_2K_3OM_1$	22.27	23.31	104.16	101.92
8	$N_0P_2K_2OM_1$	22.53	22.98	100.80	96.32
9	$N_2P_2K_2OM_2$	21.73	22.34	103.04	99.68
10	$N_2P_3K_2OM_2$	22.27	26.87	63.84	57.12
11	$N_0P_0K_0OM_2$	22.00	25.25	91.84	86.24
12	$N_2P_1K_2OM_2$	22.53	27.19	90.72	87.36
13	$N_3P_3K_1OM_2$	21.19	24.28	70.56	70.56
14	$N_3P_2K_2OM_2$	22.27	23.63	70.56	68.32
15	$N_1P_2K_2OM_2$	23.07	27.84	85.12	79.52
16	$N_2P_2K_0OM_2$	23.34	26.54	81.76	76.16
17	$N_0P_0K_0OM_1$	22.00	24.60	113.12	109.76
18	$N_1P_1K_2OM_1$	23.88	22.34	117.60	110.88
19	$N_3P_3K_2OM_1$	24.68	22.01	118.72	117.6
20	$N_3P_3K_3OM_1$	25.48	27.84	117.60	113.12
21	$N_2P_1K_1OM_0$	26.29	25.25	125.44	125.44
22	$N_2P_2K_1OM_0$	26.02	24.92	122.08	115.36
23	$N_0P_0K_0OM_0$	26.56	25.25	129.92	124.32
24	$N_1P_1K_1OM_0$	23.88	28.81	132.16	129.92
Mean		**23.43**	**24.79**	**114.24**	**109.9**

Cont…….

Strip III

S.No.	Treatments	AB-DTPA P	Mehlich-I P	AB-DTPA K	Mehlich-I K
1	$N_2P_3K_3OM_0$	25.22	27.19	140.00	141.12
2	$N_3P_2K_3OM_0$	23.07	23.63	169.12	171.36
3	$N_3P_1K_1OM_0$	26.02	24.92	176.96	179.2
4	$N_3P_3K_3OM_0$	26.29	25.57	174.72	170.24
5	$N_2P_1K_2OM_1$	26.56	26.54	164.64	157.92
6	$N_2P_2K_2OM_1$	27.36	25.57	140.00	136.64
7	$N_2P_3K_2OM_1$	28.97	25.57	123.20	116.48
8	$N_3P_3K_1OM_1$	26.29	24.28	95.20	91.84
9	$N_2P_1K_1OM_2$	25.75	21.04	84.00	82.88
10	$N_0P_0K_0OM_2$	19.58	17.80	125.44	123.2
11	$N_2P_2K_1OM_2$	25.75	22.34	116.48	113.12
12	$N_1P_2K_1OM_2$	23.34	21.36	95.20	88.48
13	$N_1P_1K_1OM_2$	22.00	25.25	113.12	107.52
14	$N_2P_0K_2OM_2$	23.88	25.57	115.36	110.88
15	$N_2P_2K_3OM_2$	23.07	24.60	101.92	96.32
16	$N_3P_2K_1OM_2$	24.68	26.54	131.04	125.44
17	$N_3P_2K_2OM_1$	20.92	24.92	107.52	106.4
18	$N_1P_2K_2OM_1$	21.19	25.57	115.36	112
19	$N_0P_0K_0OM_1$	21.19	25.57	123.20	116.48
20	$N_2P_2K_0OM_1$	21.46	25.90	117.60	113.12
21	$N_1P_1K_2OM_0$	22.27	26.87	188.16	184.8
22	$N_0P_2K_2OM_0$	22.27	26.87	140.00	135.52
23	$N_3P_3K_2OM_0$	22.80	27.51	141.12	137.76
24	$N_0P_0K_0OM_0$	23.88	28.81	138.88	132.16
Mean		**23.91**	**24.99**	**130.76**	**127.12**

APPENDIX V

Strip and treatment wise fresh and dry matter yield of rhizome and haulm

STRIP-I

Plot no.	Treatments	Rhizome Fresh yield (q ha^{-1})	Rhizome Drymatter yield (q ha^{-1})	Haulm Fresh yield (q ha^{-1})	Haulm Drymatter yield (q ha^{-1})
1.	$N_2P_1K_2OM_0$	283.33	146.93	29.17	19.98
2.	$N_3P_3K_1OM_0$	240.83	124.90	29.17	19.98
3.	$N_1P_2K_2OM_0$	201.88	104.69	30.83	21.12
4.	$N_3P_2K_2OM_0$	230.21	119.39	37.50	25.69
5.	$N_2P_1K_1OM_1$	194.79	101.02	34.17	23.40
6.	$N_2P_2K_1OM_1$	226.67	117.55	23.33	15.98
7.	$N_0P_0K_0OM_1$	166.46	86.33	16.67	11.42
8.	$N_1P_1K_1OM_1$	155.83	80.81	25.00	17.13
9.	$N_3P_3K_3OM_2$	286.88	148.77	31.67	21.69
10.	$N_3P_1K_1OM_2$	194.79	101.02	23.33	15.98
11.	$N_0P_0K_0OM_2$	177.08	91.84	21.67	14.84
12.	$N_2P_3K_3OM_2$	247.92	128.57	24.17	16.55
13.	$N_0P_2K_2OM_2$	198.33	102.86	10.83	7.42
14.	$N_3P_2K_3OM_2$	247.92	128.57	20.83	14.27
15.	$N_1P_1K_2OM_2$	233.75	121.22	25.00	17.13
16.	$N_3P_3K_2OM_2$	283.33	146.94	25.00	17.13
17.	$N_3P_2K_1OM_1$	244.38	126.73	14.17	9.70
18.	$N_2P_0K_2OM_1$	251.46	130.41	17.50	11.99
19.	$N_1P_2K_1OM_1$	212.50	110.20	25.00	17.13
20.	$N_2P_2K_3OM_1$	223.13	115.71	28.33	19.41
21.	$N_2P_2K_0OM_0$	187.71	97.35	25.83	17.70
22.	$N_0P_0K_0OM_0$	113.33	58.77	10.92	7.47
23.	$N_2P_2K_2OM_0$	255.00	132.24	23.33	15.98
24.	$N_2P_3K_2OM_0$	251.46	130.41	20.00	13.70
Mean		221.21	114.72	23.89	16.37

Cont…….

