OPTIMIZATION OF FERTILIZER DOSES THROUGH STCR APPROACH FOR CAULIFLOWER (*BRASSICA OLERACEA* L VAR. BOTRYTIS) GROWN IN MOLLISOLS

Thesis

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(Alka Arya)
Authoress

CERTIFICATE

This is to certify that the thesis entitled **"OPTIMIZATION OF FERTILIZER DOSES THROUGH STCR APPROACH FOR CAULIFLOWER (*BRASSICA OLERACEA* L VAR. BOTRYTIS) GROWN IN MOLLISOLS"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** with major in **Soil Science and Minor in Vegetable Science,** 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 **Ms. Alka Arya, Id. No. 36064**, 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 duly acknowledged.

Pantnagar
May, 2019

(Sobaran Singh)
Chairman
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CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Ms. Alka Arya, Id. No. 36064**, a candidate for the degree of **Doctor of Philosophy** with major in **Soil Science** and minor in **Vegetable Science**, agree that the thesis entitled **"OPTIMIZATION OF FERTILIZER DOSES THROUGH STCR APPROACH FOR CAULIFLOWER (*BRASSICA OLERACEA* L VAR. BOTRYTIS) GROWN IN MOLLISOLS"** may be submitted in partial fulfillment of the requirements for the degree.

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Introduction

Today's main priority is feeding ever-increasing populations. We have to look for the approaches for vertical growth in crop production on a sustainable basis, as the horizontal expansion in area is not possible. The per capita land availability is likely to be reduced from 0.14 ha in 2000 to 0.10 ha in the year 2025 (Kumar and Shivay, 2010). It would mean augmenting the food production from the shrinking land and other natural resources by increasing their use efficiency. To meet out the future necessities, there is a need of better planning and resource management except for intensification of cropping intensity. Improving soil health is important for India as it support 17 per cent of the world's population on just 2.4 per cent of the world's geographical area. Agriculture continues to be a dynamic component of India's economy contributing over 13.7 per cent of India's GDP and providing employment to 55 per cent of its population. Managing soil health is a difficult challenge for national food security to ensure productivity, profitability and sustainability. Maintaining soil health is one of the key elements that contribute to sustainable production of agriculture.

Intensive cropping has led to impressive growth in food grain production driven by advanced seed varieties, fertilizer application, and assured irrigation. NPK consumption ratio changed from 7.2:2.9:1 during 2012-13 to 6.1:2.5:1 during 2017-18 (FAI, 2017-18). The inadequate and imbalanced nutrient use coupled with low nutrient use efficiency and devoid of organic manures has caused multinutrient deficiencies in many areas with time. Moreover, low nutrient use efficiencies, which vary from 30-50% (N), 15-20% (P), 60-70% (K), 8-10% (S) and 1-2% (micronutrients). The overall fertilizer response in the irrigated area decreased nearly three times from 13.4 kg grain kg^{-1} NPK in 1970 to 3.7 kg grain kg^{-1} NPK in 2005. This indicates that nearly four times more fertilizers are being required presently compared to that of 1970 to sustain the same yield (Chaudhary *et al.*, 2015). Benbi *et al*. (2006) reported that NPK's deteriorating partial factor productivity in food grain production fell from 81 kg of grain per kg of NPK in 1966-67 to 16 kg of grain per kg of NPK in 2003-04.

Fertilizers are the key player among different factors contributing towards agricultural production. One of the most vital factors in sustaining agricultural production and soil health is balanced nutrient use. Due to their differential production potential and their ability to mine nutrients from native and fertilizer sources, the fertilizer needs of different crops differ. The amount of fertilizer applied to crops therefore, depends on the soil's initial nutrient status, yield and management of crop and fertilizers. Management of fertilizers plays an essential role in achieving a satisfactory yield. This can be done by involving organic resources, bio-fertilizers, and micronutrients in order to increase crop productivity (Pingali and Pandey, 2005).

The present day objective of soil testing is to recommend “balanced and integrated use of fertilizers”. Balanced fertilization would essentially mean rational use of fertilizers and organic manures (integrated use) for the supply of plant nutrients for agricultural production in such a way as to ensure; i) fertilization efficiency ; (ii) optimal positive and synergistic interactions between the various other production factors (seed, water, etc.); (iii) least adverse environmental effects (for example, leaching, denitrification and other N losses), (iv) minimum nutrient losses, and (v) high yields appropriate to the biological potential of the crop variety under the unique soil-climate-agro-ecological set-up (Goswami, 1982). In many cases, farmers apply very high doses of fertilizers than required particularly N without adequate P and K. Such conditions not only results in crop failures through pest and diseases but also causes soil deterioration and pollution risks besides increasing input cost. Thus, balanced nutrition after soil testing will enhance the fertilizer use efficiency and help in achieving sustainable economic farming. Balanced nutrition no longer means the application by fertilizer of nitrogen, phosphorus and potassium alone in a certain proportion, but it should ensure that the nutrients in the available forms are the insufficient quantity and proportion required within the soil to satisfy the requirement of the crops to acquire the desired yield levels. In soil, nutrients are often found in sufficiently good quantities and in a balanced proportion to meet the requirements of crop nutrients. In order to attain this, it is essential that the number of nutrients removed from the soil should be replenished through judicious use of fertilizers and manures. This needs a more comprehensive approach for fertilizer use, incorporating components like soil test, field research and economic evaluation of the results. Soil test provides the required information on the amount of nutrients available in the soil and its imbalances, while recommendations for fertilizers are intended to correct crop requirements for nutrient imbalances. Soil testing has been recognized as reliable tools for balanced fertilization and efficient fertilizer management. Soil testing programme turned into began in India during the year 1955-56 with the setting-up of 16 soil testing laboratories under the Indo-US Operational Agreement for "Determination of Soil Fertility and Fertilizer Use". At present 1250 soil testing labs are in operation in the country. Soil testing is a sound scientific device for measuring soil's inherent ability to deliver plant nutrients, established through scientific research, extensive field demonstrations and on the premise of actual fertilizer use recommendations by farmers on soil test based fertilizer use.

Among various fertilizer recommendation approaches, including general recommended dose, recommendation based on soil testing, critical soil test value approach, etc. The targeted yield approach based on soil test-crop response (STCR) is unique in the sense that this method indicates not only the soil test-based fertilizer dose, but also the extent of yields that the farmer may wish to achieve if good agronomic practices are applied to the crop. The concept of targeted yield strikes a balance between crop fertilization and soil fertilization. Numerous fertilizer adjustment equations have been generated by the All India Coordinated Research Project on STCR (AICRP on STCR) to recommend fertilizers to crops grown on different soils in different agroecological areas across the country. Further, for recommending fertilizers to cropping systems, initial and predicted post – harvest soil test values have been employed with reasonable success (Rao and Srivastava, 1998). One of the important advantages of this approach is that farmers have the options to relate their resources with a desired level of yield target. Choosing the appropriate target and application of required amount of plant nutrient ensure the most judicious and balance fertilization and also helps to sustain soil productivity and crop production. The theory of formulating optimum fertilizer recommendation for a targeted yield of crops was first given by Truog (1960), which was further modified by Ramamoorthy *et al*. (1967).

Experimental data based on field experiments with soil test crop response (STCR) provide scope for a wide range of soil test values, nutrient uptake, and yield levels, enabling a researcher to derive four basic parameters: (i) nutrient requirement (NR), (ii) per cent contribution of available nutrient from soils (CS). (iii) Per cent contribution from the applied fertilizer (CF), and (iv) per cent contribution from the organic manures (CFYM). Applying soil-based fertilizer doses to a crop would help achieve a higher response ratio and a higher benefit cost ratio as the nutrients are applied in proportion to the magnitude of a particular nutrient's deficiency. This targeted yield approach is also scientifically sound as balanced fertilization is ensured not only among the nutrients of the fertilizer but also among the nutrients available in the soil. Rao and Srivastava (1999) reiterated that the calibration of the soil test is intended to establish a relationship between the levels of soil nutrients as determined in the laboratory and the response of crops to fertilizers observed in the field. Because of a wide variety of soils, different climates, crops, and management practices, the great difficulty in soil testing crop response increases. A well-established calibration of soil testing, therefore, helps to apply fertilizers in accurate quantities and to obtain high efficiency of use for maximum possible yield in an eco-system.

Continued use of inorganic nutrients can adversely affect the soil's physicochemical properties and thus affect crop yields. Conjunctive use of organic manures, biofertilizers, and fertilizers is very important in order to maintain yield and reduce dependence on inorganic fertilizer use. The various AICRP centers on STCR have developed equations to include organic manures and/or biofertilizers to prescribe the nutrients to the crop's specific yield target. However, such information on the use of fertilizer adjustment equations for prescribing nutrients from different sources is very meager.

Vegetables are of great importance as a source of vitamins, minerals and plant proteins which play vital role in human diet all over the world. India is the world’s second largest vegetable producer, next to china and accounts for about 15% of the world’s production of vegetables. Significant emphasis has been placed on increasing vegetable crop production in India over the last two decades. Consequently, adequate and balanced use of fertilizer in vegetable production will not only improve the nutritional requirement but can also meet the challenge of providing adequate food to the country's growing population.

Cauliflower (*Brassica oleracea* var. botrytis L.) is one of the most popular vegetable crop among the cole crops and has originated from the Mediterranean region. It was introduced in our country in 1822. Cauliflower belongs to family brassicaceae and is grown for its white tender curd which is used for vegetable, curry, soup and pickle preparations. The name cauliflower originated respectively from the Latin words 'caulis' and 'floris' meaning cabbage and flower. The edible part of this vegetable is about 45% of the plant. (Rai and Yadav, 2005). Besides being good source of protein and carbohydrates, cauliflower is a rich source of vitamins and minerals (Bana *et al*., 2012). Cauliflower fresh curd are highly nutritive and contain moisture 90.8 g, protein 2.6 g, fat 0.4 g, minerals 1.0 g, fiber 1.2 g, carbohydrates 4.0 g, calcium 33 mg, phosphorous 57 mg, iron 1.5 mg, carotene 30 mg, thiamine 0.04 mg, riboflavin 0.10 mg, niacin 1.0 mg vitamin-C 56 mg per 100 g of edible portion (Jood and Neelam, 2011). Cauliflower's therapeutic effect was well recognized. The inflorescence extract was used as a blood purifier and as an antacid in the treatment of scurvy. The seeds have the properties of contraception. It has been reported that cauliflower extract is effective in inhibiting carcinogenesis initiation and promotion in vitro. Ascorbic acid, carotenoids, tocopherols, isothiocyanates, indoles, and flavonoids are potential chemopreventive agents. When consumed, the vegetable provides health benefits for both humans and animals due to its abundance of vitamins, particularly vitamin C, which is known to provide protection against certain types of cancer, help lower blood cholesterol and serve as strong antioxidants Batabyala *et al*. (2016).

India ranks second in area and production of cauliflower in the world after China. India contributes approximately 13 per cent of the world's vegetable production and ranks first in the world's cauliflower, second in onion and third in cabbage. In India major cauliflower growing states are West Bengal, Bihar, Maharashtra, Madhya Pradesh, Orissa, Gujarat, and Haryana, etc. It is grown in an area of 9,73,452 ha at global level with an annual production of 1,76,62,424 MT (FAO, 2005). Cauliflower in India occupies an area of 426,000 ha with a production of 80, 90,000 MT while cauliflower occupies an area of 3,010 ha with a production of 38,490 MT in Uttarakhand (NHB, 2017). With the adoption of high yielding varieties and improved production technologies, there has been a significant increase in both vegetable production and productivity. At the same time, indiscriminate use of chemical fertilizers has resulted in many problems such as soil productivity degradation, pollution of the environment, depletion of non-renewable energy sources, etc. The use of chemical fertilizers should, therefore, be balanced, judicious and minimized and can be replaced by the integrated use of manures, fertilizers, green leaf manure and bio-fertilizers.

The reason behind poor productivity is the adoption of unscientific crop management practices. The growing of high yielding varieties and the use of chemical fertilizers are increasing day by day. Among the crop management practices, balanced use of nutrients plays a key role in improving productivity and quality. Plant nutrients are the essential components of sustainable agriculture. Undoubtedly, for optimum plant growth and production, the essential nutrient must be readily available in sufficient amount and balanced form. Nitrogen, phosphorus, and potassium are the most effective nutrients for enhancement of growth, yield, and quality of cauliflower. Nitrogen enhances vegetative growth, phosphorus promotes the development of root and shoot and potassium provides resistance against diseases and insect pests (Das, 2012).

Cauliflower is a heavy nutrient feeder that thoroughly responds to nutrient supplements through farm yard manure (FYM), bio fertilizers, green manures, and chemical fertilizers (Sharma and Rana, 1993). The doses of fertilizer recommended by the Soil Test Crop Response (STCR) correlation method are based on fertilizer adjustment equations. These equations are developed after a significant relationship has been established for a particular soil type between soil test values and added fertilizer levels and crop response. Therefore, recommendations for fertilizers based on the concept of STCR are more quantitative, accurate and meaningful because it involves the combined use of soil and plant analysis. It provides a real balance between the nutrients applied and the nutrients already present in the soil.

Keeping above all in view, the present experiment "Optimization of fertilizer doses through STCR approach for cauliflower (*Brassica oleracea* L var. botrytis) grown in Mollisols" was conducted with the following objective:

1. To study response of soil and applied N, P, K and FYM on growth, yield and quality of cauliflower.
2. Evaluation of availability indices of phosphorus and potassium for cauliflower.

3. To estimate the soil and applied nutrients efficiencies of N, P, K and FYM by cauliflower.
4. To predict post-harvest soil test value for N, P and K.
5. To generate database for online fertilizer recommendations.

Review of Literature

REVIEW OF LITERATURE

Soil testing is a scientific tool to estimate soil fertility by predicting the probability of a profitable response to fertilizer recommendation. Soil testing plays a vital role in recommending soil test fertilizer that ensures balanced crop nutrition and also avoids the wasteful use of this expensive input. Soil testing is the first entry point to the field of the farmer to extend the transfer of agro-technology to him, including long-term management of soil fertility (Ramamoorthy and Velayutham, 2011). Therefore, soil-based application of fertilizer is encouraged worldwide. Soil testing helps us to know the nutrient status and soil imbalances and apply the amount of nutrients needed to overcome imbalances and maintain yield (Subba Rao and Srivastava, 1998). In conventional soil testing, the fertilizer recommendation is usually given for different crops, taking into account only the available soil nutrient status prior to growing a crop, by classifying soil into low, medium and high fertility classes. Within a fertility class there is a very wide range of particular nutrients, ignoring vast differences in the absolute amount in the soil while recommending fertilizer. "Inductive cum Targeted yield approach" provided initially by Truog (1960) and redesigned by Ramamoorthy *et al*. (1967) states a scientific principle for balanced fertilization and balance of soil and applied nutrients.