STRIP-II

Plot no.	Treatments	Rhizome Fresh yield (q ha^{-1})	Rhizome Drymatter yield (q ha^{-1})	Haulm Fresh yield (q ha^{-1})	Haulm Drymatter yield (q ha^{-1})
1.	$N_3P_2K_1OM_0$	265.63	137.75	25.83	17.70
2.	$N_2P_2K_3OM_0$	223.13	115.71	35.00	23.98
3.	$N_2P_0K_2OM_0$	233.75	121.22	29.17	19.98
4.	$N_1P_2K_1OM_0$	180.63	93.67	20.83	14.27
5.	$N_2P_3K_3OM_1$	255.00	132.24	30.00	20.55
6.	$N_3P_1K_1OM_1$	247.92	128.57	31.67	21.69
7.	$N_3P_2K_3OM_1$	251.46	130.41	28.33	19.41
8.	$N_0P_2K_2OM_1$	177.08	91.84	21.67	14.84
9.	$N_2P_2K_2OM_2$	315.21	163.47	23.33	15.98
10.	$N_2P_3K_2OM_2$	276.25	143.26	24.17	16.55
11.	$N_0P_0K_0OM_2$	191.25	99.18	19.17	13.13
12.	$N_2P_1K_2OM_2$	208.96	108.37	14.17	9.70
13.	$N_3P_3K_1OM_2$	184.17	95.51	12.50	8.56
14.	$N_3P_2K_2OM_2$	340.00	176.32	24.17	16.55
15.	$N_1P_2K_2OM_2$	226.67	117.55	22.50	15.41
16.	$N_2P_2K_0OM_2$	187.71	97.35	16.67	11.42
17.	$N_0P_0K_0OM_1$	184.17	95.51	18.33	12.56
18.	$N_1P_1K_2OM_1$	198.33	102.86	21.67	14.84
19.	$N_3P_3K_2OM_1$	283.33	146.94	35.83	24.55
20.	$N_3P_3K_3OM_1$	315.21	163.47	30.00	20.55
21.	$N_2P_1K_1OM_0$	173.54	90.00	24.17	16.55
22.	$N_2P_2K_1OM_0$	194.79	101.02	20.00	13.70
23.	$N_0P_0K_0OM_0$	123.95	64.28	12.33	8.45
24.	$N_1P_1K_1OM_0$	212.50	110.20	29.17	19.98
Mean		227.11	117.78	23.78	16.29

Cont…….

STRIP-III

Plot no.	Treatments	Rhizome Fresh yield (q ha^{-1})	Rhizome Drymatter yield (q ha^{-1})	Haulm Fresh yield (q ha^{-1})	Haulm Drymatter yield (q ha^{-1})
1.	$N_2P_3K_3OM_0$	318.75	165.30	43.33	29.68
2.	$N_3P_2K_3OM_0$	286.88	148.77	33.33	22.83
3.	$N_3P_1K_1OM_0$	276.25	143.26	26.67	18.27
4.	$N_3P_3K_3OM_0$	318.75	165.30	31.67	21.69
5.	$N_2P_1K_2OM_1$	219.58	113.88	38.33	26.26
6.	$N_2P_2K_2OM_1$	354.17	183.67	41.67	28.54
7.	$N_2P_3K_2OM_1$	286.88	148.77	25.00	17.13
8.	$N_3P_3K_1OM_1$	255.00	132.24	24.17	16.55
9.	$N_2P_1K_1OM_2$	230.08	119.32	21.67	14.84
10.	$N_0P_0K_0OM_2$	177.08	91.84	15.83	10.85
11.	$N_2P_2K_1OM_2$	297.50	154.28	27.50	18.84
12.	$N_1P_2K_1OM_2$	219.58	113.87	16.67	11.42
13.	$N_1P_1K_1OM_2$	205.42	106.53	15.83	10.85
14.	$N_2P_0K_2OM_2$	216.04	112.04	31.67	21.69
15.	$N_2P_2K_3OM_2$	318.75	165.30	34.17	23.40
16.	$N_3P_2K_1OM_2$	258.54	134.08	25.00	17.13
17.	$N_3P_2K_2OM_1$	290.42	150.61	40.83	27.97
18.	$N_1P_2K_2OM_1$	283.33	146.93	45.00	30.83
19.	$N_0P_0K_0OM_1$	173.54	90.00	32.50	22.26
20.	$N_2P_2K_0OM_1$	247.92	128.57	37.50	25.69
21.	$N_1P_1K_2OM_0$	279.79	145.10	40.00	27.40
22.	$N_0P_2K_2OM_0$	191.25	99.18	31.67	21.69
23.	$N_3P_3K_2OM_0$	336.46	174.49	36.67	25.12
24.	$N_0P_0K_0OM_0$	134.58	69.79	9.33	6.39
	Mean	257.36	133.46	30.25	20.72

APPENDIX VI

Strip and treatment wise N, P and K content (%) in rhizome and haulm of turmeric

STRIP-I

Plot no.	Treatments	Nitrogen		Phosphorus		Potassium	
		Rhizome	Haulm	Rhizome	Haulm	Rhizome	Haulm
1.	$N_2P_1K_2OM_0$	1.54	1.33	0.252	0.169	2.4	0.27
2.	$N_3P_3K_1OM_0$	1.4	1.05	0.228	0.136	1.55	0.35
3.	$N_1P_2K_2OM_0$	1.75	1.26	0.234	0.151	1.95	0.38
4.	$N_3P_2K_2OM_0$	1.89	1.47	0.25	0.157	1.95	0.31
5.	$N_2P_1K_1OM_1$	1.68	0.98	0.256	0.136	1.75	0.44
6.	$N_2P_2K_1OM_1$	1.68	1.19	0.26	0.166	2.65	0.30
7.	$N_0P_0K_0OM_1$	1.54	1.33	0.266	0.178	1.15	0.30
8.	$N_1P_1K_1OM_1$	1.4	1.05	0.234	0.154	1.05	0.32
9.	$N_3P_3K_3OM_2$	1.26	0.98	0.242	0.136	2.35	0.42
10.	$N_3P_1K_1OM_2$	1.4	1.12	0.258	0.15	1.95	0.33
11.	$N_0P_0K_0OM_2$	1.33	0.42	0.264	0.164	1.95	0.45
12.	$N_2P_3K_3OM_2$	1.68	0.98	0.266	0.164	1.45	0.39
13.	$N_0P_2K_2OM_2$	1.82	1.05	0.272	0.146	1.95	0.44
14.	$N_3P_2K_3OM_2$	1.75	1.05	0.262	0.122	1.6	0.46
15.	$N_1P_1K_2OM_2$	1.4	1.12	0.258	0.18	1.75	0.40
16.	$N_3P_3K_2OM_2$	1.54	0.84	0.264	0.19	1.55	0.36
17.	$N_3P_2K_1OM_1$	1.68	1.26	0.26	0.17	2.5	0.28
18.	$N_2P_0K_2OM_1$	1.89	1.19	0.244	0.156	1.9	0.29
19.	$N_1P_2K_1OM_1$	1.82	0.98	0.278	0.148	2	0.28
20.	$N_2P_2K_3OM_1$	1.96	1.47	0.272	0.164	1.75	0.46
21.	$N_2P_2K_0OM_0$	1.68	1.54	0.252	0.162	1.05	0.34
22.	$N_0P_0K_0OM_0$	1.12	0.42	0.228	0.122	1.15	0.35
23.	$N_2P_2K_2OM_0$	1.61	1.33	0.26	0.164	2.9	0.37
24.	$N_2P_3K_2OM_0$	1.75	1.05	0.256	0.17	1.55	0.32
Mean		1.61	1.10	0.25	0.16	1.83	0.36

Cont…….