The STCR based fertilizer recommendations also known as "Prescription Based Fertilizer Recommendations" takes into account every bit of nutrient present in the soil for achieving a targeted yield of crops under a particular agro-climatic situation. The prescription-based fertilizer recommendation approach not only helps in achieving higher yield, benefit-cost ratio and response ratio but also in improving crop nutrient uptake. Khosa *et al*. (2012) achieved reasonable limits of yield and economic return when the fertilizer was applied on a soil test basis in the majority of the crops thus establishing the usefulness of the prescription equations for recommending soil test-based fertilizer application to the farmers, they also established the superiority of the target yield concept over other practices. The recommendations here are more quantitative, more accurate and more meaningful because it involves the combined use of soil and plant analysis. Like other vegetables, cauliflower responds well to the addition of nutrients through Farm Yard Manure (FYM), organic fertilizers, green manures and chemical fertilizers (Sharma and Rana, 1993).

Therefore, the present investigation entitled "Optimization of fertilizer doses through STCR approach for cauliflower (*Brassica oleracea* L var. *botrytis*) grown in Mollisols" was carried out and search of relevant review is made in this chapter. The information on above aspects has been reviewed under following heads:

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

In research and development of soil testing, the greatest efforts initially devoted to (I) development of better tests and techniques for obtaining indices of nutrient availability and (II) use of these tests to chemical analysis of soil samples and make fertilizer recommendation for farmers. Since soil test methods differ with crop and soil. Therefore, to increase the suitability of soil tests necessitates an update of methods and instrumentation. The development of new procedures, refinement and standardization of existing ones ensure increased accuracy and precision of tests, and reproducibility of results needed in the rapid analysis of soil samples. The development of a multinutrient sextractant is one of such advancement needed to cut down cost, save time and increase the efficiency in routine analysis of large numbers of soil samples (Jones, 1990 and Westerman, 1990). Since the studies involved establishing extractant for determination of available N, P and K from soils, number of extractant were used by the researcher to make testing more precise and accurate.

Soil test method for available nitrogen, phosphorus and potassium were evaluated for various crops are as follow:

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	Bremer (1965)

Joshi *et al*. (1973) found that 'A' value of wheat was closely correlated with organic carbon (r=0.95). Vatsa *et al*. (1973) evaluated eight methods for determination of nitrogen in Tarai soils using maize (Ganga-4). The linear and multiple regression analysis revealed that organic carbon method (R^2=0.48) is good for estimating the availability of nitrogen for soils of Nainital *Tarai*.

Dhawan *et al*. (1992) concluded that alkaline $KMnO_4$ method was best suited for nitrogen determination in rice grown soils but organic carbon method was most suitable for wheat grown soils.

Hussain *et al*. (1994) found that computation of mineral plus mineralizable nitrogen by modified alkaline $KMnO_4$ method which was most closely correlated with wheat dry matter and nitrogen uptake, compared with mineral nitrogen as (NH_4^+ + NO_3^-) by 2 N KCl and mineral nitrogen as NO_3^- by 2N KCl while measuring soil available nitrogen in fifty soils from agricultural fields of Pakistan. Among chemical methods, available nitrogen extracted by hot $K_2Cr_2O_7$, cold $K_2Cr_2O_7$ and alkaline $KMnO_4$ was suitable for predicting nitrogen availability to rice. But the $K_2Cr_2O_7$ oxidizable nitrogen method was 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 (Rao *et al.,* 2002).

Laxminarayana and Patiram (2006) reported that ammonical N determination 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 for yellow sarson in Pantnagar, Uttrakhand.

Sati (2008) and Upadhayay (2012) observed that organic carbon and alkaline-$KMnO_4$ methods were equally suitable for evaluation of available nitrogen in Mollisol of Uttrakhand.

Bordoloi (2013) conducted a pot experiment to study the estimate of soil N-supplying capacity which is essential for efficient fertilizer use. Six chemical indices of soil N-availability were evaluated in this study involving twenty acidic soils that vary widely in properties, viz. organic carbon, total N, acid and alkaline-$KMnO_4$ extractable-N, hot KCl extractable-N and phosphate-borate buffer extractable-N, Based on their correlation strength with available-N values obtained through aerobic incubation and anaerobic incubation, as well as dry matter yield, N percentage and plant (maize) N uptake. Correlations of the N-availability indices with aerobic incubation and anaerobic incubation decreased in the order: Phosphate-borate buffer extractable-N (r = 0.784** and 0.901**) > KCl extractable-N (r = 0.773** and 0.743**) > acid $KMnO_4$-N (r = 0.575** and 0.651**) ≥ organic carbon (r = 0.591** and 0.531**) ≥ alkaline $KMnO_4$-N (r = 0.394** and 0.548**) > total N (r = 0.297** and 0.273*). Of all the indices evaluated, Phosphate-borate buffer extractable-N showed the best correlations with plant parameters (r = 0.790** and 0.793** for dry matter yield and plant N uptake respectively). Based on the highest correlations of extractable-N phosphate-borate buffer with biological indices as well as plant responses, they reported extractable-N phosphate-borate buffer as an appropriate N-availability index in India's acidic soils and other similar soil regions.

Thus considering suitability, simplicity and cost. 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

Available phosphorus in soil is estimated by common methods 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)

Singh (1973) reported that Olsen's method to be highly correlated with phosphorus uptake and percentage yield response using wheat as a test crop in six alluvial soils of Uttar Pradesh. Similar results were also obtained in maize by Singh (1973) and in wheat by Dubey *et al*. (1974).

Pathak *et al*. (1975) found that Olsen's extractable phosphorus have significant correlation with crop yield while working on alluvial soils of Indo-Gangetic plains. Thakur *et al*. (1977) observed that Olsen's phosphorus was closely correlated with yield and phosphorus uptake of crop while testing six available phosphorus methods.

Dalwadi (1993) evaluated different methods of Phosphorus at NAU, Navsari. Soil samples were collected from nine soil series of Navsari district and P determined through Olsen's, Modified Olsen's, Bray's P-1, Ammonium acetate + Acetic acid, Sodium acetate + Acetic acid, North Carolina, Triacid, Mehlich 2, Mehlich 3 and AB-DTPA methods. He also correlated the P amount extracted by different methods with yield and uptake of P by sugarcane and found that P extracted by Olsen and AB-DTPA methods were significantly and positively correlated.

Sharma and Parmar (1998) reported that Olsen's phosphorus gave positive and significant correlation value of 0.708 with crop yields and phosphorus uptake by wheat. Gonzalez *et al*. (1999) studied the correlations and calibration of four extraction methods for available phosphorus viz. Olsen's, North Carolina, Bray P and Soltanpour and Schwab, and found that best extraction method was the Olsen's method.

Sarkar and O'connor (2001) used Pi 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) carried an experiment to calibrate soil test methods for available phosphorus in swell-shrink soils for wheat. Soil available P was estimated with 6 extractants viz. 0.5 M $NaHCO_3$ pH 8.5 (Olsen P), 10% NaOAc pH 4.8 (Morgan P), 0.03N NH_4F+0.025N 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 NH_2SO_4 (Nelson P). Critical limits were calculated using the scatter diagram and yield percentage and P uptake. Soils with low Olsen P recorded lower grain yield percentage pointing to efficient use of applied P than in medium and high Olsen P soils. The percentage of wheat yield showed a significant relationship with soil-extractable Olsen, Morgan, Soltanpour, and Bray estimates. Between Olsen P and percentage of wheat grain yield (r=0.915) and Olsen P and percentage of wheat uptake (r=0.894) the highest correlation coefficient values were observed. The scatter diagram showed that, according to Olsen's method, the critical limit for soil P was 29 kg ha^{-1}. Thus, it was found that Olsen's method is best suited for estimating available P in Western India swell-shrink (Inceptisols) soils. 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 superphosphate-treated soils in south-western Australia (most soils), Instead of the Colwell sodium bicarbonate method, the Mehlich-3 method could be used to measure soil test P, supporting the Mehlich-3 procedure to be developed as a 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 *et al.* (2003) found that the Olsen method provided the best correlation coefficients with rice growth parameters (dry matter yield and P uptake), followed under aerobic conditions by Colwell and Soltanpour and under anaerobic conditions by Soltanpour, and suggested Olsen's test method as a more suitable extract to predict rice availability of P 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 and compared it with Bray-1, Mehlich-3 and Olsen's test with corn and showed that ion- exchange resin membrane and Olsen's had similar capacity to predict corn response to phosphatic fertilizer but lower than for Mehlich-3 and Bray-1 was equally good except for high pH and calcareous soil.

Olsen (0.5 M $NaHCO_3$, pH 8.5), Mehlich-3 (0.2 N CH_3COOH + 10 0.013 N HNO_3 + 0.015 N N NH_4F + 0.25 N N NH_4NO_3 + 0.001 M EDTA) and Bray and Kurtz-1 (0.03 N N NH_4F + 0.025 N HCl) were compared by Enamul *et al.* (2013) in Bangladesh. In Olsen > Mehlich-3 > Bray and Kurtz-1, they found the mean extractable P. The correlation between Olsen-P and mehlich-3-P (r=0.924**) and Bray and Kurtz-1-P (r=0.929**) was significantly higher.

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 physio-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 in soil.

2.1.3 Available potassium

Important chemical methods to estimate 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 soil 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)

Soil test crop response correlation studies at Pantnagar showed good correlation between potassium extracted by neutral normal ammonium acetate and yield of paddy and wheat (ICAR, 1970). Sachan *et al*. (1972) found that neutral normal ammonium acetate method of potassium extraction worked well in Mollisol using mustard as a test crop. Pathak *et al*. (1975) reported that in alluvial soils of Indo-Gangetic plains, exchangeable and hydrochloric acid soluble forms of potassium correlated well with available potassium as determined by NH_4OAC and Morgan's extractant, respectively.

At the same time as examining the routine soil analysis methods, Johnston and Goulding (1990) concluded that exchangeable K as determined by extraction with normal neutral ammonium acetate provides a good estimate of soil K availability to plants.

Pal and Bansal (1999) evaluated different soil extractant for better prediction of plant available potassium in smectite soils and noticed the average amount of K extracted by six extractant was in the order: H_2SO_4> NH_4OAc > HNO_3> AB-DTPA > Mehlich-3 >NaCl. On the basis of final regression values, NH_4OAc was the best predictor of K availability in smectite soils.

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.

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.

Matula (2009) conducted an experiment to test the universality of three water, NH4OAc and Mehlich 3 multinutrient soil tests with 36 soils. Barley pot experiment was also conducted in a growth chamber to determine soil bioavailability of K. The range of water, NH_4OAc and Mehlich 3 extracted K was 8-212, 82-831 and 89-1032 mg kg^{-1}. However, nutrient uptake by barley was highly correlated with NH_4OAc extracted K (r=0.83**) followed by water (r=0.82**) and Mehlich 3 (r=0.79**) extracted K.

Hosseinpur and Zarenia (2012) were classified into 4 groups based on the extraction mechanism using nine extraction solutions for soil potassium extraction. The first group was acid 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 NH_4OAc (ammonium acetate), and AB-DTPA (ammonium bicarbonate-diethylenetri-aminepentaaceticacid), and finally distilled water. The correlation studies showed that NH_4OAc, AB-DTPA, 0.1mol/L $BaCl_2$, 0.1 mol/L HCl, and boiling 1 mol/L HNO_3 could not be used as available K extractants. But other extractants were significantly correlated with relative yield, plant response, K concentration, and K uptake. These extracting solutions can therefore be used as K extractants available.

2.2 Different approaches of calibration of Soil Test Value, Interpretation and Fertilizer Recommendation

After soil testing, calibration become next most critical step, unless soil test values are related to some measures of crop productivity, the soil test values are simple numbers with no relevance for fertilizer recommendation. The process of determining the crop productivity and soil test value relationship is commonly referred as calibration of chemical soil test value. The calibrated soil test value indicates the degree of the nutrient's deficiency and the amount of nutrient used as fertilizer to correct the deficiency. While interpretation of the soil test includes an economic evaluation of the relationship between the value of the soil test and the response of nutrients. The task of making fertilizer recommendation from soil test require comprehensive knowledge of diverse area such as soil chemistry, fertility, mineralogy, classification of crop and economics. Various approaches for calibration of soil test values, interpretation and fertilizer recommendation are as follows:

2.2.1 Various approaches of calibration and interpretation of soil test values

2.2.1.1 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 that a plant under optimum conditions produces maximum yield but if one essential factor is deficient, a corresponding decrease in yield takes place. Which was expressed as:

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

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.

2.2.1.2 Mitscherlich-Bray approach

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:

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

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 apply 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).

2.2.1.3 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.

2.2.1.4 Multiple regression approach

Ramamoorthy *et al*. (1967) suggested a realistic and more practical approach for prescribing fertilizer doses based on soil test values for achieving either maximum yield or maximum profit, based on the creation of artificial fertility gradients (Inductive approach). In this approach, Ramamoorthy (1974) established a significant relationship between soil tests, fertilizer doses and crop yield by fitting a multiple regression of the quadratic form taking linear terms of soil and fertilizer nutrients and interaction terms of soil and fertilizer nutrients. By conducting gradient experiment, a range of soil test values are created in one and the same field for minimizing interference of other factors affecting crop yield and relate them through multiple regression with curvilinear response function.

The regression equation obtained using quadratic function is as given below:

Y = A ± b1SN ± b2 SN2 ± b3 SP ± b4SP2 ± b5 SK ± b6 SK2 ± b7 FN ± b8 FN2 ± b9 FP ± b10 FP2 ± b11 FK ± b12 FK2 ± b13 FN SN ± b14 FPSP ± b15 FK SK

Where, Y = crop yield (kg ha^{-1}), A = intercept (kg ha^{-1}), b1 to b15 = regression co-efficient; SN, SP and SK are soil available N, P and K (kg ha^{-1}) respectively and FN, FP and FK are fertilizer N, P_2O_5 and K_2O (kg ha^{-1}) respectively. Fertilizer calibrations for obtaining maximum yield and profit per hectare could be derived where the response to added nutrient follows the "law of diminishing return" with a response type of +, - and - typified by significant linear, quadratic and interaction terms and by partial differentiation of regression equations as fertilizer dose for maximum yield is [(b7/2b8) - (b13/2b8)] x soil test value (kg ha^{-1}) and for maximum profit is [(b7/2b8) - (b13/2b8)] x soil test value (kg ha^{-1}) - 1/2b8 x R where b7, b8 and b13 represent the coefficients of linear, quadratic and interaction terms of fertilizer nitrogen and R represents the ratio of the cost of one kg of fertilizer nutrient to one kg of economic produce. The R^2 value should be more than 67 per cent to make use of the regression equation for improved prediction of yield and optimization of fertilizer doses. Santhi *et al*. (2005) reported that there was an over optimization of fertilizer doses and the fertilizer K_2O requirement could not be optimized by regression model for rice on inceptisol.