STRIP-II

Plot no.	Treatments	Nitrogen		Phosphorus		Potassium	
		Rhizome	Haulm	Rhizome	Haulm	Rhizome	Haulm
1.	$N_3P_2K_1OM_0$	1.75	0.98	0.24	0.16	1.95	0.33
2.	$N_2P_2K_3OM_0$	1.54	1.61	0.24	0.16	2.10	0.58
3.	$N_2P_0K_2OM_0$	1.47	1.40	0.27	0.16	2.45	0.30
4.	$N_1P_2K_1OM_0$	1.61	1.12	0.26	0.16	2.50	0.36
5.	$N_2P_3K_3OM_1$	1.82	1.40	0.26	0.16	1.25	0.63
6.	$N_3P_1K_1OM_1$	1.61	1.26	0.24	0.14	1.85	0.37
7.	$N_3P_2K_3OM_1$	1.26	1.26	0.25	0.13	1.95	0.49
8.	$N_0P_2K_2OM_1$	1.47	0.98	0.26	0.16	1.25	0.62
9.	$N_2P_2K_2OM_2$	1.68	1.33	0.27	0.19	2.10	0.53
10.	$N_2P_3K_2OM_2$	1.54	0.98	0.28	0.18	2.40	0.48
11.	$N_0P_0K_0OM_2$	1.19	0.84	0.29	0.17	1.40	0.37
12.	$N_2P_1K_2OM_2$	1.12	1.47	0.26	0.16	1.90	0.41
13.	$N_3P_3K_1OM_2$	1.26	1.26	0.27	0.14	2.10	0.28
14.	$N_3P_2K_2OM_2$	1.68	1.12	0.26	0.16	2.25	0.66
15.	$N_1P_2K_2OM_2$	1.89	0.98	0.27	0.17	1.55	0.42
16.	$N_2P_2K_0OM_2$	1.82	1.54	0.27	0.17	1.40	0.34
17.	$N_0P_0K_0OM_1$	1.54	0.98	0.26	0.17	2.25	0.30
18.	$N_1P_1K_2OM_1$	1.75	1.40	0.28	0.18	1.75	0.35
19.	$N_3P_3K_2OM_1$	1.61	1.19	0.24	0.19	2.00	0.59
20.	$N_3P_3K_3OM_1$	1.82	1.26	0.26	0.13	2.20	0.47
21.	$N_2P_1K_1OM_0$	2.03	1.12	0.26	0.16	1.85	0.34
22.	$N_2P_2K_1OM_0$	1.68	1.12	0.27	0.14	2.10	0.31
23.	$N_0P_0K_0OM_0$	1.19	0.84	0.24	0.13	1.40	0.23
24.	$N_1P_1K_1OM_0$	1.75	1.19	0.25	0.16	1.20	0.32
Mean		1.59	1.19	0.26	0.16	1.88	0.42

Cont…….

STRIP-III

Plot no.	Treatments	Nitrogen		Phosphorus		Potassium	
		Rhizome	Haulm	Rhizome	Haulm	Rhizome	Haulm
1.	$N_2P_3K_3OM_0$	1.54	1.40	0.26	0.17	1.55	0.50
2.	$N_3P_2K_3OM_0$	1.82	1.19	0.24	0.13	2.10	0.51
3.	$N_3P_1K_1OM_0$	1.68	1.33	0.24	0.14	1.75	0.37
4.	$N_3P_3K_3OM_0$	1.26	1.26	0.26	0.13	2.90	0.45
5.	$N_2P_1K_2OM_1$	1.05	1.40	0.26	0.16	2.05	0.45
6.	$N_2P_2K_2OM_1$	1.61	1.61	0.27	0.17	2.05	0.53
7.	$N_2P_3K_2OM_1$	1.33	1.12	0.24	0.17	1.70	0.29
8.	$N_3P_3K_1OM_1$	1.54	1.54	0.26	0.15	1.90	0.32
9.	$N_2P_1K_1OM_2$	1.82	1.47	0.24	0.18	1.65	0.32
10.	$N_0P_0K_0OM_2$	1.40	0.98	0.27	0.17	2.00	0.33
11.	$N_2P_2K_1OM_2$	1.54	0.91	0.27	0.18	2.10	0.31
12.	$N_1P_2K_1OM_2$	1.26	0.98	0.26	0.16	1.95	0.34
13.	$N_1P_1K_1OM_2$	1.12	1.47	0.25	0.17	1.40	0.45
14.	$N_2P_0K_2OM_2$	1.19	1.05	0.26	0.16	2.10	0.46
15.	$N_2P_2K_3OM_2$	1.47	1.26	0.26	0.16	1.95	0.63
16.	$N_3P_2K_1OM_2$	1.75	0.98	0.26	0.18	1.75	0.29
17.	$N_3P_2K_2OM_1$	2.03	0.98	0.25	0.16	2.05	0.32
18.	$N_1P_2K_2OM_1$	1.68	0.98	0.24	0.16	1.75	0.49
19.	$N_0P_0K_0OM_1$	1.47	1.33	0.28	0.17	1.90	0.40
20.	$N_2P_2K_0OM_1$	1.54	1.33	0.25	0.16	1.75	0.40
21.	$N_1P_1K_2OM_0$	1.68	1.33	0.24	0.15	2.05	0.44
22.	$N_0P_2K_2OM_0$	1.75	1.26	0.24	0.17	2.15	0.77
23.	$N_3P_3K_2OM_0$	1.96	1.19	0.24	0.16	2.10	0.42
24.	$N_0P_0K_0OM_0$	1.40	0.91	0.22	0.13	1.40	0.25
Mean		1.54	1.22	0.25	0.16	1.92	0.42

Appendix VII
Strip and treatment wise uptake by rhizome and haulm

Strip I

Plot No.	Treatment	Nutrient Uptake by Haulm			Nutrient Uptake by Rhizome			Total Nutrient Uptake		
		N	P	K	N	P	K	N	P	K
1.	$N_2P_1K_2OM_0$	26.57	3.38	5.39	226.28	37.03	352.64	252.85	40.40	358.04
2.	$N_3P_3K_1OM_0$	20.98	2.72	7.07	174.85	28.48	193.59	195.83	31.19	200.66
3.	$N_1P_2K_2OM_0$	26.61	3.19	7.94	183.21	24.50	204.15	209.82	27.69	212.09
4.	$N_3P_2K_2OM_0$	37.76	4.03	7.96	225.64	29.85	232.80	263.40	33.88	240.77
5.	$N_2P_1K_1OM_1$	22.94	3.18	10.34	169.71	25.86	176.78	192.65	29.04	187.13
6.	$N_2P_2K_1OM_1$	19.02	2.65	4.80	197.48	30.56	311.51	216.50	33.22	316.30
7.	$N_0P_0K_0OM_1$	15.18	2.03	3.40	132.94	22.96	99.27	148.13	24.99	102.68
8.	$N_1P_1K_1OM_1$	17.98	2.64	5.51	113.14	18.91	84.85	131.12	21.55	90.37
9.	$N_3P_3K_3OM_2$	21.26	2.95	9.11	187.45	36.00	349.62	208.71	38.95	358.73
10.	$N_3P_1K_1OM_2$	17.90	2.40	5.27	141.43	26.06	196.99	159.33	28.46	202.26
11.	$N_0P_0K_0OM_2$	6.23	2.43	6.74	122.14	24.24	179.08	128.37	26.68	185.82
12.	$N_2P_3K_3OM_2$	16.22	2.71	6.52	216.00	34.20	186.43	232.22	36.91	192.95
13.	$N_0P_2K_2OM_2$	7.79	1.08	3.28	187.20	27.98	200.57	194.99	29.06	203.85
14.	$N_3P_2K_3OM_2$	14.98	1.74	6.54	225.00	33.69	205.71	239.98	35.43	212.25
15.	$N_1P_1K_2OM_2$	19.18	3.08	6.85	169.71	31.28	212.14	188.89	34.36	218.99
16.	$N_3P_3K_2OM_2$	14.39	3.25	6.20	226.28	38.79	227.75	240.67	42.05	233.95
17.	$N_3P_2K_1OM_1$	12.23	1.65	2.76	212.91	32.95	316.83	225.14	34.60	319.59
18.	$N_2P_0K_2OM_1$	14.27	1.87	3.48	246.47	31.82	247.77	260.73	33.69	251.25
19.	$N_1P_2K_1OM_1$	16.78	2.53	4.80	200.57	30.64	220.41	217.35	33.17	225.20
20.	$N_2P_2K_3OM_1$	28.53	3.18	8.93	226.80	31.47	202.50	255.33	34.66	211.42
21.	$N_2P_2K_0OM_0$	27.25	2.87	5.95	163.54	24.53	102.21	190.79	27.40	108.16
22.	$N_0P_0K_0OM_0$	3.14	0.91	2.64	65.83	13.40	67.59	68.96	14.31	70.23
23.	$N_2P_2K_2OM_0$	21.26	2.62	5.98	212.91	34.38	383.50	234.17	37.00	389.48
24.	$N_2P_3K_2OM_0$	14.39	2.33	4.41	228.21	33.38	202.13	242.60	35.71	206.54
Mean		**18.45**	**2.56**	**5.91**	**185.65**	**29.29**	**214.87**	**204.11**	**31.85**	**220.78**

Cont……….

Strip II

Plot No.	Treatment	Nutrient Uptake by Haulm			Nutrient Uptake by Rhizome			Total Nutrient Uptake		
		N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
1.	$N_3P_2K_1OM_0$	17.34	2.87	5.91	241.07	32.51	268.62	258.41	35.38	274.53
2.	$N_2P_2K_3OM_0$	38.60	3.84	13.95	178.20	28.23	243.00	216.80	32.07	256.95
3.	$N_2P_0K_2OM_0$	27.97	3.16	6.03	178.20	32.49	297.00	206.17	35.64	303.03
4.	$N_1P_2K_1OM_0$	15.98	2.34	5.19	150.81	24.17	234.18	166.80	26.51	239.37
5.	$N_2P_3K_3OM_1$	28.77	3.29	12.91	240.68	33.85	165.30	269.45	37.14	178.21
6.	$N_3P_1K_1OM_1$	27.33	3.12	7.98	207.00	31.37	237.85	234.33	34.49	245.84
7.	$N_3P_2K_3OM_1$	24.45	2.60	9.59	164.31	32.86	254.29	188.77	35.46	263.88
8.	$N_0P_2K_2OM_1$	14.54	2.34	9.17	135.00	24.06	114.79	149.54	26.41	123.97
9.	$N_2P_2K_2OM_2$	21.26	3.04	8.54	274.62	44.46	343.28	295.88	47.50	351.82
10.	$N_2P_3K_2OM_2$	16.22	2.91	7.88	220.63	39.54	343.83	236.85	42.45	351.71
11.	$N_0P_0K_0OM_2$	11.03	2.26	4.83	118.03	28.96	138.86	129.06	31.22	143.69
12.	$N_2P_1K_2OM_2$	14.27	1.55	3.96	121.37	28.18	205.90	135.63	29.73	209.85
13.	$N_3P_3K_1OM_2$	10.79	1.23	2.36	120.34	25.41	200.57	131.13	26.64	202.93
14.	$N_3P_2K_2OM_2$	18.54	2.58	10.86	296.22	46.20	396.73	314.76	48.78	407.59
15.	$N_1P_2K_2OM_2$	15.10	2.59	6.41	222.17	31.27	182.20	237.27	33.86	188.61
16.	$N_2P_2K_0OM_2$	17.58	1.96	3.86	177.17	26.09	136.28	194.75	28.05	140.14
17.	$N_0P_0K_0OM_1$	12.31	2.13	3.77	147.08	24.83	214.89	159.39	26.97	218.66
18.	$N_1P_1K_2OM_1$	20.78	2.70	5.25	180.00	28.39	180.00	200.78	31.09	185.25
19.	$N_3P_3K_2OM_1$	29.21	4.57	14.58	236.57	35.56	293.87	265.78	40.12	308.45
20.	$N_3P_3K_3OM_1$	25.89	2.71	9.74	297.51	41.85	359.63	323.40	44.56	369.37
21.	$N_2P_1K_1OM_0$	18.54	2.58	5.60	182.70	23.04	166.50	201.24	25.62	172.09
22.	$N_2P_2K_1OM_0$	15.34	1.97	4.22	169.71	26.87	212.14	185.06	28.84	216.36
23.	$N_0P_0K_0OM_0$	7.10	1.08	1.93	76.49	15.17	89.99	83.59	16.25	91.92
24.	$N_1P_1K_1OM_0$	23.78	3.20	6.39	192.85	27.11	132.24	216.63	30.31	138.64
Mean		**19.70**	**2.61**	**7.12**	**188.70**	**30.52**	**225.50**	**208.39**	**33.13**	**232.62**

Cont……….

Strip III

Plot No.	Treatment	Nutrient Uptake by Haulm			Nutrient Uptake by Rhizome			Total Nutrient Uptake		
		N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
1.	$N_2P_3K_3OM_0$	41.56	4.93	14.96	254.57	42.32	256.22	296.12	47.25	271.18
2.	$N_3P_2K_3OM_0$	27.17	2.92	11.65	270.77	36.30	312.42	297.94	39.22	324.07
3.	$N_3P_1K_1OM_0$	24.29	2.52	6.83	240.68	33.81	250.71	264.98	36.33	257.54
4.	$N_3P_3K_3OM_0$	27.33	2.78	9.85	208.28	42.32	479.38	235.61	45.09	489.23
5.	$N_2P_1K_2OM_1$	36.76	4.31	11.82	119.57	29.15	233.45	156.33	33.46	245.26
6.	$N_2P_2K_2OM_1$	45.95	4.97	15.07	295.71	49.59	376.53	341.66	54.56	391.60
7.	$N_2P_3K_2OM_1$	19.18	2.88	5.03	197.87	35.71	252.91	217.05	38.58	257.95
8.	$N_3P_3K_1OM_1$	25.49	2.52	5.23	203.65	34.38	251.26	229.15	36.90	256.49
9.	$N_2P_1K_1OM_2$	21.82	2.67	4.72	217.16	28.16	196.88	238.98	30.83	201.60
10.	$N_0P_0K_0OM_2$	10.63	1.80	3.56	128.57	24.80	183.67	139.20	26.60	187.23
11.	$N_2P_2K_1OM_2$	17.14	3.39	5.84	237.60	41.04	324.00	254.74	44.43	329.83
12.	$N_1P_2K_1OM_2$	11.19	1.80	3.93	143.48	29.15	222.05	154.67	30.96	225.98
13.	$N_1P_1K_1OM_2$	15.94	1.80	4.88	119.31	26.63	149.14	135.26	28.43	154.02
14.	$N_2P_0K_2OM_2$	22.78	3.38	10.02	133.33	29.35	235.28	156.10	32.74	245.30
15.	$N_2P_2K_3OM_2$	29.49	3.79	14.70	243.00	42.65	322.34	272.49	46.44	337.04
16.	$N_3P_2K_1OM_2$	16.78	3.08	5.03	234.64	34.86	234.64	251.42	37.94	239.67
17.	$N_3P_2K_2OM_1$	27.41	4.42	8.95	305.74	37.35	308.75	333.15	41.77	317.70
18.	$N_1P_2K_2OM_1$	30.21	4.93	15.04	246.85	34.97	257.14	277.06	39.90	272.18
19.	$N_0P_0K_0OM_1$	29.61	3.83	8.82	132.30	25.20	171.00	161.91	29.03	179.81
20.	$N_2P_2K_0OM_1$	34.16	4.01	10.33	198.00	32.14	225.00	232.16	36.15	235.32
21.	$N_1P_1K_2OM_0$	36.44	4.06	12.06	243.77	34.24	297.45	280.21	38.30	309.51
22.	$N_0P_2K_2OM_0$	27.33	3.69	16.66	173.57	24.20	213.24	200.90	27.89	229.90
23.	$N_3P_3K_2OM_0$	29.89	3.97	10.50	342.00	41.53	366.42	371.88	45.50	376.92
24.	$N_0P_0K_0OM_0$	5.82	0.83	1.57	97.71	15.08	97.71	103.53	15.91	99.29
Mean		**25.60**	**3.30**	**9.04**	**207.84**	**33.54**	**259.07**	**233.44**	**36.84**	**268.11**