2.2.1.5 Law of the maximum

The “Law of the Maximum” advocated by Wallace (1993) states that “when the need is fully satisfied for every factor required in the process, the rate of the process can be at its maximum potential, which is greater than the sum of the individual parts because of the sequentially additive interactions”. This law has two major characteristics; first, the effect of a given input is progressively magnified as other limiting factors are corrected. The final result is greater than the sum of the effects of the individual inputs, because of the way in which they interact and the interaction multiplies the effects of each. Second, yields can be the highest or maximum only if there are no remaining limiting factors; the less limiting factors that remain, the higher will be the yield.

2.2.1.6 Law of Optimum

The “Law of Optimum” proposed by Ramamoorthy and Velayutham (2011) is propounded as the merging concept in 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 a range of soils and crops in India over four decades and validated through hundreds of demonstrations in farmers’ fields. The "Law of Optimum" is defined as the concept of soil-based application of major plant nutrients (N, P and K) to crops, taking into account the percentage of soil-based nutrient contribution as estimated by chemical soil testing and the percentage of nutrient contribution from added fertilizers and manures and the nutrient requirement of the crop as estimated from plant uptake.

The principles underlying the “Law of Minimum”, “Law of Diminishing Returns” and the “Law of the Maximum” governing plant nutrition are not only embedded in the “Law of Optimum” but this Law also provides a basis for soil fertility maintenance and efficient Nutrient management in “Precision Farming” for sustainable and enduring Agriculture. Operationally this law harmonizes the much deliberated 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.

2.2.2 Various approaches for fertilizer recommendations

"Soil testing is a phase where the basic research on soil chemistry culminates and applied research on soil fertility begins. The combined research efforts of soil chemist and soil fertility expert are reflected in and explained to farmers as fertilizer recommendations" (Goswami, 1982). Many approaches based on soil test levels have been tried to get a precise or workable basis for predicting the fertilizer requirement of crops are as follow:

2.2.2.1 General / Blanket recommendation

This was the first attempt made in India in 1953 to relate the knowledge of soils to the judicious use of fertilizers. Based on the results of model agronomic experiments on Government farms and simple fertilizer trials on cultivator's field, blanket fertilizer recommendations were reached at. Since the fertility variations were not accounted for, uniform adoption of this kind of recommendations did not ensure economy and efficiency of fertilizer use. Although this is a sound recommendation for majority of the situations, it leads to either over or under usage of fertilizer nutrients (Reddy *et al*. 1994).

2.2.2.2 Soil test rating and fertilizer adjustments

Making use of the services of soil testing labs at IARI and the results of Adhoc Research Projects, tentative soil testing procedures were identified and soil test values were empirically grouped into categories like low, medium and high (Muhr *et al*. 1965 and Perur *et al*. 1973). The general or blanket recommendation is equated to medium fertility status of soil available NPK. For soils testing low or high category, the fertilizer recommendations are increased or decreased by 30 per cent of the general recommendations. This is a development over the general recommendation, since the fertilizer adjustments are made not entirely on qualitative basis but on semi quantitative basis. An average increase of 11 per cent in crop yield was reported when fertilizer doses were based on this adjustment over the blanket recommendation (Randhawa and Velayutham, 1982).

2.2.2.3 Nutrient indexing system

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

Nutrient index = (Nl x 1) + (Nm x 2) + (Nh x3)/Total number of samples

Where,

Nl, Nm and Nh were the number of samples falling in low, medium and high category of nutrient status respectively. Separate indices are calculated for different nutrients like N, P and K. The index value of less than 1.67 and more than 2.33 indicates low and high fertility class respectively. Nutrient index value ranging from 1.67 to 2.33 indicates medium fertility class.

2.2.2.4 Critical level of a nutrient in soil

The critical limits of available nutrients are established by adopting three techniques viz., the graphical procedure (Cate and Nelson, 1965), mathematical procedure using two mean square discontinuous model (Cate and Nelson, 1971) and Linear Response Plateau (LRP) model (Anderson and Nelson, 1975).

Tandon (1987) has summarized such critical limits of available P for various crops as reported by different workers in various soils and agro-climatic situations and these critical limits vary depending on soil, crop, variety, soil test method employed and seasonal variations (Subba Rao and Reddy, 2005) However this approach does not provide how much of fertilizer is to be adjusted for varying soil test values below the critical level. The obvious advantage of knowing the level is that fertilizer addition is not warranted for those soils which test above the critical limit.

2.2.2.5 Soil test based fertilizer recommendations for a certain percentage of yield maximum

This is commonly called the approach of Mitscherlich and Bray. In this, an empirical relationship develops between per cent yield and soil and fertilizer nutrient in order to recommend fertilizer doses for different percentages of maximum yield (Bray, 1944, 1945; Ranganathan *et al*., 1969). The Department of Agriculture is currently using this approach in a modified method. Tamil Nadu for giving site specific fertilizer recommendations. The Mitscherlich- Bray equation is:

Log (A-Y) = Log A-C, b-CX

Where,

A is the calculated maximum yield, Y is the percentage yield, b is the soil test value, C, is the proportionately factor for soil form of the nutrient, C is the proportionately factor for added form of the nutrient and X is the dose of fertilizer added. The maximum yield (A) could be calculated by extrapolation method of Ranganathan *et al*. (1969).

2.2.2.6 Colwell's deductive approach

Colwell (1968) of Australia developed this approach which includes conduct of multilocational trials and the data generated are pooled and used to establish the soil test based calibration. Velayutham *et al*. (1978) used this model to derive location specific Fertilizer recommendations for wheat grown in black soils. Multilocational soil test crop response experiments in farmer's fields were conducted in All India Co-ordinated Research Project on Soil Test Crop Response Correlation studies based on Colwell's approach and optimization of fertilizer nutrients was done for crops such as rice, millets, groundnut and cotton (Anon, 1982). However, the data from these experiments have not met with much success in deriving soil test based fertilizer calibrations in India (Velayutham *et al*., 1985).

2.2.2.7 Inductive approach

In the STCR field experimentation "Inductive Approach," all the desirable variant in soil fertility level is not obtained by selecting soils at different locations as in previous Agronomic studies, But by deliberately developing it in one and the same field experiments to reduce the heterogeneity of the studied soil population (types and units), management practices and climatic conditions. Ramamoorthy and Velayutham (1971, 1972 & 1974) have developed this inductive approach and the field design of STCR, which Black (1993) also quotes. The experimental records can be used to develop recommendations on fertilizer for maximum yield and profit as well as desired crop yield targets. Various types of recommendation under this approach are as follow:

a. Fertilizer recommendations for maximum yield and profit

From significant multiple regressions of the quadratic form recognized between the soil tests, the added fertilizer levels, the interaction term for the soil and fertilizer nutrients and crop yield, fertilizer calibration for varying soil test values for obtaining maximum economic yield (MEY) and maximum profit ha^{-1} have been derived, where the response to added nutrients follow the "Law of Diminishing Returns" (Ramamoorthy, 1974). Hariprakasa Rao and Subramanian (1994) calculated fertilizer doses for maximum yield of vegetable crops such as bhendi, tomato, brinjal, onion, cabbage, cauliflower and green chillies in Alfisols of southern India making use of the multiple regression models. Highly significant relationships indicated by the co-efficient as high as 0.80 have been reported by various workers for different crops (Subba Rao and Srivastava, 1998). However this approach suffers from the limitation that fertilizer doses worked out for getting maximum profits would usually give yields lower than the potential yields. This may lead to low levels of crop production (Dev, 1997). Moreover, if the response type of +, - and – for linear, quadratic and interaction terms are not obtained, the optimization could not be done.

b. Soil test based fertilizer recommendations through targeted yield approach under fertilizers alone and IPNS

Truog (1960) illustrated the possibility of “Prescription method” of fertilizer use for gaining high yields of maize using empirical values of nutrient availability from soil and fertilizer. However, during 1965-67 Ramamoorthy and his associate established the theoretical basis and field experimental evidence and validation for the fact that Liebig's "Law of Minimum" on Plant Nutrition works equally well for N, P and K on high yielding wheat, rice and pearl millet varieties, although this law is generally believed to be valid for N and not for P and K which were supposed to follow Mitscherlich and Baule and Mitscherlich and Bray's percentage sufficiency concept. Among the numerous methods of formulating fertilizer recommendations, the one based on yield targeting is unique in the sense that this method indicates not only the soil-based fertilizer dose but also the level of yield that the farmer may wish to achieve if a good cultivation package is followed when the crop is raised (Velayutham, 1979).

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

$$FD = \{(NR \times 100\ T) / Cf\} - \{(Cs \times STV) / Cf\}$$

Under IPNS situations, the fourth parameter viz., the per cent contribution of nutrients from the added organic manure (Co) is also used to relate with the yield target (T), then the equation takes the form as indicated below

$$FN = \{(NR \times 100\ T) / Cf\} - \{(Cs \times SN) / Cf\} - \{(Co \times ON) / Cf\}$$

This approach coupled with inductive methodology termed as "Inductive cum targeted yield approach" forms the basis for the ICAR sponsored All India Coordinated Research Project for Soil Test Crop Response Correlation Studies (AICRP-STCR). Experiments have been conducted in all the centres and fertilizer adjustment equations were developed for various crops (Subba Rao and Srivastava, 2001a &b; Muralidharudu *et al.*, 2007 & 2011). Singh *et al.*, 2007, documented soil test based fertilizer recommendations for different crops- A success story of Uttarakhand & Western Uttar. Pradesh and Singh *et al.*, 2016, documented advisory on soil testing and fertilizer use for Uttarakhand (In Hindi). The dimensions, scope and prospects of fertilizer recommendation based on the concept of yield targeting were documented by Randhawa and Velayutham (1982). These soil test equations have been dynamically tested and evaluated for their predictability through series of field verification trials (follow up trials) in farmer's holding. If 90 per cent of the targeted yield was achieved, then the equations are found to be valid (Velayutham *et al.*, 1984). The fertilizer prescription equations, after evaluation in the follow-up trials, are used to rationalize the fertilizer recommendations for all the major crops grown in the states.

The results from more than 2000 follow-up trials in farmer's fields over the four decades indicated that by following the soil test based fertilizer use for targeted yield approach adopting the recommended best agronomic management practices, it is possible to achieve the yield targeted within a variation of ± 10 per cent, provided the targets are within the range of yields obtained in the STCR calibration field experiment conducted at the research station. The outcome was brought out from time to time through documentations (Reddy *et al.*, 1994; Subba Rao and Srivastava, 2001b & Subba Rao and Rathore, 2003 and Muralidharudu *et al.*, 2007 & 2011a).

c. Fertilizer recommendations for a cropping sequence based on initial soil test values through post-harvest soil test values prediction equations

Sustainable agriculture requires soil test based nutrient management practices to be adopted for better productivity, profitability, sustainability and environmental safety (Venugopalan *et al.*, 2011). Using a soil test-based approach to nutrient management needs index measurement associated with crop yield or effective nutrient supply over the growth period, regular monitoring of soil test values and well-developed qualitycontrolled service infrastructure (Dobermann *et al*., 2003), which is not viable from the farmer's point of view. So the soil test values had to be predicted after a crop was harvested. Also, though there are numerous soil testing laboratories in operation, in a massive country like India with millions of hectares of cultivated land, soil testing for each field season after season and prior to the cultivation of each crop seems to be practically difficult for the want of time, money and labour. Hence the prediction of post-harvest soil fertility status using the pre-sowing soil test values, fertilizer doses and yield or uptake by the crop has much of practical significance. Studies on this aspect were carried out by many workers for various cropping sequences and soil types which has been documented by Subba Rao and Rathore, 2003 and Muralidharudu *et al*. (2007 & 2011a).

d. Fertilizer recommendation for maintenance of soil fertility through yield targeting

It is judicious to adjust the fertilizer practices over seasons in such a way so as to strike a balance between high yields and maintenance of soil fertility. The generation of basic data for targeted yield of crops in a crop rotation would hence enable application of fertilizer for appropriate yield targets in multiple cropping for maintenance of soil fertility. Ramamoorthy and Mahajan (1974) showed that the yield target and the required fertilizer dose for maintenance of soil fertility can be calculated from the equations: T = n.s / (m-r) and F.D = r.n.s / (m-r) where T is yield target in q ha^{-1}; n is ratio between the per cent contribution from soil and fertilizer nutrient; r is nutrient requirement in kg q^{-1}; m is ratio between nutrient requirement and contribution from fertilizer nutrient; s is soil test value in kg ha^{-1} and F.D is fertilizer nutrient dose in kg ha^{-1}. Currently long-term demonstrations are being carried out at several STCR centers to obtain the most suitable fertilizer rate to obtain optimum yield and maintain soil fertility. Sharma and Singh (2000) reported that the targeted yield approach was more balanced, profitable and helpful in proving soil nutrient mining as compared to fertilizer recommendations for economic yield based on regression approach.

e. Yield targeting for a fixed cost of fertilizer investment

The significance and value of soil testing increases by choosing the yield target at such a level so that the cost of fertilizer requirement becomes more or less same as what was being practiced by the farmer already (Ramamoorthy and Velayutham, 2011). The results of such demonstration trials conducted in Delhi villages reveal that the response per unit Fertilizer is higher than that from other practices, when balanced fertilization is adopted for targeted yield (Velayutham, 1979).

f. Yield targeting under resource (fertilizer/credit) constraints

When fertilizer availability is limited or the resources of the farmers are also limited, planning for reasonable yield targets, which are at the same time higher than the yield levels normally obtained by the farmers or the average yield of the district, provides means for saturating more areas with the available fertilizers and ensuring increased total production also (Ramamoorthy and Velayutham, 2011). The consequence of this approach - Ramamoorthy and Velayutham, (1973); Velayutham *et al*. (1975); Ponnamperuma, (1979) and Velayutham, (1979) shows that fertilizer use efficiency and the total production are higher when the available fertilizers are applied for low or moderate yield targets rather than arbitrary reduction in fertilizer dose. This approach allows balanced fertilizer use under resource constraints and maintenance of soil fertility ensuring efficient and economic use of available fertilizers (Muralidharudu *et al*., 2012).