APPENDIX VIII

Strip and treatment wise quality parameter of turmeric (Cucurma longa L.)

STRIP-I

Plot no.	Treatments	Quality parameter (%)		
		Protein	**Curing**	**Curcumin**
1.	$N_2P_1K_2OM_0$	9.63	19.78	3.70
2.	$N_3P_3K_1OM_0$	8.75	15.22	3.94
3.	$N_1P_2K_2OM_0$	10.94	17.66	3.94
4.	$N_3P_2K_2OM_0$	11.81	21.04	4.17
5.	$N_2P_1K_1OM_1$	10.50	16.02	3.47
6.	$N_2P_2K_1OM_1$	10.50	18.78	3.01
7.	$N_0P_0K_0OM_1$	9.63	11.76	2.31
8.	$N_1P_1K_1OM_1$	8.75	14.83	2.78
9.	$N_3P_3K_3OM_2$	7.88	19.02	3.94
10.	$N_3P_1K_1OM_2$	8.75	19.97	3.47
11.	$N_0P_0K_0OM_2$	8.31	13.62	3.24
12.	$N_2P_3K_3OM_2$	10.50	14.89	2.78
13.	$N_0P_2K_2OM_2$	11.38	17.33	3.47
14.	$N_3P_2K_3OM_2$	10.94	14.93	4.40
15.	$N_1P_1K_2OM_2$	8.75	20.09	3.01
16.	$N_3P_3K_2OM_2$	9.63	16.83	3.24
17.	$N_3P_2K_1OM_1$	10.50	16.29	3.24
18.	$N_2P_0K_2OM_1$	11.81	14.12	3.47
19.	$N_1P_2K_1OM_1$	11.38	14.30	3.01
20.	$N_2P_2K_3OM_1$	12.25	21.04	3.24
21.	$N_2P_2K_0OM_0$	10.50	11.76	2.78
22.	$N_0P_0K_0OM_0$	7.00	11.45	2.55
23.	$N_2P_2K_2OM_0$	10.06	19.38	3.70
24.	$N_2P_3K_2OM_0$	10.94	18.89	3.47
Mean		**10.04**	**9.92**	**9.61**

Cont……

STRIP-II

Plot no.	Treatments	Quality content (%)		
		Protein	**Curing**	**Curcumin**
1.	$N_3P_2K_1OM_0$	10.94	15.44	4.17
2.	$N_2P_2K_3OM_0$	9.63	20.92	4.40
3.	$N_2P_0K_2OM_0$	9.19	13.62	3.01
4.	$N_1P_2K_1OM_0$	10.06	12.12	2.78
5.	$N_2P_3K_3OM_1$	11.38	17.46	3.70
6.	$N_3P_1K_1OM_1$	10.06	15.27	3.01
7.	$N_3P_2K_3OM_1$	7.88	15.27	3.24
8.	$N_0P_2K_2OM_1$	9.19	16.78	3.01
9.	$N_2P_2K_2OM_2$	10.50	22.45	3.94
10.	$N_2P_3K_2OM_2$	9.63	20.15	3.47
11.	$N_0P_0K_0OM_2$	7.44	14.30	3.24
12.	$N_2P_1K_2OM_2$	7.00	23.42	3.01
13.	$N_3P_3K_1OM_2$	7.88	19.85	3.47
14.	$N_3P_2K_2OM_2$	10.50	23.42	4.17
15.	$N_1P_2K_2OM_2$	11.81	19.82	3.47
16.	$N_2P_2K_0OM_2$	11.38	16.49	3.01
17.	$N_0P_0K_0OM_1$	9.63	14.12	2.78
18.	$N_1P_1K_2OM_1$	10.94	19.85	2.55
19.	$N_3P_3K_2OM_1$	10.06	18.76	3.24
20.	$N_3P_3K_3OM_1$	11.38	19.56	3.47
21.	$N_2P_1K_1OM_0$	12.69	19.45	3.24
22.	$N_2P_2K_1OM_0$	10.50	16.49	3.47
23.	$N_0P_0K_0OM_0$	7.44	13.32	2.55
24.	$N_1P_1K_1OM_0$	10.94	18.76	3.24
Mean		**9.92**	**17.80**	**3.32**

Cont…….

STRIP-III

Plot no.	Treatments	Quality content (%)		
		Protein	Curing	Curcumin
1.	$N_2P_3K_3OM_0$	9.63	17.56	3.24
2.	$N_3P_2K_3OM_0$	11.38	17.68	4.40
3.	$N_3P_1K_1OM_0$	10.50	18.89	4.63
4.	$N_3P_3K_3OM_0$	7.88	17.92	4.17
5.	$N_2P_1K_2OM_1$	6.56	21.32	3.94
6.	$N_2P_2K_2OM_1$	10.06	22.06	3.94
7.	$N_2P_3K_2OM_1$	8.31	19.73	3.70
8.	$N_3P_3K_1OM_1$	9.63	21.04	3.47
9.	$N_2P_1K_1OM_2$	11.38	23.32	3.24
10.	$N_0P_0K_0OM_2$	8.75	14.30	3.24
11.	$N_2P_2K_1OM_2$	9.63	20.92	3.47
12.	$N_1P_2K_1OM_2$	7.88	21.94	3.24
13.	$N_1P_1K_1OM_2$	7.00	19.86	3.01
14.	$N_2P_0K_2OM_2$	7.44	16.48	3.24
15.	$N_2P_2K_3OM_2$	9.19	24.42	4.40
16.	$N_3P_2K_1OM_2$	10.94	17.98	3.47
17.	$N_3P_2K_2OM_1$	12.69	21.02	4.40
18.	$N_1P_2K_2OM_1$	10.50	19.83	3.24
19.	$N_0P_0K_0OM_1$	9.19	13.30	2.78
20.	$N_2P_2K_0OM_1$	9.63	14.55	3.24
21.	$N_1P_1K_2OM_0$	10.50	23.70	3.24
22.	$N_0P_2K_2OM_0$	10.94	15.57	3.01
23.	$N_3P_3K_2OM_0$	12.25	22.30	3.24
24.	$N_0P_0K_0OM_0$	8.75	12.50	2.55
Mean		**9.61**	**19.09**	**3.52**