2.3 Response of Soil and applied N, P, K and FYM on growth, yield and quality of cauliflower

Cauliflower is a heavy nutrient feeder and thoroughly responds to nutrient supplements through Farm Yard Manure (FYM), organic fertilizers, green manures and chemical fertilizers (Sharma and Rana, 1993). Nitrogen is an essential plant nutrient, which involved in physiological processes and enzyme activities. Nitrogen may increase cauliflower production, but it affects curd quality. High levels of nitrogen with other nutrient deficits could reduce cauliflower storage life (Kirthisinghe, 2006). Phosphorus is a constituent of nucleic acid, phytin and phosphorus. It is also an important component of most enzymes that are of great importance in the energy transformation in carbohydrate and fat metabolism as well as in plant respiration. Potassium imparts increased vigor and disease resistance to the plant. It also controls water conduction in the plant cell and water loss from the plant by means of maintaining the stability among anabolism, respiration, and transpiration. Thus reduces the tendency to wilt and help in better utilization of available water which ultimately helps in the formation of protein and chlorophyll and quality (Rutkauskiene and Poderys, 1999).

Mineral nutrition also plays a vital role in influencing the quality of crops and soil health deteriorates due to the continuous use of chemical fertilizers (Savci, 2012). At the same time, the indiscriminate use of chemical fertilizers has led to many problems such as soil productivity degradation, pollution of the environment, depletion of non-renewable energy sources, etc. The use of chemical fertilizers should therefore be judicious and minimized and can be replaced by the integrated use of organic fertilizer. Therefore, since fertilizer is expensive input in agriculture, economic criteria for its use are essential for maximizing profit in the current product marketing. Therefore, the response of soil and applied N, P, K and FYM on growth, yield, nutrient content and uptake and quality parameters of cauliflower are described here with consideration of the economics of fertilizer use.

2.3.1 Growth, Yield and Economics

Raut and Kedar (1981) reported that application of 100 kg N ha^{-1} was found best in respect to plant growth of cauliflower preferentially increasing vegetative growth. Sharma and Lal (1986) observed that plant height, plant spread and number of outer leaves increased in cabbage by increased application of nitrogen from 60 to 120 kg ha^{-1}.

Sharma and Arora (1987), with application of N @ 150 kg ha^{-1} in CV Pusa Synthetic, observed the highest curd yield of 18.9 t ha^{-1}. In CV Snowball-16, i.e. 210.9 q ha^{-1} and 196.8 cm^2, the marketable yield of cauliflower and curd size index was high at 120 kg N ha^{-1}.

Singh and Sharma (1990) observed the maximum yield (10.24 t ha^{-1}) and high ratio of curd to foliage in cauliflower cv Snowball-16 were obtained with the application of 100 kg N and 15 t FYM ha^{-1} along with 22 kg and 42 kg P and K, respectively in potato- cauliflower cropping sequence. Khurana *et al*. (1990) reported that for cauliflower crop planted at 60 x 30 cm spacing with optimum nitrogen and phosphorus doses were 120 and 40 kg ha^{-1} respectively for highest yield.

Thakur (1991) found that the net curd weight of cauliflower (CV Pusa Snowball-1) was high (725.7 g $plant^{-1}$) when N @ 200 kg ha^{-1} was applied in and also reported that significant in gross weight and net curd yield with the application of phosphorous. Application of phosphorous at 200 kg ha^{-1} significantly increased the morphological characters viz., number of leaves, leaf size and stalk length, thereby increasing the yield.

Samant *et al.* (1993) reported that in trial with cabbage cv. Pride of India, application of 80 kg P_2O_5 ha^{-1} gave the highest yield (17.42 t ha^{-1}) in the first year and (12.03 t ha^{-I}) in the second year. Singh and Naik (1993) reported that 100 kg P_2O_5 ha^{-1} gave the highest number of marketable curds and maximum yield of cauliflower.

Kunwar and Pandey (1994) found that the combination of NPK @ 120:60:60 kg ha^{-1} was found to be the best way to achieve maximum cauliflower yield, but found that 75 kg K_2O ha^{-1} and N and P are needed to achieve higher yield.

Hariprakash Rao and Subramanian (1994**)** developed fertilizer prescription equation for cauliflower. The study indicates that there is a decline in response to applied fertilizer with increasing soil fertility levels. Yong *et al.* (1994) advocated that application of potash at the rate of 0, 50 and 100 kg ha^{-1} increased growth, curd yield and improved photosynthetic rate of broccoli up to 100 kg ha^{-1}.

Baghel and Singh (1995) observed that the application of 100 kg K_2O ha^{-1} increased the curd yield to 24.98 t ha^{-1} in comparison to 19.53 t ha^{-1} with no fertilization application.

Tarata *et al.* (1995) observed that the application of two doses of potassium at 50 and 100 or 150 kg ha^{-1} increased the leaf area and number of leaves per plant of cabbage. The number of leaves, plant height and head weight of cabbage cv. "Golden Acre" were also found to be increased with increasing levels of nitrogen by Lai and Lai (1996).

Lisiewska and Kmiecik (1996) conducted an experiment on broccoli cultivar, Corvet F and cauliflower cultivar, Sernio RS, which were grown in the autumn cycle located in southern Poland (Krakow region). The vegetables were grown in loamy-silty soil. They found that nitrogen fertilization doses of 80 and 120 kg N ha^{-1} had significantly produces higher commercial yield of broccoli (80 kg ha^{-1}: 19.1 t ha^{-1}; 120 kg N ha^{-1}: 23.2 t ha^{-1}) and cauliflower (80 kg N ha^{-1}: 26.5 t ha^{-1}; 120 kg Nha^{-1}: 31.0 t ha^{-1}) over control.

Pant and Kumar (1996) conducted a field experiment at Pithoragarh (1650 m above sea level in Kumaon hills, India) to evaluate the influence of N (40, 60, 80, 100, 120, 140, 180 or 200 kg ha^{-1}) on the marketable head yield of cabbage (cv-ARU Glory) and found that yield increased up to 498.33 q ha^{-1} with increasing rates of N up to 180 kg N ha^{-1}.

Ingle and Jadhao (1997) conducted a field experiment in Akola, Maharashtra, India, applying nitrogen at 150 kg ha^{-1} resulted in a significantly higher yield of cabbages (cv. Pride of India, Golden Acre and Pusa Early) compared to the control.

Dixit (1997) conducted an experiment on the growth of cabbages (cv. Pride of India) at Himachal Pradesh. He investigated the effect of nitrogen (0, 40, 80, 120 or 160 kg ha^{-1}) and Farmyard manure (0 or 20 t ha^{-1}) and found that yield increased (from 136.8 to 175.1 q ha^{-1}) with increasing nitrogen rate (0 and 160 kg N ha^{-1}, respectively) and with increasing FYM rate yield increased (from 129.5 to 144 q ha^{-1}) and yield increased (176.1 qha^{-1} in presence of FYM+160 kg N ha^{-1}).

Sharma (2000) conducted an experiment on Broccoli production (variety Green curd) and found that integrated organic and inorganic fertilizer application significantly increases the curd yield over inorganic fertilizer alone and also control.

Das *et al.* (2000) reported that application of 200:150:125 kg NPK ha^{-1} being at par with 160:120:100 kg NPK ha^{-1} resulted in significantly tallest plant, highest number of leaves, plant spread, curd yield over other lower levels.

Singh *et al.* (2000) conducted a field experiment to standardize the K requirement of broccoli @ 0, 25 and 50 kg ha^{-l}. Plant height was increased with the application of K rates. Potash improved the development of root and utilization of nitrogen. The highest net head weight and yield were obtained with the application of 50 kg K ha^{-l}.

Singh *et al.* (2001) found that application of nitrogen significantly influenced the number, length and area of leaf, plant spread and height of plant in cabbage. The length and diameter of stem showed significant improvements up to 50 kg N ha^{-1} level. Significantly higher yield was recorded with -200 and 250 kg N ha^{-1} levels, respectively, in the first and second years (74.6 and 81.5 t ha^{-1}, respectively).

Jana and Mukhopadhyay (2001) conducted an experiment in Cooch Behar, West Bengal to study the effect of N (0, 50, 100, and 150 kg ha^{-1}) and P (0, 40, 80, and 120 kg ha^{-1}) on the yield and yield components of cauliflower cv. Aghani. The results indicated that an application of 150 kg N and 80 kg P_2O_5 ha^{-1} recorded the highest value with respect to number of leaves per plant, curd diameter, curd depth, net curd weight, curd solidity, marketable curd yield and net returns (Rs. 37,285 ha^{-1}) and improved the benefit: cost ratio (3.25:1) than other treatment combinations.

Sharma and Arya (2001) conducted an experiment on cabbage cv. Pride of India under dry temperature conditions in Himachal Pradesh and reported that the marketable yield increased with increasing levels of nitrogen up to 160 kg N ha^{-1} and FYM at 20 t ha^{-1} compared with the controls.

Mohd *et al.* (2002) studied the impact of organic and inorganic fertilizers on yield and quality of tomato (cv. Parbhani "Yashashri") at Parbhani, Maharashtra. They found that application of 50% recommended a dose of FYM (12.5 t ha-1) along with reduced levels of recommended doses of fertilizers (50% of the RDF 100:50:50 NPK kg ha^{-1}) resulted in the maximum yield with high quality.

Kumar and Chaudhary (2002) carried out an experiment at Kullu, Himachal Pradesh on cauliflower cv. Pusa Snowball-1 to study the effects of chemical fertilizer alone or in combination with 25 t FYM ha^{-1} on the yield and yield components of cauliflower. They found that the application of FYM with 100 per cent recommended NPK enhanced the yield of cauliflower by about 27 per cent compared to NPK alone.

Kanwar *et al*. (2002) carried out an experiment to study the effect of different NPK fertilizer rates (0, 50 and 100 per cent) applied alone or in combination with different organic manures (no manure, vermicompost, and FYM) on cauliflower (CV, Pusa Snow Ball K-1) yield and soil fertility in Dhaulakuan, Himachal Pradesh. They reported increased curd weight, diameter, plant height, and curd yield by applying NPK fertilizer (100 per cent). But when organic manure (vermicompost or FYM) was applied, a significant increase in all these parameters viz., curd diameter (21.88 cm), plant height and marketable curd yield (25.7 t ha^{-1}) was found at 100 per cent NPK level with vermicompost.

Kumar and Rawat (2002) observed that highest head diameter (14.30 cm) was obtained with 200 kg N ha^{-1}. However, 150 kg N ha^{-1} gave the highest mean head weight (1127.22 g) and head yield (312.42 q ha^{-1}).

Shalini *et al*. (2002) studied the effect of integrated nitrogen management on yield of knol-khol and found that application of 50 per cent nitrogen (Urea) + 50 per cent nitrogen (vermicompost) + Azospirillum resulted in maximum yield (37 t ha^{-1}).

Brahma *et al*. (2002) conducted a field experiment to ascertain the effect of NPK fertilizers on yield of broccoli cv. KTS-1. The treatment comprised application of 80:30:20, 100:60:40, 150:80:60 and 200:120:80 kg NPK ha^{-1}. NPK at 200:120:80 kg ha^{-1} resulted in the highest values for head diameter (19.52 cm), head number (7.09), head yield (13.41 t ha^{-1}), secondary head yield (4.70 t ha^{-1}) and total yield (18.11 t ha^{-1}).

Mohd *et al*. (2003) studied the effect of nitrogen and phosphorus on growth and yield of cauliflower at Leh, Ladakh (Jammu and Kashmir) on sandy soil. They found that an application of nitrogen and phosphorus at higher rate markedly influenced plant height (44.74 cm), plant spread (56.70 cm), curd diameter (12.16 cm), curd depth (9.55 cm), average curd weight (0.999 kg) and curd formation (60.33 per cent) over the control. They suggested to apply of 225 kg N ha^{-1} along with 100 kg P_2O_5 ha^{-1} for obtaining maximum growth of plant.

Choudhury *et al*. (2004) studied the effect of integrated use of organic manure, biofertilizers, and chemical fertilizer on cauliflower growth and yield and found that increases in plant growth and cauliflower yield were recorded with Azotobacter, PSB, and manure from farms along with inorganic fertilizers.

Singh (2004) reported that the application of 140 kg N and 80 kg P_2O_5 ha^{-1} had the highest number of leaves per plant (19.44), curd diameter (16.42 cm), curd depth (10 cm), net curd weight (740.38 g), curd solidity (66.84 g cm^{-1}) and marketable curd yield (236.92 q ha^{-1}) with the highest net yield and improved benefit: cost ratio (6.81) compared to other combinations of treatment. Wenqiang *et al*. (2004) reported that nitrogen application increases curd weight and diameter.

Tripathi *et al*. (2004) found that the integrated application of 75 per cent RDF with vermicompost @ 5 t ha^{-1} significantly gave higher marketable head yield (340 q ha^{-1}) over control and other treatments. They further reported that for better vegetable growth, yield attributes and marketable yield in cabbage, integrated use of inorganic and organic/biological sources of nutrient supply is suggested than their sole application.

Chaudhary and Choudhaty (2005) conducted a field experiment on hybrid cabbage consisting four level of phosphorus (30, 60, 90 and 120 kg ha^{-1}) and found that maximum plant height, plant spread and number of outer leaves were recorded with phosphorus application up to 90 kg ha^{-1}.

Sharma *et al*. (2005) carried out a field experiment to study the response of broccoli (*Brassica oleracea* L. var. italica cv. Palam Smridhi) to the integrated use of chemical fertilizers and FYM. There were eight treatments (0, 50, 75, 100, 125 and 150 per cent of RD of NPK along with FYM at 20 t ha^{-1}, 100 per cent NPK alone and a control. The highest net returns (Rs. 132 220 ha^{-1}) were recorded in 150 per cent NPK+20 t FYM ha^{-1} with a benefit-cost ratio of 3.27.

Kumar and Sharma (2007) conducted an experiment and applied different INM practices in cabbage-tomato sequence under mid hill conditions of Himachal Pradesh and reported that treatments FYM 10 t ha^{-1}+ 150% NPK (i.e. 90:90:45 kg ha^{-1} NPK) in cabbage was found best for obtaining higher values for growth and yield in both the crops.

Kumar *et al*. (2008) studied the effect of integrated nutrient management on growth attributing parameters in cabbage and found that treatment (100:80:60 kg NPK ha^{-1} +20 kg $ZnSO_4$ ha^{-1} +10t FYM ha^{-1}) and treatments (80:80:60 kg NPK ha^{-1} +20 kg $ZnSO_4$ ha^{-1} + 5t VC ha^{-1}) recorded the highest values for the growth-attributing parameters.

Padamwar and Dakore (2009) recorded maximum curd weight (1335 g) and curd yield (51.91 t ha^{-1}) due to vermicompost application, followed by the mixture of biofertilizers. Sharma *et al*. (2009) mentioned higher marketable curd yield (9 per cent) together with maximum net returns and benefit-cost ratio of 3.99 obtained when recommended chemical fertilizers (NPK) were combined with Azotobacter and PSB vis-a-vis NPK alone.

Gayathri *et al*. (2009) developed soil-based fertilizer prescription equations for potato under the Integrated Plant Nutrition System (STCR-IPNS) in Ultisols. These equations have been demonstrated in the fields of farmers and it has been found that more than 90 per cent of the targets have been achieved. The STCR-IPNS for 40 t ha^{-1} recorded relatively higher response ratio (38.05 kg kg^{-1}) and benefit-cost ratio (15.3) over other treatments indicating the validity of the equations for prescribing fertilizer doses for potato.

Thilagam (2011) reported that efficient nutrient management was a prerequisite for achieving maximum yield in cauliflower with good curd quality. Neither chemical fertilizers alone nor the organic manures exclusively sustain the productivity of cauliflower but a judicious combination of both along with their efficient management is potential tool for sustaining the productivity. Combined use of FYM and bio-fertilizers with chemical fertilizers will increase the yield with higher cost: benefit ratio.

Bashyal (2011) conducted an experiment on cauliflower at Rampur, Chitwan, Nepal and found that maximum stem height, stem diameter, highest curd height, curd diameter, fresh curd weight and curd yield were recorded at 120 kg nitrogen and 2 kg biofertilizers ha^{-1}. So the application of nitrogen along with the biofertilizers significantly increased morphological and yield characters as compared to application of nitrogen without biofertilizers.

Chatterjee *et al*. (2012) reported that the application of inorganic fertilizers with organic manure and bio-fertilizers has significant effect on curd initiation and curd maturity of cauliflower.

Kumar *et al*. (2013) reported that integration of organic and inorganic fertilizers application significantly increased the yield in broccoli over inorganic fertilizers alone and also over control.

Mishra *et al*. (2013) gave the fertilizer adjustment equation for tomato (cv. BT-10) under rice-tomato cropping system in an Ustochrept of Odisha. The fertilizer adjustment equations are FN = 1.32T – 0.45SN, FP_2O_5 = 0.72 T – 1.72 SP and FK_2O = 0.92 T - 0.96 SK. It was observed that with increase in graded doses of fertilizer the tomato fruit yield increased with increase in fertility strip 149.4, 162.7 and 175.8 q ha^{-1} in L0, L1 and L2 respectively.

Shree *et al*. (2014) carried out an experiment on cauliflower cv. Poosi. The experiment comprised different sources of nutrients including organic, inorganic and bio fertilizers alone and in combinations. They found that maximum curd diameter (16.09 cm), depth of curd (11.76 cm), weight of curd (568.00 g) and yield (252.48 q ha^{-1}) was noted by application of ½ N:P:K (recommended dose)+ FYM@5t ha^{-1} + poultry manure@2t ha^{-1}+ Azospirillum.

Amran *et al*. (2014) located that application of FYM @ 25 t ha^{-1} significantly increased growth and yield attributes viz. number of leaves, number of branches and plant height, average number of fruit per plant, average fresh weight of fruit, fruit yield per plant and maximum average fruit yield per hectare (16.25 t ha^{-1}) in okra fruits.

Prabhakar *et al*. (2015) conducted a field experiment at the IIHR farm in Hessaraghatta, Bengaluru to study the effects on cauliflower growth and yield of various levels of organic manures and conventional practices. They found that treatment that received a recommended dose of farmyard manure along with recommended NPK produced the highest mean curd yield (21.23 t ha^{-1}) followed by treatments that received 100 per cent and 75 per cent of recommended organic dosage of nitrogen (19.36 and 18.42 t ha^{-1}). A higher growth value and yield parameters like a number of leaves, curd diameter and curd weight were also recorded in the same treatment.

Kumar *et al*. (2017) conducted an experiment at Varanasi (U.P.) on cauliflower. The soil was sandy loam and has good fertility. They found that nitrogen sprayed in the form of urea was found significant in each growth characters i.e. a number of leaves per plant, height, thickness, fresh weight and dry weight of leaves and curd

Dhinesh *et al*. (2017) conducted an experiment in Tamil Nadu's Western Zone Thondamuthur Block, Coimbatore Dt.) to assess the soil test-crop response fertilizer prescription model under the Integrated Plant Nutrition System (STCR-IPNS) for desired yield targets of brinjal on red non-calcareous soils. The experimental results indicated that the percentage achievement of the targeted yield was within ±10 per cent variation proving the validity of the equations for prescribing integrated fertilizer doses for brinjal. Among the treatments, STCR-IPNS-35 t ha^{-1} of brinjal has proved its superiority and recorded a yield increase of 23.7 and 45.3 per cent, respectively over blanket and farmer’s practice. The increase in response ratio due to STCR-IPNS-35 t ha^{-1} over blanket and farmer’s practice was 4.71 and 19.57 kg kg^{-1}, respectively and that of BCR was 0.62 and 0.90, respectively. Among the treatments, STCR-IPNS-30 t ha^{-1} recorded relatively higher Response Ratio (97.37 kg kg^{-1}) and STCR-IPNS-35 t ha^{-1} BCR in (3.01) than other treatments.

In Varanasi (UP) India, Singh *et al*. (2018) accompanied an experiment to investigate the impact of integrated nutrient management on cauliflower growth, quality and yield**.** Application of half dose of NPK ha^{-1} + Vermicompost @ 2.5 Tonnes ha^{-1} + Azospirillium @ 5 Kg ha^{-1} + VAM @ 5 Kg ha^{-1} observed significantly higher number of leaves $plant^{-1}$ (24.44), diameter of curd (17.99 cm), weight of curd (943.55g) and yield of curd (265.65q ha^{-1}) as related to other treatments and this treatment was observed to be the most profitable treatment in cauliflower exhibiting highest net return Rs.157757.

2.3.2 Nutrient content and uptake

Sharma and Rana (1993) observed that nitrogen content in leaves and curds and uptake of nitrogen in cauliflower cv. Pusa Snowball K-1 increased linearly with increasing levels of N and the significant increase was recorded up to 200 kg N ha^{-1}.

Boogaard and Kristensen (1997) reported that a higher nitrogen uptake by cauliflower crop resulted in higher total nitrogen concentrations in the leaves and in the curds.

Sharma and Arya (2001) evaluated the effect of different rates of N (0, 40, 80, 120 and 160 kg ha^{-1}) and farmyard manure (0 and 20 t ha^{-1}) on cabbage cv. Pride of India and found that the uptake of N, P and K increased significantly with 20 tonnes FYM ha^{-1} (18, 15 and 26 kg ha^{-1}, respectively) and increasing N rates (from 40 to 160 kg N ha^{-1}).

Gowda *et al*. (2002) reported higher accumulation of N, P and K with increase in fertilizer levels. Highest content of N (2.72 per cent), P (0.63 per cent) and K (3.65 per cent) in okra leaves was observed at higher dose of fertilizers (175:125:100 kg NPK ha^{-1}). Gyanendra *et al*. (2002) reported that increasing doses of nitrogen (0 to 120 kg ha^{-1}) significantly increased the N content (2.13 to 2.62 per cent) and K content (2.29 to 2.35 per cent) in potato tubers. Increasing doses of potassium (0 to 100 kg ha^{-1}) also increased N content (2.13 to 2.59 per cent) and K content (2.20 to 2.41 per cent). Maximum N content (2.99 per cent) and K content (2.47 per cent) was recorded when 120 kg ha^{-1} N was applied along with 100 kg K_2O ha^{-1}.

Gupta *et al.* (2002) conducted a field experiment to study the influence of nitrogen, boron on dry matter accumulation and uptake of nutrients in cauliflower. Plants were supplied with 15, 20 or 25 kg B ha^{-1} and 100, 150 or 200 kg N ha^{-1}. Dry matter content, nitrogen and boron content in the leaves and curd, and N and B uptake increased with increasing rates of N. Except for dry matter content, all the parameters measured increased with increasing rates of B up to 20 kg ha^{-1} and decreased with further increase in B rates.

Shalini *et al*. (2002) studied the impact of integrated nitrogen management on nutrient uptake by knol-khol. Application of 50 % nitrogen (Urea) + 50 per cent nitrogen (vermicompost) + Azospirillum resulted in more uptake of nutrients via knol-khol.

Kadam and Sahane (2002) observed higher NPK content and uptake in both fruits, as well as a plant in tomato with the application of 100 per cent, recommended a dose of NPK as compared to 50 per cent.

Bhatt *et al*. (2002) conducted a field experiment on Kashmir's temperate conditions to study the response of four phosphorus levels in field pea (0, 30, 60, and 90 kg P_2O_5 ha^{-1}). The results indicated that the use of phosphorus up to 60 kg P_2O_5 ha^{-1} significantly increased the uptake of nutrients.

Brahma *et al*. (2002) conducted a field experiment to ascertain the effect of NPK fertilizers on the nutrient uptake of broccoli cv. KTS-1. The treatment comprised application of 80:30:20, 100:60:40, 150:80:60 and 200:120:80 kg NPK ha^{-1}. NPK at 200:120:80 kg ha^{-1} resulted in the highest values of nutrient uptake and content in leaf N (3.90 per cent), P (0.44 per cent) and K (2.75 per cent).

Datt *et al*. (2003) studied the impact of supplementary use of FYM along with chemical fertilizers on nutrient uptake by pea in Lahaul valley of Himachal Pradesh. They reported that there was a consistent increase in nutrient uptake with each increment in NPK fertilizer along with a constant level of FYM.

Pintu and Das (2006) reported that adoption of INM practices increased the yield and nutrient uptake by cabbage. The application of recommended levels of N, P and K with 4 t organic manure ha^{-1} and 0.5 kg Zn ha^{-1} proved superior in augmenting yield and nutrient uptake. A significant positive correlation was observed between yield and uptake of N (r=0.928**), P (r=0.935**), K (r=0.949**), Fe (r=0.758*), Mn (r=0.744*), Cu (r=0.598**) and Zn (r=0.846*).

Sharma *et al*. (2009) accompanied an experiment to investigate the impact of biofertilizers alone or in combination with chemical fertilizers in the uptake of cauliflower nutrients and concluded that the highest uptake of nitrogen, phosphorus and potassium was recorded with the combined inoculation of azotobacter and phosphorous solubilizing bacteria.

Patel *et al*. (2011) carried out an experiment at Anand Agricultural University, Anandon integrated nutrient management in cauliflower. The treatment consisted of four levels of organic manure (FYM @ 15 and 20 t ha^{-1} and vermicompost @ 3 and 4 t ha^{-1}) and three levels of NPK (100 per cent RDF, 75 per cent RDF and NPK according to soil test values). Vermicompost application @ 3 or 4 t ha^{-1} recorded a higher uptake of nutrients compared to FYM application.

Wani *et al*. (2011) reported that twelve treatments were tried in cauliflower cv. Snowball-16. Among the organic manures, poultry manure (PM) in combination with chemical fertilizers proved superior. The uptake of nutrients (NPK) by the cauliflower plants significantly increased with individual and combined application of organic manures and/or inorganic fertilizers over control. The maximum gross income of Rs 227, 570/-, net income Rs. 178,096/- per hectare with the highest benefit: cost ratio to the tune of Rs 3.59 was obtained by the treatment combination of 50 per cent PM+50 per cent RDF.

2.3.3 Quality parameters

The crop quality is an integrated effect of nutritional, physiological and biochemical factors. Quality is an important parameter which fetches good market price to the farmer. Application of fertilizers ensure quick supply of nutrients, resulting in increased quality but due to their ill effects on soil health and vegetable quality they need to be partially replaced by organic source for obtaining sustainable and higher quality. Using biofertilizers in combination with chemical fertilizers and organic manures provides a great opportunity to increase cauliflower production and quality. Therefore, quality parameters in response to the fertilization framed in the trail with respect to curd protein, ascorbic acid content, total soluble solid and antioxidant properties are described here:

Maurya (1992) conducted an experiment on cauliflower (CV Snowball-16) and found that foliar application of 30 per cent N was beneficial for cauliflower. Yield and ascorbic acid content were increased significantly by 3.0 per cent spray of N (197.90 q ha^{-1}, 70.25 mg $100g^{-1}$) from control (68.25 q ha^{-1}, 61.00 mg100 g^{-1}).

Farag *et al*. (1994) found that leaf nitrogen content in cauliflower increased with increased nitrogen application. Whereas, increased amount of nitrogen fertilizer from 80 to 120 kg N ha^{-1} decreased the concentration of vitamin C, in cauliflower by 7 per cent.

Kunwar and Pandey (1994) observed that application of 75 kg K_2O ha $^{-1}$ along with N and P is required for obtaining higher quality of cauliflower and also to maintain K status of the soil to avoid hidden hunger.

Mahendran and Kumar (1997) observed highest TSS and ascorbic acid contents in cabbage with 75 % of the recommended rate of NPK combination with digested organic supplement and vermicompost. Sendurkumaran *et al*. (1998) found that the quality parameters such as TSS, ascorbic acid and licopene were comparatively higher in tomato when grown organically.

Kumar and Veeragavathatham (2001) carried out a field experiment with brinjal cv. 'Palur-1' at Tamil Nadu and found that the treatment containing 100 per cent NPK (100 : 50 : 30 kg NPK ha^{-1}, respectively) + FYM + Azospirillum and Phosphobacteria @ 2 kg each ha^{-1} mixed in 20 kg FYM produced the fruits with maximum ascorbic acid, carbohydrate and crude protein contents. Kumar and Rawat (2002) observed that highest total soluble solid (8.80 per cent) and chlorophyll (0.29 mg g^{-1}) contents were obtained with 200 kg N ha^{-1}.

Mohd *et al*. (2002) studied the effect of organic and inorganic fertilizers on quality of tomato (cv. Parbhani "Yashashri") at Parbhani, Maharashtra. They revealed that application of 50% recommended dose of FYM (12.5 t ha^{-1}) along with reduced levels of recommended doses of fertilizers (50 per cent of the RDF 100:50:50 NPK kg ha^{-1}) resulted in high quality.

Brahma *et al*. (2002) carried out a field experiment to ascertain the impact of NPK fertilizers on quality of broccoli cv. KTS-1. The treatment comprised application of 80:30:20, 100:60:40, 150:80:60 and 200:120:80 kg NPK ha^{-1}. NPK at 200:120:80 kg ha^{-1} resulted in the highest values for protein (3.36 per cent), total chlorophyll (0.46 mg g^{-1}) and ascorbic acid content (128.05 mg 100 g^{-1}) of the crop.