APPENDIX IX

Strip and plot wise post harvest soil test values of experimental field predicted on the basis of yield

STRIP-I

Plot No.	Treatments	Alkaline $KMnO_4$-N (kg ha^{-1})		Olsen's-P (kg ha^{-1})		NH_4OAC-K (kg ha^{-1})	
		Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value
1	$N_2P_1K_2OM_0$	150.53	142.29	24.29	23.97	87.36	85.20
2	$N_3P_3K_1OM_0$	200.70	164.72	22.71	18.29	96.32	80.43
3	$N_1P_2K_2OM_0$	188.16	169.11	22.21	22.14	115.36	103.75
4	$N_3P_2K_2OM_0$	150.53	139.94	21.17	22.15	101.92	85.77
5	$N_2P_1K_1OM_1$	200.70	155.72	17.40	21.42	108.64	81.16
6	$N_2P_2K_1OM_1$	175.62	162.39	15.80	18.19	71.68	75.08
7	$N_0P_0K_0OM_1$	137.98	142.60	18.56	18.65	69.44	77.21
8	$N_1P_1K_1OM_1$	200.70	154.78	19.14	20.21	85.12	81.05
9	$N_3P_3K_3OM_2$	175.62	145.21	21.36	23.14	112	88.34
10	$N_3P_1K_1OM_2$	137.98	150.39	17.56	18.22	92.96	93.74
11	$N_0P_0K_0OM_2$	100.35	133.54	21.44	19.50	77.28	101.35
12	$N_2P_3K_3OM_2$	125.44	152.73	17.62	18.74	86.24	97.78
13	$N_0P_2K_2OM_2$	125.44	174.65	18.76	20.32	84	91.85
14	$N_3P_2K_3OM_2$	150.53	155.86	16.03	17.75	75.04	84.70
15	$N_1P_1K_2OM_2$	150.53	141.94	17.72	21.56	86.24	85.09
16	$N_3P_3K_2OM_2$	163.07	170.79	17.20	21.32	92.96	79.16
17	$N_3P_2K_1OM_1$	125.44	181.45	18.34	21.61	101.92	76.23
18	$N_2P_0K_2OM_1$	100.35	194.83	16.15	21.51	88.48	90.27
19	$N_1P_2K_1OM_1$	100.35	160.06	17.29	20.85	99.68	93.38
20	$N_2P_2K_3OM_1$	137.98	145.67	17.88	20.63	106.4	104.02
21	$N_2P_2K_0OM_0$	112.90	156.12	17.91	20.18	81.76	83.22
22	$N_0P_0K_0OM_0$	125.44	145.58	20.75	22.95	87.36	97.41
23	$N_2P_2K_2OM_0$	163.07	135.42	20.22	19.26	104.16	90.60
24	$N_2P_3K_2OM_0$	150.53	152.53	19.70	21.27	104.16	86.24
	Mean	**147.91**	**155.35**	**19.05**	**20.58**	**92.35**	**88.04**

Cont…….

STRIP-II

Plot No.	Treatments	Alkaline $KMnO_4$-N (kg ha^{-1})		Olsen's P (kg ha^{-1})		NH_4OAC-K (kg ha^{-1})	
		Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value
1.	$N_3P_2K_1OM_0$	150.53	163.33	21.99	22.95	150.08	124.51
2.	$N_2P_2K_3OM_0$	188.16	171.05	23.16	25.61	170.24	144.77
3.	$N_2P_0K_2OM_0$	238.34	238.13	23.76	26.26	98.56	113.27
4.	$N_1P_2K_1OM_0$	112.90	153.39	25.50	24.00	113.12	107.51
5.	$N_2P_3K_3OM_1$	150.53	143.88	23.28	21.31	120.96	121.08
6.	$N_3P_1K_1OM_1$	137.98	147.40	24.46	25.29	87.36	107.25
7.	$N_3P_2K_3OM_1$	125.44	155.66	22.79	22.77	79.52	104.65
8.	$N_0P_2K_2OM_1$	175.62	167.38	24.54	23.60	75.04	100.94
9.	$N_2P_2K_2OM_2$	125.44	140.49	23.44	22.51	78.4	94.71
10.	$N_2P_3K_2OM_2$	150.53	151.14	24.06	23.36	80.64	77.49
11.	$N_0P_0K_0OM_2$	112.90	132.75	23.52	21.10	84	83.55
12.	$N_2P_1K_2OM_2$	137.98	146.46	25.29	23.73	88.48	94.35
13.	$N_3P_3K_1OM_2$	188.16	167.91	25.33	21.48	104.16	81.18
14.	$N_3P_2K_2OM_2$	175.62	159.15	24.80	24.61	105.28	80.42
15.	$N_1P_2K_2OM_2$	188.16	184.64	24.84	25.65	79.52	92.99
16.	$N_2P_2K_0OM_2$	137.98	156.12	25.47	23.74	73.92	79.20
17.	$N_0P_0K_0OM_1$	137.98	141.60	26.09	21.01	78.4	94.47
18.	$N_1P_1K_2OM_1$	175.62	143.93	24.39	24.66	100.8	106.94
19.	$N_3P_3K_2OM_1$	175.62	145.41	24.43	24.87	100.8	106.33
20.	$N_3P_3K_3OM_1$	112.90	143.62	25.06	24.57	120.96	107.08
21.	$N_2P_1K_1OM_0$	163.07	165.38	24.52	24.35	94.08	108.86
22.	$N_2P_2K_1OM_0$	150.53	147.26	24.56	24.54	107.52	102.29
23.	$N_0P_0K_0OM_0$	150.53	153.44	25.19	24.86	140	103.94
24.	$N_1P_1K_1OM_0$	175.62	160.06	26.40	26.27	115.36	107.47
	Mean	**155.75**	**157.48**	**24.45**	**23.88**	**101.97**	**101.89**

Cont…….

STRIP-III

Plot No.	Treatments	Alkaline $KMnO_4$-N (kg ha^{-1})		Olsen's P (kg ha^{-1})		NH_4OAC-K (kg ha^{-1})	
		Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value
1.	$N_2P_3K_3OM_0$	125.44	140.30	27.62	27.10	114.24	118.99
2.	$N_3P_2K_3OM_0$	163.07	179.06	24.73	22.15	97.44	134.63
3.	$N_3P_1K_1OM_0$	150.53	154.27	25.36	27.00	172.48	132.33
4.	$N_3P_3K_3OM_0$	150.53	151.88	28.36	27.81	159.04	132.57
5.	$N_2P_1K_2OM_1$	137.98	145.87	27.81	25.64	126.56	126.04
6.	$N_2P_2K_2OM_1$	150.53	155.23	27.27	26.92	81.76	109.42
7.	$N_2P_3K_2OM_1$	163.07	150.54	27.31	26.34	84	103.64
8.	$N_3P_3K_1OM_1$	150.53	163.93	26.76	24.16	71.68	88.29
9.	$N_2P_1K_1OM_2$	200.70	170.66	23.23	19.73	72.8	85.48
10.	$N_0P_0K_0OM_2$	150.53	133.54	20.89	15.94	122.08	100.35
11.	$N_2P_2K_1OM_2$	188.16	166.87	21.52	26.20	73.92	96.29
12.	$N_1P_2K_1OM_2$	137.98	134.28	19.16	20.23	77.28	89.52
13.	$N_1P_1K_1OM_2$	125.44	151.99	21.59	24.04	86.24	98.76
14.	$N_2P_0K_2OM_2$	150.53	171.45	23.43	25.32	86.24	105.58
15.	$N_2P_2K_3OM_2$	175.62	174.14	25.27	25.76	103.04	99.87
16.	$N_3P_2K_1OM_2$	188.16	180.65	25.32	23.57	71.68	105.73
17.	$N_3P_2K_2OM_1$	150.53	161.94	24.75	23.27	82.88	97.93
18.	$N_1P_2K_2OM_1$	225.79	198.38	26.00	24.60	103.04	101.80
19.	$N_0P_0K_0OM_1$	112.90	142.20	26.65	23.72	73.92	99.51
20.	$N_2P_2K_0OM_1$	137.98	161.20	28.52	25.21	108.64	92.87
21.	$N_1P_1K_2OM_0$	175.62	156.28	25.53	23.92	159.04	136.19
22.	$N_0P_2K_2OM_0$	200.70	175.05	26.18	23.43	117.6	117.35
23.	$N_3P_3K_2OM_0$	188.16	150.89	25.61	25.90	114.24	111.29
24.	$N_0P_0K_0OM_0$	200.70	161.31	23.21	24.64	120.96	108.45
Mean		**162.55**	**159.66**	**25.09**	**24.28**	**103.37**	**108.04**

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ABSTRACT

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Advisor	:	**Dr. Sobaran Singh**			

A field experiment was conducted during the year 2013-14 and 2014-15 in a Aquic Hapludoll at D_7 block of Norman E. Borlogue Crop Research Centre of The G.B. Pant University of Agriculture and Technology, Pantnagar (29^0 N latitude and $79^0$29' E longitude), as per the technical programme of All India Coordinated Research Project on Soil Test Crop Response Correlation. The experiment was conducted in three phases. In the first phase soil fertility gradient was developed by dividing experimental field into three strips and applying graded doses of fertilizers in them (Strip I (no fertilizer), Strip II (100,100 and 100 kg N, P_2O_5 and K_2O/ha) and Strip III (200, 200 and 200 kg N, P_2O_5 and K_2O ha^{-1}) and growing of exhaust crop fodder Oat (Var. UPO-212). In the second phase i.e. next season test crop Turmeric (*Curcuma longa* L.) was grown by dividing each strip in 24 plots having 21 treatments and 3 controlled plots. Response var. Pant peetabh of selected combinations of three levels of FYM (0, 10 and 20 t/ha), four levels of nitrogen (0, 50, 100 and 150 kg ha^{-1}), four levels of phosphorus (0, 50, 100 and 150 kg P_2O_5 ha^{-1}) and four levels of potassium (0, 50, 100 and 150 kg K_2O ha^{-1}) at different fertility levels of turmeric was studied. In third phase, a verification trial was conducted during 2014-15 to validate the fertilizer adjustment equations generated by ten treatments and three replications, with combinations of inorganic, organic and micronutrients.

The values of the organic carbon, Alkaline $KMnO_4$ extractable N, Olsen's P and neutral normal Ammonium Acetate extractable K in the experimental field ranged between 0.58 to 1.05 per cent, 112.90 to 263.42 kg ha^{-1} and 16.97 to 29.27 kg ha^{-1}, 58.24 to 189.28 kg ha^{-1}, respectively. The total uptake of N, P and K ranged from 68.96 to 371.88, 14.31 to 54.56 and 70.23 to 489.23 kg ha^{-1} by turmeric, respectively. In the present investigation the total rhizome yield ranged from 113.33 to 354.17 q ha^{-1} and total haulm yield 9.33 to 45.00 q ha^{-1}.

The nutrient requirement for production of one quintal of rhizome yield of turmeric was found to be 0.91 kg Nitrogen, 0.32 kg Phosphorus and 1.02 kg Potassium. Percent contribution of nitrogen, phosphorus and potassium was 61.45, 56.13 and 69.35 from soil, whereas from other sources as FYM was 46.31, 10.3 and 74.91 percent. Percent contribution of nitrogen, phosphorus and potassium without FYM was 119.29, 45.13 and 201.96 and with conjoint use of chemical fertilizer with FYM 143.67, 53.94 and 265.11. Fertilizer adjustment equations developed for conjoint use of fertilizers with the help of basic data are: FN= 0.63T- 0.42 SN-0.32 ON, FP= 0.59T-2.38 SP- 0.43 OP, FK= 0.38 T-0.31 SK-0.34 OK. Coefficient of quadratic multiple regression (R^2) was found highly significant (0.687**) between total rhizome yield, soil test values, added fertilizers and interaction between soil and fertilizer.

Maximum response to turmeric obtained at 100 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1}. The rhizome yield of turmeric significantly correlated with haulm yield (0.587**), applied N (0.464**), P (0.599**) and K (0.636**) uptake of N (0.883**), P (0.975**) and K (0.852**). The quality parameter of turmeric i.e. curing and curcumin % were positively and significantly correlate with the soil test value and fertilizer doses. For prediction the post harvest soil test values prediction equations were developed for available N, P and K. Verification trial was conducted to test the validity of fertilizer adjustment equations. Fertilizer application based on targeted yield approach was found to be significantly superior over general recommended dose (GRD). Suitability of soil test methods was also evaluated by R^2 value of multiple regression equation and concluded that Alkaline $KMnO_4$-N, Olsen's-P and AB-DTPA-K methods are equally suitable for the determination of available Nitrogen, Phosphorus and Potassium, respectively in *Tarai* region of Uttarakhand for turmeric crop. However, AB-DTPA may be recommended for use in soil testing laboratories.

Findings from present study can successfully utilized for the larger parts of *Tarai* region of Uttarakhand as effective guide for efficient and balanced fertilizer recommendation to turmeric.

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शोध ग्रंथ शीर्षक : **"उत्तराखण्ड की मौलीसौल मृदाओं में उगाई जाने वाली हल्दी (*Curcuma longa* L.) के लिए मृदा परीक्षण एवं फसल अनुक्रिया पर आधारित संतुलित उर्वरक हेतु एक अध्ययन"।**