Prabhakaran and Pichai (2003) studied the impact of different organic nitrogen sources on pH, TSS, titratable acidity, crude protein reducing and non-reducing sugar and ascorbic acid content of tomato fruits. They pronounced that application of organic N sources increased the quality parameters because it improved the physicochemical and biological properties of the soil which might have improved the root growth, higher nutrient content, increased dry matter production and nutrient uptake finally leading to improvements in quality of fruits.

Sharma and Sharma (2006) studied the response of nitrogen, phosphorus, and potassium on some quality traits of cabbage and found that combined application of the nutrients improved the nutritive value of the product in terms of vitamin A (retinol), ascorbic acid and TSS compared to the independent application of any of the nutrients.

Sable and Bhamare (2007) studied quality attributes of cauliflower through an experiment conducted in three levels (0, 75 and 100 per cent) of recommended dose of nitrogen (120 kg ha^{-1}) combined with four different strategies of biofertilizers i.e. no inoculation, Azospirillum, Azotobacter and Azotobacter + Azospirillum and observed that 75 per cent nitrogen + (Azotobacter + Azospirillum) exhibited significant increase in ascorbic acid content in curds (87 mg $100g^{-1}$), protein content in curds (18.62 per cent), total nitrogen content in plant (2.98 per cent) and compactness of curds (97.39 per cent).

Padamwar and Dakore (2009) found highest dry matter, protein, carbohydrate and vitamin C and calcium contents in cauliflower due to vermicompost application, followed by the mixture of biofertilizers.

Wang *et al.* (2010) established significantly higher levels of vitamin C, phenols and flavonoids when Chinese cabbage was grown in vermicompost-filled plastic pots: soil mixtures at 4:7 ratios and found 5.8- fold higher than pure soil treatment.

Sentiyangla *et al.* (2010) reported that the integrated use of chemical fertilizers, organic manures and biofertilizers alone or in combination significantly increased radish quality characters compared to control. They suggested that with an integrated application of 50 per cent NPK + 50 per cent FYM + biofertilizers, the optimum quality production of a crop can be achieved.

Bashyal (2011) applied nitrogen along with the biofertilizers resulting into significantly increased vitamin C content and the highest vitamin C content of curds. The most attractive curd color were obtained when 60 kg nitrogen and 2 kg biofertilizers $ha^{-1}$was applied.

Shree *et al.* (2014) found maximum ascorbic acid (63.12 mg $100g^{-1}$) when plants were grown under the treatment containing ½ N: P: K (recommended doses of NPK+ FYM 5 t ha^{-1}+ poultry manure 2 t ha^{-1}+ Azospirillum in cauliflower.

Prabhakar *et al.* (2015) carried out a field experiment at IIHR farm, Hessaraghatta, Bengaluru to study the impact of different levels of organic manures and conventional practices on quality of cauliflower. They reported that quality parameters in terms of total antioxidant capacity, total flavonoids and vitamin C were better with integrated nutrient management as compared to chemical fertilizers only. Similar results were reported by Young *et al*. (2005), Dangour *et al*. (2009), and Shankar *et al*. (2012).

Quality parameters of Okra (*Abelmoschus esculentus* L.) under integrated nutrient management was studied by Sachan *et al*. (2017). The results showed that plants treated with NPK @ 75 per cent recommended dose+ FYM @ 2.5 t ha^{-1} + Poultry manure @ 2.5 t ha^{-1} + Vermicompost @ 2.5 t ha^{-1} significantly exhibited maximum protein content (16.61 per cent) and TSS (2.44° Brix) as quality parameters compare to the treatment control which showed lowest response.

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

After a crop is harvested, nutrient availability in the soil is greatly influenced by the initial soil nutrient status, the amount of fertilizer nutrients added and the nature of the crop risen. In order to apply soil-based fertilizer recommendations, soils must be tested after each crop, which is not feasible. Therefore, after harvesting the crop, it has become necessary to predict the soil test values. It can be done by developing equations of prediction (Ramamoorthy and Velayutham, 1971). This provides the way to give fertilizer recommendations based on initial soil test values for the entire crop sequence. This is very useful because for practical reasons the soil of the field of the farmer under intensive cultivation cannot be tested for each crop. The available nutrients in the soil are greatly influenced by certain factors such as nature and age of crops, microbial activity, enzymatic transformations and application of organic manures and inorganic fertilizers. Distinguished changes in the soil fertility under the intensive system of agriculture are likely to occur due to high cropping intensity with high yielding varieties and high levels of nutrient input. The effect of the application of fertilizers and manure on available nutrient status of soils has been reported by numerous workers.

Maragatham and Chellumutthu (2000) reported that, the post-harvest soil of sunflower crop showed a significant build-up of soil nitrogen compared to the initial level ranging from 165 to 228 kg $ha-^{1}$ due to addition of FYM.

Parmar and Sharma (2001) studied the response of cauliflower cv. PSB-1 to NPK fertilizers and farmyard manure and observed that soil available N, P, and K increased with the increase in the rate of NPK fertilizer and farmyard manure.

Duraisami *et al*. (2001) registered progressive increase in NH_4-N and NO_3-N with similar increase in the level of nitrogen applied to the sorghum crop on sandy clay loam soil. The available N and inorganic nitrogen fractions were positively correlated with N uptake.

Singh *et al*. (2001) observed that the organic matter and total N status decreased with application of fertilizers alone and increased with conjunctive use of fertilizer N and organic manure. The amount of available N in soil increased from 140 to 300 kg ha^{-1} in 1997-98 as the dose of FYM increased from 0 to 10 t ha^{-1}. The corresponding increase in 1998-99 was from 139 to 300 kg ha^{-1}. The N balance due to the use of fertilizer N alone was negative and integration of organic and biological N resulted in positive N balance (Duraisami *et al*., 2002).

Verma *et al*. (2002) observed that prescription based fertilizer recommendation for the yield targets could be integrated with additional 5 t FYM ha^{-1} , would not only increase rice, maize and wheat yields by 4.2 to 5.7 q ha^{-1} but also build up soil fertility in terms of available N, P_2O_5 and K_2O and DTPA extractable micronutrients.

Duraisami and Mani (2002) found a positive increase in the available K with the increase in the dose of potassium in loamy sand soils for tomato and highest availability of K (209.5 kg ha^{-1}) was recorded at 80 kg K_2O ha^{-1} as against only 181.8 kg K ha^{-1} at control.

Brahma *et al*. (2002) conducted a field experiment to ascertain the effect of NPK fertilizers on the fertility status of soil. The treatment comprised application of 80:30:20, 100:60:40, 150:80:60 and 200:120:80 kg NPK ha^{-1}. NPK at 200:120:80 kg ha^{-1} resulted in the highest values for residual available N (383.84 kg ha^{-1}), P (41.58 kg ha^{-1}) and K (72.37 kg ha^{-1}).

Shalini *et al*. (2002) conducted an experiment on knol- khol and studied the effect of integrated nitrogen management and nutrient availability in soil. Application of 50 per cent nitrogen (Urea) + 50 per cent nitrogen (vermicompost) + Azospirillum resulted in higher availability of nutrients in soil.

Santhi *et al.* (2002) reported that the post-harvest soil fertility was maintained due to IPNS for onion in Inceptisols of Tamil Nadu. Similar results were obtained by Gayathri (2003) for potato in Ultisols, Thilagam (2004) for cauliflower, John (2004) for cabbage and Devi (2005) for carrot.

Choudhury *et al.* (2004) studied the effect on soil nutrient status and cauliflower productivity of integrated use of organic manure, biofertilizers and chemical fertilizer. With the conjunctive use of inorganic fertilizers, biofertilizers, and farmyard manure, the organic carbon and available N status increased significantly. Soil nutrients such as N, P and K increased significantly over chemical fertilizers alone with the application of various organic and microbial nutrient sources in combination with fertilizers.

Roy *et al.* (2006) noted that integrated applications with a judicious combination of mineral fertilizer with organic and biological nutrient sources are not only complementary but also synergistic since organic inputs have beneficial effects. Therefore, INM was used to make sustainable cauliflower cultivation and to improve soil productivity and fertility.

Sharma *et al.* (2006) studied the response of different levels of potassium on the green pea production at Nauni (Solan). They observed that there was significant increase in available potassium in the soil after crop harvest for different potassium levels. The maximum value 279.3 kg K_2O ha^{-1} was recorded at 130 kg K_2O ha^{-1} which was 19.3 per cent higher than its initial available K status (234.2 kg ha^{-1}).

Sharma *et al.* (2008) conducted an experiment to study broccoli's response to integrated nutrient management using organic manure, Azotobacter and synthetic fertilizers. It concluded that the application of 100 per cent NPK+Azotobacter+20 t ha^{-1} cow manure resulted in the highest increase in the content of organic carbon and available nitrogen, phosphorus and potassium, respectively, by 36, 32 and 19 per cent over their initial soil status. Approximately 31, 8.4 and 12.5 kg ha^{-1} of nitrogen, phosphorus and potassium can be saved in broccoli production if cow manure @ 20 t ha^{-1} is used in combination with synthetic fertilizers.

Organic manures significantly influenced the chemical properties of the soil. With poultry manure, the Nitrogen (32 kg ha^{-1}), Phosphorus (68 kg ha^{-1}) and Potassium (4 kg ha^{-1}) levels of the soil improved (Madukue *et al.*, 2008).

Gopinath *et al.* (2009) in a study found that both composted farm yard manure (FYMC) and (FYMC+ Poultry manure + Vermicompost + Biofertilizers) enhanced soil pH (7.1) and oxidizable organic carbon (1.2-1.3 per cent) compared with (FYMC+NPK) and un- amended control after a two-year transition period in capsicum.

Sur *et al.* (2010) while analyzing the availability status of N, P, K and cationic micronutrients in soils in relation to ' Green Express ' cabbage (*Brassica oleracea* L. var. capitata) indicated that the adoption of INM practices generally contributed to the development of soil nutrient status in relation to N, P, K, Fe, Mn, Cu and Zn content. The treatment receiving recommended N, P and K levels, 4 t ha^{-1} organic manures and 0.5 kg ha^{-1} Zn as Zn-EDTA proved superior in soil fertility increase. However, the highest organic carbon content (0.88 per cent) was observed in the treatment where 4 t ha^{-1} organic manure and recommended NPK and zinc levels were applied at 0.5 kg ha^{-1}.

Bharadwaj *et al.* (2010) observed that Increase in NPK application changes macronutrient availability in soil after harvesting of pea and available NPK increased significantly with increase in NPK application. Highest available N (334.9 kg ha^{-1}), P (42.80 kg ha^{-1}) and K (265.56 kg ha^{-1}) were recorded with 100 per cent NPK over control.

Reddy *et al.* (2010) in a field experiment on a sandy loam soil during *kharif* (onion) and *rabi* (radish) seasons found an increase in the exchangeable NH_4 + -N (37.76 to 43.82 mg kg^{-1}) and NO_3-N (10.99 to 14.80 mg kg^{-1}) after the harvesting of onion crop with the levels of nitrogen increasing from 0 to 120 kg N ha^{-1}. Similar results were found after the harvest of radish crop.

Santhi *et al.* (2011) reported that the magnitude of buildup of available nutrient status was higher with STCR-IPNS treatment under beetroot cultivation in red calcareous soil (TypicHaplustalf). Similar finding was also obtained by Poongothai *et al.* (2011) under radish and Dixit *et al.* (2011) in maize cultivation.

Sarangthem *et al.* (2011) conducted an experiment to study the impact of organic manures on soil parameters and cabbage (*Brassica oleracea* L. var. capitata) yields in acid soils. The study consisted of two sources of organic manure (vermicompost and FYM) and Azospirillum (4 Kg ha^{-1}). The post-harvest organic carbon and available NPK content of soil drastically improved with using vermicompost and Azospirillum. The concentration of nutrient (NPK) in shoot and root of cabbage was also observed highest in the treatment receiving vermicompost 3 t ha^{-1} along with Azospirillum as compared to FYM treatments.

Ceronio *et al.* (2012) analyzed soil properties after growing cabbage for two years under different organic regimes viz. chicken manure, kraal manure and compost and found their significant influence on chemical status of the soil. Of the three manures, compost significantly affected most of the chemical properties of the soil, increasing the phosphorus, potassium, sulphur, calcium, total carbon and total cations content of the soil. They concluded that though two years were relatively short period, yet compost and kraal manure seamed to improve the chemical properties of soil more than chicken manure.

Angelova *et al.* (2013) reported that the soil treated with organic amendments showed apparent increase of organic matter, total N, EC, available macro (P, K, Ca and Mg) and secondary nutrient content of soil.

Ashima *et al.* (2017) conducted an experiment at ICAR Research complex Tripura Centre, Lembucherra to evaluate the efficacy of organics (vermicompost and Farm yard manure) with or without Azotobacter on the soil fertility of cauliflower. Vermicompost and FYM were applied @ 1, 2 and 3 t ha^{-1} with or without Azotobacter @ 4 kg ha^{-1} in cauliflower. Results revealed that available nitrogen, phosphorus, potassium and organic carbon content of the soil after the harvest of cauliflower was significantly enhanced as compared to that of control.

2.5 Soil test based fertilizer recommendation for desired yield targets of various crops

Fertilizer prescription equations based on targeted yield model was generated by Thilagam and Natesan, 2009, for desired cauliflower yield targets under integrated plant nutrient system. The nutrient requirement for the production of one quintal of cauliflower was 0.34 kg of nitrogen, 0.19 kg of phosphorus and 0.36 kg of potassium. Per cent contribution of nitrogen, phosphorus, and potassium from soil was 29.0, 33.5 and 12.3, respectively. Per cent contribution of nitrogen, phosphorus and potassium from fertilizer was 36.9, 44.2 and per cent respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium was 23.3, 16.3 and 31.8, respectively. Per cent contribution of nutrients was 29.5, 17.4 and 33.8 with FYM+AZO for nitrogen, phosphorus and potassium, respectively. Rao and

Subramanian (1994) also worked out basic parameters for cauliflower. The above parameters were also worked out by Saxena *et al*. (2008) for onion and Chatterjee *et al*. (2010) for potato crop.

John, 2004 developed basic data for Cabbage and found that 0.28 kg of nitrogen, 45.71 kg of phosphorus and 51.08 kg of potassium required for the production of one quintal of cabbage. Per cent contribution of nitrogen, phosphorus and potassium from soil was 0.13, 53.10 and 44.19, respectively. Per cent contribution of nitrogen, phosphorus and potassium from fertilizer was 0.29, 20.28 and 79.59, respectively. Per cent contribution of nutrients applied from FYM for nitrogen, phosphorus and potassium was 30.20, 38.80 and 35.30, respectively. Per cent contribution of fertilizer nutrients was 38.70, 44.90 and 46.70 with FYM+AZO.