सलाहकार : डा0 सोबरन सिंह

मृदा परीक्षण एवं फसल अनुक्रिया सहसंबंध पर अखिल भारतीय समन्वित शोध परियोजना के तकनीकी कार्यक्रम के अनुसार गो0ब0 पन्त कृषि एवं प्रौ0 विश्वविद्यालय के नार्मन ई0 बोरलाग फसल अनुसंधान केन्द्र के $डी_7$ खण्ड (29^0 उत्तरी अक्षांश एवं $79^0 29'$ पूर्व देशांतर) की एक्यूक हेप्लूडाल में जायद 2013–14 एवं 2014–15 के दौरान एक प्रक्षेत्रीय प्रयोग किया गया। प्रयोग को तीन चरणो में किया गया। पहले चरण में प्रायोगिक क्षेत्र को तीन पट्टियों में बॉटकर एवं उनमें श्रेणीबद्ध उर्वरक की मात्रा डालकर (पट्टी प्रथम (उर्वरक रहित), पट्टी द्वितीय (प्रति हेक्टेयर 100, 100, 100 किग्रा नाइट्रोजन, फास्फोरस एवं पोटाश), पट्टी तृतीय (प्रति हेक्टेयर 200, 200, 200 किग्रा नाइट्रोजन, फास्फोरस एवं पोटाश) एवं उर्वरताहारी चारा फसल जई को उगाकर मिट्टी की उर्वरता ढाल को विकसित किया गया। द्वितीय चरण में अर्थात् अगले मौसम में परीक्षण फसल हल्दी (किस्म–पन्त पीताभ) की प्रत्येक पट्टी को 24 खंडों में बॉटकर उगाया गया जिसमें 21 उपचार एवं तीन अनुपचारित खंड थे। एफ0वाई0एम0 के तीन चरण (0, 10, एवं 20 टन $हे0^{-1}$), नाइट्रोजन के चार चरण (0, 50, 100 एवं 150 किग्रा नाइट्रोजन $हे0^{-1}$), फास्फोरस के चार चरण (0, 50, 100 एवं 150 किग्रा फास्फोरस $हे0^{-1}$) एवं पोटेसियम के चार चरण (0, 50, 100 एवं 150 किग्रा पोटाश $हे0^{-1}$) से हल्दी के विविध उर्वरता स्तरो पर चयनीत संयोजन के प्रति प्रतिक्रिया का अध्ययन किया गया। प्रयोग द्वारा विकसित उर्वरक समायोजन समीकरणों को सत्यापित करने के लिए तृतीय चरण में सत्यापन परीक्षण दस उपचारों एवं तीन पुनरावृत्तियों में अकार्बनिक, कार्बनिक एवं सूक्ष्म पोशक तत्वों के साथ वर्ष 2014–15 में किया गया।

प्रायोगिक क्षेत्र में जैव कार्बन, क्षारीय पोटेशियम परमैंनेट से निष्कर्षित नाइट्रोजन, ओल्सन फास्फोरस एवं सामान्य उदासीन अमोनियम एसिटेट निष्कर्षित पोटेषियम का परिसर मान 0.58–1.05 प्रतिशत, 112.90–263.42 किग्रा $हे0^{-1}$ तथा 16.97–29.27 किग्रा $हे0^{-1}$, 58.24–189.28 किग्रा $हे0^{-1}$ के मध्य था। नाइट्रोजन, फास्फोरस एवं पोटेशियम का हल्दी द्वारा कुल उदग्रहण परिसर मान क्रमशः 68.96–371.88, 14.31–54.56 एवं 70.23–489.23 किग्रा $हे0^{-1}$ के मध्य था। वर्तमान अन्वेषण में कुल कंद उपज का परिसर मान 113.33–354.17 कु0 $हे0^{-1}$ एवं कुल फूस उपज का परिसर मान 9.33–45.00 कु0 $हे0^{-1}$ के मध्य था।

एक कुन्तल हल्दी की कंद पैदावार उत्पादन के लिये 0.91 किग्रा नाईट्रोजन, 0.32 किग्रा फास्फोरस (P_2O_5), एवं 1.02 किग्रा पोटेशियम (K_2O) का प्रयोग पोषक तत्वो के रूप में आवश्यक पाया गया। एन0पी0के0 के सन्दर्भ में नाईट्रोजन, फास्फोरस एवं पोटेशियम का योगदान क्रमश– मिट्टी से 61.45, 56.13 एवं 69.35 प्रतिशत जबकि अन्य स्रोत से जैसे कि एफ0वाई0एम0 सें 46.31, 10.30, और 74.91 प्रतिशत पाया गया। प्रयोग में लाये गये नत्रजन, फास्फोरस और पोटेशियम उर्वरकों से पोषक तत्वों के उपयोग की क्षमता क्रमशः 119.29, 45.13, और 201.96 प्रतिशत, उर्वरक और एफ.वाई.एम. के संयुक्त प्रयोग से नत्रजन, फास्फोरस एवं पोटेशियम के उपयोग की क्षमता क्रमशः 143. 67, 53.94 और 265.11 पायी गयी। उपरोक्त मानों के आधार पर रासायनिक एवं गोबर की खाद के संयुक्त प्रयोग पर आधारित उर्वरक सामायोजन समीकरणों को विकसित किया गया (FN = 0.63T- 0.42SN-0.32ON, FP_2O_5 = 0.59T-2.38SP- 0.43OP, FK_2O = 0.38T-0.31SK-0.34OK)। हल्दी की कुल गांठ उपज, मृदा परीक्षण मानों, प्रयोग में लाये गये उर्वरक और मृदा एंव उर्वरकों की अनुक्रिया के मध्य प्रतिगमन गुणांक (R^2) अत्यंत सार्थक (0.687′′) पाया गया।

100 किग्र नाइट्रोजन, 100 किग्रा फास्फोरस, तथा 100 किग्रा पोटाश $है0^{-1}$ में उच्चतम फसल अनुक्रिया प्राप्त हुई। हल्दी की गांठ का फूस उपज (0.587^{**}), प्रयुक्त नत्रजन (0.587^{**}), फास्फोरस (0.599^{**}), पोटेशियम (0.636^{**}), उदग्रहण नत्रजन (0.883^{**}), फास्फोरस (0.975^{**}) एवं पोटेशियम (0.552^{**}′) से सार्थक धनात्मक संबंध पाये गये। हल्दी की गुणवत्ता वाले गुण जैसे क्यूरिंग एवं कुरकुमिन का मृदा परीक्षण मान एवं प्रयुक्त उर्वरक से सार्थक धनात्मक संबंध पाये गये। प्रारम्भिक एवं अंतिम मृदा परीक्षण मानों, प्रयोग किये गये उर्वरकों की मात्रा एवं पैदावार के द्वारा मृदा परीक्षण अनुमान समीकरण विकसित की गयी। उर्वरक समायोजन समीकरणों को सत्यापित करने के लिए सत्यापन परीक्षण किये गये और निर्धारित उपज लक्ष्णों के लिए उर्वरक अनुमोदन, सामान्य उर्वरक अनुमोदन से श्रेष्ठ पाया गया।

प्रतिगमन गुणांक के (R^2) मान के द्वारा मृदा परीक्षण विधियों की उपयुक्तता का भी मूल्यांकन किया गया और यह निष्कर्ष निकाला गया कि उत्तराखण्ड के तराई भागों में हल्दी की फसल के लिए क्षारीय पोटेशियम परमेंगनेट–नत्रजन, ओलसन फास्फोरस तथा एबी–डीटीपीए पोटेशियम विधियां क्रमशः उपलब्ध नाइट्रोजन, फास्फोरस व पोटाश के निर्धारण के लिए उपयुक्त है। जबकि एबी–डीटीपीए, मृदा परीक्षण प्रयोगशाला में प्रयोग के लिए उपयुक्त हो सकता है।

वर्तमान अध्ययन से प्राप्त निष्कर्षो का उपयोग उत्तराखण्ड के तराई क्षेत्र के वृहद भाग में हल्दी के संतुलित उर्वरक संस्तुति के लिये निदेशन के रूप में सफलतापूर्वक किया जा सकता है।

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