Fertilizer adjustment equations were developed by Arya *et al*. (2017) on tomato. The nutrient requirement for the production of one quintal of tomato was 0.58 kg of nitrogen, 0.11 kg of phosphorus and 0.55 kg of potassium. Per cent contribution of nitrogen, phosphorus and potassium from soil was 45.22, 66.08 and 48.61, respectively. Per cent contribution of fertilizer nutrients was 72.55, 76.98 and 140.67 with FYM and 67.84, 69.98 and 134.37 without FYM for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium were 22.29, 30.46 and 30.96, respectively. The Cooperating Centers of Soil Test Crop Response Correlation (STCR) have developed fertilizer prescription/adjustment equations for targeted yields of some important crops on different soils and they are as given below:

Fertilizer prescription equations developed for cabbage (Var. Pragati) during 2009- 10. The nutrient requirement for the production of one quintal of cabbage was 0.37 kg of nitrogen, 0.21 kg of phosphorus and 0.18 kg of potassium. Per cent contribution of nitrogen, phosphorus and potassium from soil was 16, 40 and 13, respectively. Per cent contribution of fertilizer nutrients was 46.1, 57.3 and 44.2 for nitrogen, phosphorus and potassium, respectively. Cabbage (Var. Green Express) during 2006-07, nutrient requirement for the production of one quintal of cabbage was 2.07 kg of nitrogen, 0.42 kg of phosphorus and 1.74 kg of potassium. Per cent contribution of nitrogen, phosphorus, and potassium from soil was 23.77, 31.77 and 24.55, respectively. Per cent contribution of fertilizer nutrients was 44.65, 45.47 and 44.33 for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium was 33.62, 21.95 and 36.34, respectively. For cauliflower (Var. Sungru Pusi) during 2007-08, the nutrient requirement for the production of one quintal of cauliflower was 0.57 kg of nitrogen, 0.10 kg of phosphorus and 0.66 kg of potassium. Per cent contribution of nitrogen, phosphorus and potassium from soil was 11.54, 20.06 and 5.61, respectively. Per cent contribution of fertilizer nutrients was 39.41, 27.00 and 116.17 for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium was 3.55, 1.35 and 2.45, respectively.

For cabbage (Var. NTJ-2) during 2008-09, the nutrient requirement for the production of one quintal of cabbage was 0.76 kg of nitrogen, 0.09 kg of phosphorus and 1.00 kg of potassium. Per cent contribution of nitrogen, phosphorus, and potassium from soil was 72, 82 and 131, respectively. Per cent contribution of fertilizer nutrients was 89, 9 and 145 for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium was 59, 14 and 53, respectively (Anonymous, 2007-10 and Anonymous, 2010-13).

Anonymous (2013-16), reported basic data for fertilizer prescription/adjustment equations for targeted yields of some crops on different soils. For cabbage (var. Golden Acre) nutrient requirement for the production of one quintal of cabbage was 2.20 kg of nitrogen, 0.50 kg of phosphorus and 2.90 kg of potassium. Per cent contribution of nitrogen, phosphorus and potassium from soil was 21.20, 40.60 and 24.90, respectively. Per cent contribution of fertilizer nutrients was 25.20, 20.60 and 100.20 for nitrogen, phosphorus and potassium, respectively.

For broccoli (Var. CSH-1) nutrient requirement for the production of one quintal of cauliflower was 0.72 kg of nitrogen, 0.08 kg of phosphorus and 0.55 kg of potassium. Per cent contribution of nitrogen, phosphorus, and potassium from soil was 18.86, 16.98 and 31.67, respectively. Per cent contribution of fertilizer nutrients was 50.01, 22.79 and 98.49 for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium was 8.38, 19.93 and 9.58, respectively and for cauliflower (Var. Swati) nutrient requirement for the production of one quintal of cauliflower was 0.72 kg of nitrogen, 0.07 kg of phosphorus and 0.47 kg of potassium. Per cent contribution of nitrogen, phosphorus, and potassium from soil was 26.25, 72.70 and 228.35, respectively. Per cent contribution of fertilizer nutrients was 89.36, 7.64 and 115.27 for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus, and potassium was 78.01, 6.82 and 59.58, respectively.

Fertilizer prescription equations developed by Pande and singh (2016) on cabbage. The nutrient requirement for the production of one quintal of cabbage was 0.92 kg of nitrogen, 0.10 kg of phosphorus and 1.03 kg of potassium. Per cent contribution of nitrogen, phosphorus and potassium from soil was 59, 66 and 123, respectively. Per cent contribution of fertilizer nutrients was 104, 11 and 162 with FYM and 85, 9 and 126 without FYM for nitrogen, phosphorus and potassium, respectively. Per cent contribution of nutrients from applied FYM for nitrogen, phosphorus and potassium was 59, 14 and 53, respectively. Similar findings have also been made by Kadam and Sonar (2006) on onion, Muralidharudu *et al.* (2007) on potato, turmeric, garlic, pumpkin, and ladies finger and Muralidharudu *et al.* (2011a) on brinjal, tomato, radish, chilly, carrot and fenugreek. Gogoi and Mishra (2015) on the pumpkin.

Materials and Methods

Chapter 3 MATERIALS AND METHODS

The details of the materials used and methodology adopted during the research work entitled **“**Optimization of fertilizer doses through STCR approach for cauliflower (*Brassica oleracea* L var. *botrytis*) grown in Mollisols**”** are described in this chapter.

3.1 Experimental Site

3.1.1 Site

Field experiments were conducted at Vegetable Research Centre (29° N latitude, 79° 27’ E longitudes and an altitude of 217 m above the mean sea level) during 2015-16 and at Crop Research Centre (29^0 N latitude, $79^0$29’ E longitudes and an altitude of 243.84 m above the mean sea level) during 2016-17 of G.B. Pant University of Agriculture and Technology Pantnagar, Udham Singh Nagar (Uttarakhand). Follow up trial was also conducted on farmer’s field at Golapaar, Haldwani during 2016-17.

3.1.2 Weather and climate

Pantnagar falls in the humid subtropical zone and comes under the *tarai* region of Uttarakhand at the foothills of *Shivalik* range of Himalayas. This place has humid and subtropical climate with the maximum temperature ranging from 32ºC to 44ºC during summer and minimum temperature ranging from 4.4ºC during winter. The summers are dry and hot, winters are too cold and frost expected from last week of December to end of the January. The onset of monsoon usually occurs from the last week of June and continues in appreciable amount up to the middle of September. During this period maximum rainfall occurs. The mean annual rainfall records approximately 1300 mm. A few or little showers also expected during the winter month. Different weather parameters during the period of experimentation (October 2015 to march 2016 and October 2016 to march 2017) as recorded at the meteorological observatory located at CRC are depicted in figure 3.1 and 3.2 and presented appendix I & II.

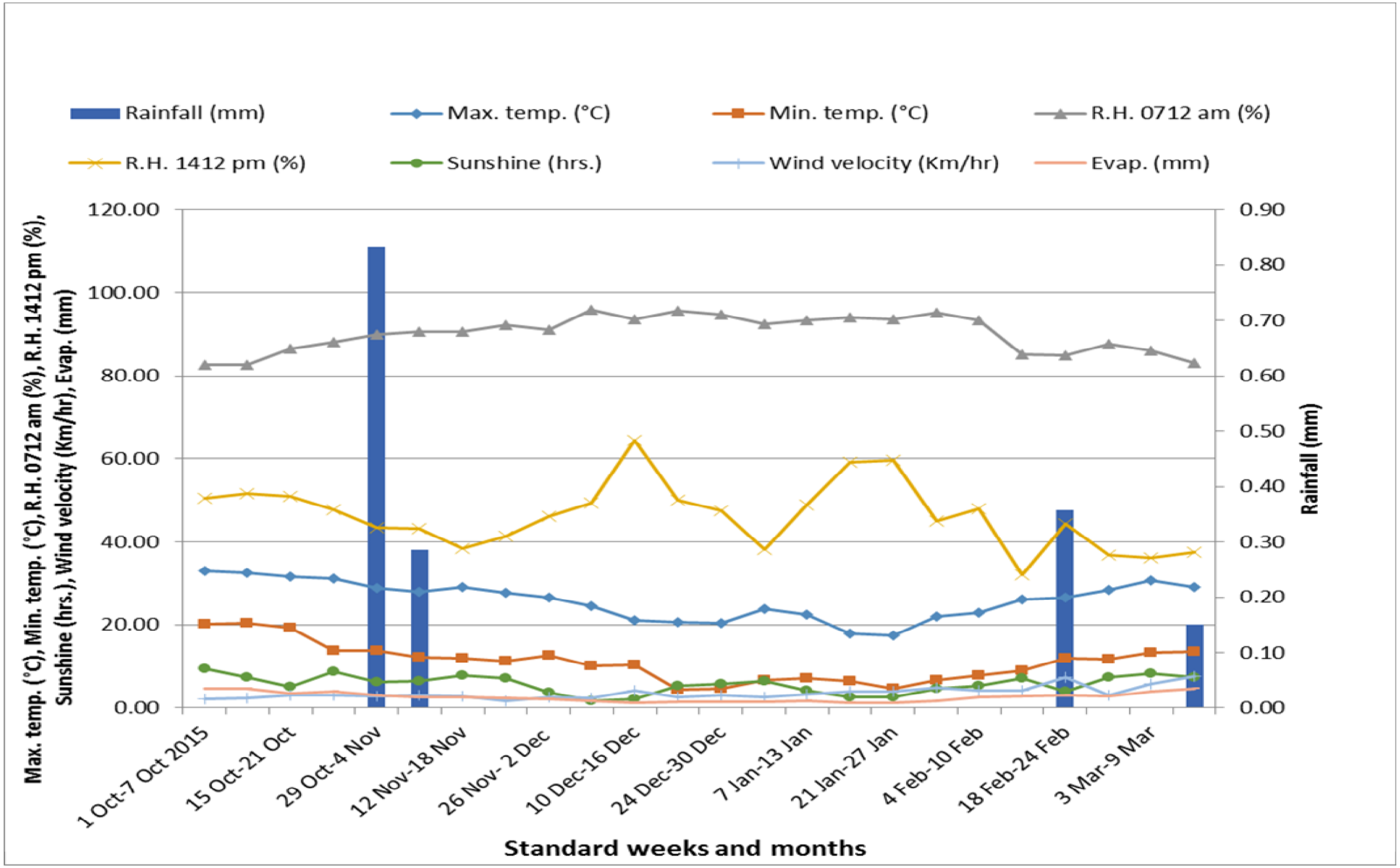


Fig 3.1: Weather data during experimental period October, 2015 – March, 2016

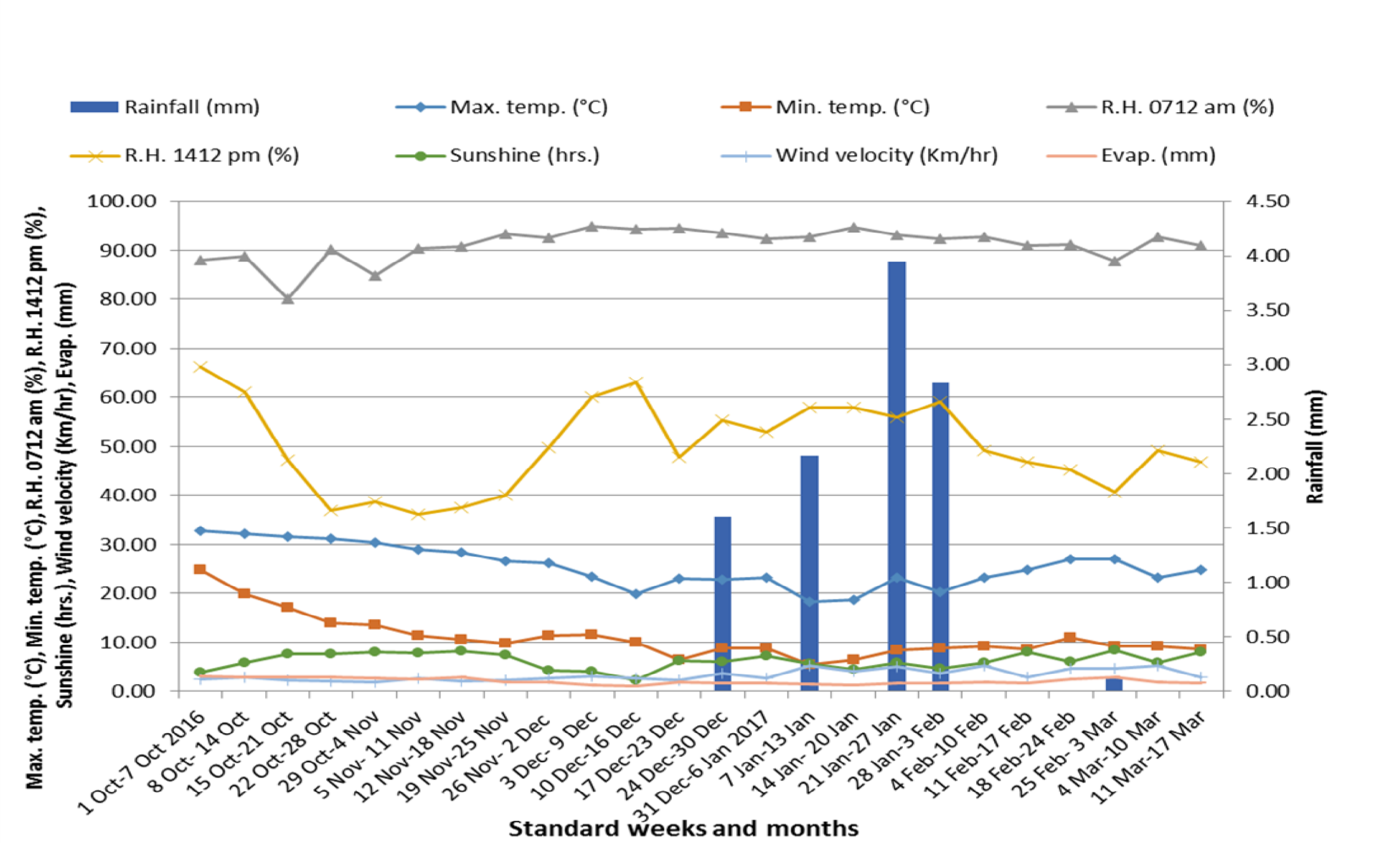


Fig 3.2: Weather data during experimental period October, 2016 – March, 2017

3.1.3 Soil

The soil of the experimental site was classified (Deshpande *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.

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 (%)	53.6	
	Silt (%)	34.2	
	Clay (%)	12.2	
	Textural class	Sandy loam	USDA textural triangle
2.	pH (1:2 soil water suspension)	6.8	Glass electrode pH meter (Jackson, 1958)
3.	Electrical conductivity (dSm^{-1})	0.20	Bower and Wilcox (1965)
4.	Organic carbon (%)	0.89	Walkley and Black method (1934)
5.	Available nitrogen (kg N ha^{-1})	152.89	Alkaline $KMnO_4$ method (Subbiah and Asija, 1956)
6.	Available phosphorus (kg P ha^{-1})	17.21	Olsen's extraction method (Olsen *et al.*, 1954)
7.	Available potassium (kg K ha^{-1})	260.61	Neutral 1 N NH_4OAc extraction method (Hanway and Hiedal, 1952)
8.	P fixing capacity (%)	80.16	Waugh and Fits (1996)
9.	K fixing capacity (%)	44.08	Waugh and Fits (1996)

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 drained
- ❖ Present land use : Cultivated land.
- ❖ Colour : Yellowish brown
- ❖ Soil texture : Sandy loam
- ❖ Consistency : Moist friable to loose
- ❖ Soil Structure : Granular

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-6.9, EC-0.21, Org. C-0.89%, Available N-150.71 kg ha^{-1}, Available P-18.41 kg ha^{-1}, Available K-251.60 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-0.20, Org. C-0.85%, Available N-147.98 kg ha^{-1}, Available P- 16.46 kg ha^{-1}, Available K- 230.40 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-6.2, EC-0.18, Org. C-0.79, Available N-130.42 kg ha^{-1}, Available P- 15.20 kg ha^{-1}, Available K-192.98 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-6.1, EC-0.16, Org. C-0.70, Available N-100.26 kg ha^{-1}, Available P- 10.25 kg ha^{-1}, Available K-115.12 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-6.0, EC-0.16, Org. C-0.65, Available N-94.20 kg ha^{-1}, Available P- 9.46 kg ha^{-1}, Available K-86.66 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-5.8, EC-0.15, Org. C-0.60, Available N-87.89 kg ha^{-1}, Available P- 9.20 kg ha^{-1}, Available K-78.68 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-5.8, EC-0.13, Org. C-0.58, Available N-64.2 kg ha^{-1}, Available P- 8.0 kg ha^{-1}, Available K-56.87 kg ha^{-1}.

3.2 Methodology of Experiments

This study comprised of three field experiments in three phases *viz.*, Phase I, fertility gradient experiment with maize var. (Kanchan), Phase II, test crop experiment Cauliflower var. (Snowball-16) in year 2015-16 and Phase III, verification trial with cauliflower of same variety in year 2016-17. Before starting experiment composite soil sample from the experimental field was collected and analyzed for various physico-chemical properties as presented in table 3.1. The above experiments were conducted as per the technical programme and methodology of STCR (Annonymous 2013-16) to Optimizing fertilizer doses for cauliflower**.** The details of the field experiments carried out and methods of analysis of soil and plant samples done and the methodology followed in fulfilling objectives of study 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 received 200:200:200 N, P_2O_5 and K_2O Kg ha^{-1} (N2P2K2) and a exhaust crop of Maize (kanchan) was grown during *kharif* 2015 for successful conduct of soil test crop response correlation study and to minimize the interference of other soil and management factors affecting crop yield. By adopting usual agronomic practices, the crop raised till maturity. The layout of first phase is shown in figure 3.3.

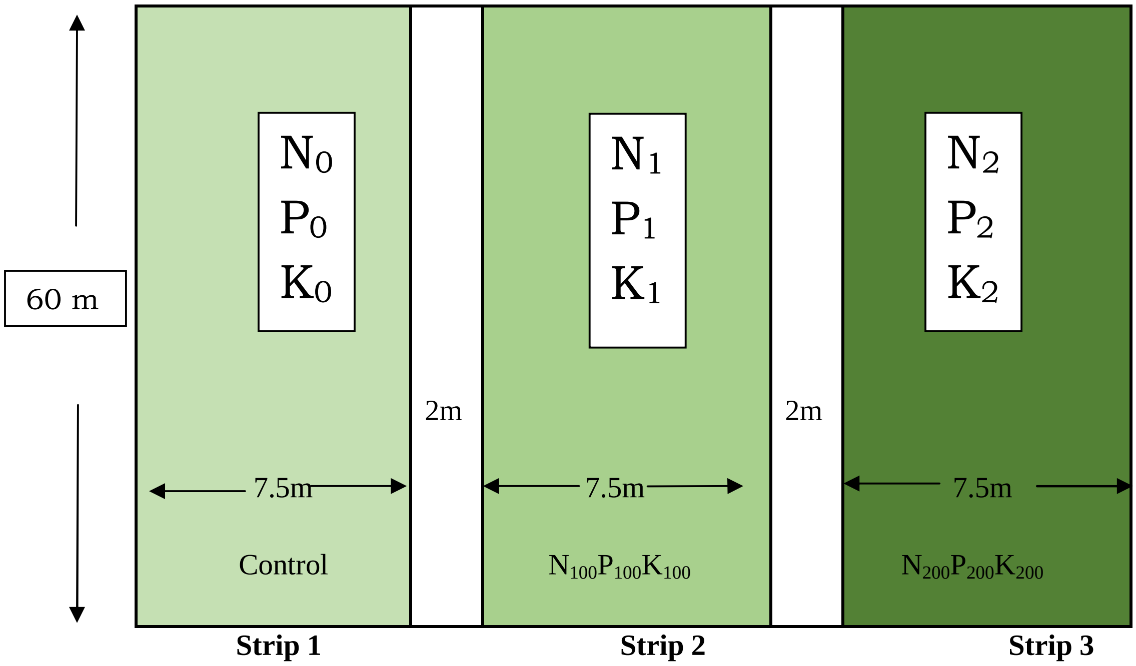


Fig. 3.3: Layout of the soil fertility gradient experiment

In the first phase during 2015, land was prepared in the month of July. For preparation of field one disc ploughing followed by two cross harrowing was done on July 20. 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 sowing as basal. While remaining half dose of nitrogen was applied in two splitting doses 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 22 cm row to row distance on July 20, 2015. Seeds of variety kanchan were sowing at the rate of 20 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. Crop was harvested at full maturity Stover yield recorded strip wise (Table 3.4). Photographic view of this experiment is presented in Plate 1**.**

Table 3.4: Strip wise yield of maize in fertility gradient experiment

Strip	Symbol	Fertilizer Dose (N, P_2O_5 & K_2O)	Grain + Stover yield (q ha^{-1})
I	$N_0P_0K_0$	0,0,0	90
II	$N_1P_1K_1$	100,100,100	120
III	$N_2P_2K_2$	200,200,200	150

3.2.2 Test Crop Experiment (Second Phase):

For conducting test crop experiment on cauliflower, first nursery was raised and then cauliflower seedlings were transplanted in the experimental field. The details of nursery raising and transplanting are given below.

A. Raising of nursery

To prepare the nursery cauliflower seeds were sown in well prepared raised nursery bed in rows 15 cm apart and at 1.5 cm deep (Plate 2). Nursery bed was well prepared before 3-4 days of sowing so that the soil may be well solarized and free from disease organisms. Well rotten FYM @ 15-20 kg/ bed and N, P and K @ 15-20g, 25-40g and 40-60g/ bed in the form of urea, single super phosphate and muriate of potash were applied and mixed well with soil. After sowing the seeds, bed was covered with straw mulch just after sowing for 4-5 days to protect the germinating seedlings from adverse weather conditions and maintaining moisture. The seed bed cover was removed as soon as the emergence of young seedlings started. After one week thinning was done for proper growth and development of seedlings. Water supply maintained as and when required.

B. Transplanting

The four weeks old seedlings were transplanted on the site of fertility gradient experiment during *rabi*, 2015-16. Land was prepared in the month of October with one disc ploughing followed by four cross harrowing. The field was leveled without disturbing strip boundaries with the help of leveler to furnish gentle slope for better drainage. Layout of field was done as mentioned in figure 3.4 and presented in plate 3. Each strip was divided into 24 plots (23 treatments+ 1 control) of size 12m^2 (4mX3m), and initial soil samples were collected for analyzing available N, P and K status of experimental plot of cauliflower. The levels of nitrogen, phosphorus, potassium and FYM used in the experiment are given in table 3.5 and photographic view of transplanting is presented in plate 4.

Table 3.5: Levels of nitrogen, phosphorus, potassium and FYM used for the experiment on cauliflower

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	30	30
2	20	100	60	60
3	-	150	90	90

Nitrogen, phosphorus, potassium and organic manure were applied through urea, single super phosphate, muriate of potash and FYM, respectively. Half of nitrogen, total phosphorus, total potash and total dose of FYM were applied as basal. While remaining half of nitrogen was applied after 35 days of transplanting. Healthy, disease free, four weeks old cauliflower seedlings were transplanted in the field at 60×50 cm spacing. Important dates for various operations during crop season are presented in the table 3.6.

C. Gap filling

A week after, damaged and dead seedlings were replaced by healthy ones to maintain the desired plant population in the plot.

D. Irrigation

A light irrigation was applied just after the transplanting and subsequent irrigations were given at an interval of about 10-12 days depending upon the soil condition and crop requirement.

Plate 1: Photographic views of exhaust crop- Maize (var. Kanchan)

Plate 2: Photographic views of Cauliflower nursery

Plate 3: Layout of the experimental field

Plate 4: Transplanting in the experimental field

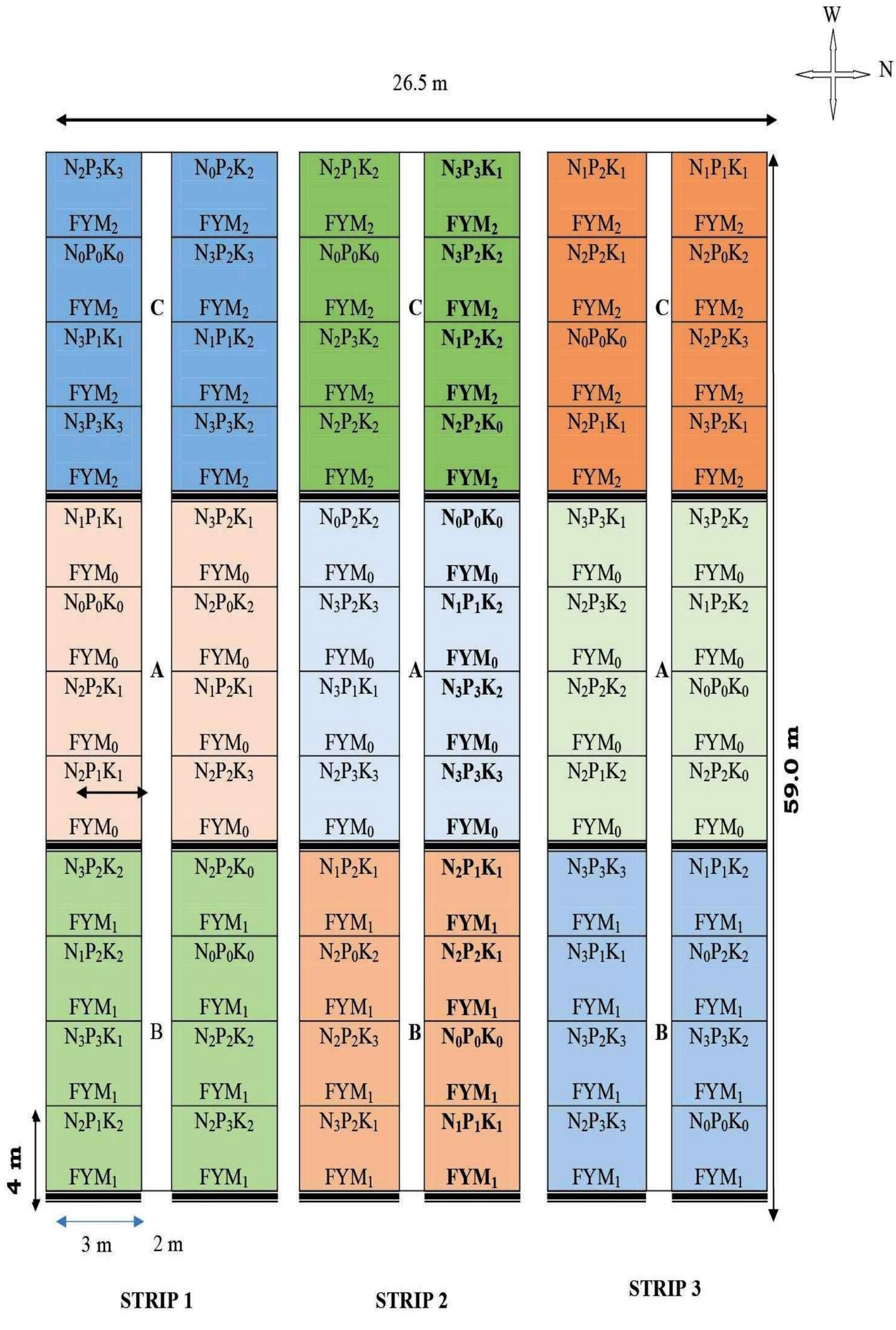


Fig. 3.4: Layout and treatment combinations of the test crop experiment

E. Weeding operations

Manual weeding was done after six weeks of transplanting.

F. Plant protection

Application of Endosulfan 35% @ 0.2 per cent was done to control insects like cutworm and aphids.

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

Operations	Date
Harrowing and leveling,	07.11.2015
Layout preparation	07.11.2015
Date of initial soil sample collection	07.11.2015
Application of fertilizers & FYM	09.11.2015
Transplanting	10.11.2015
First irrigation	10.11.2015
Second irrigation	26.11.2015
Top dressing of half dose of urea	14.12.2015
Observation and plant sampling	24.02.2016
Harvesting	15.03.2016
Post-harvest soil samples	16.03.2016

3.3 Observations recorded

In the present investigation five plants were randomly selected for all the observations listed as below. Strip wise and plot wise data of these observations are presented in appendix IV.

3.3.1 Number of leaves per plant

Total numbers of leaves per plant was recorded at the time of curd harvesting in the randomly selected plants and their mean was calculated.

3.3.2 Gross plant weight (Kg)

The weight of plant including the stalk, leaves and curd was recorded at the time of harvesting on five randomly selected plants and their mean was calculated as average plant weight.

3.3.3 Marketable curd weight (Kg)

The individual curd weight (excluding stalk and including 3-4 leaves) was recorded at the time of harvest.

3.3.4 Net curd weight (Kg)

The individual net curd weight (excluding stalk and leaves) was recorded at the time of harvest.

3.3.5 Curd diameter (cm)

The equatorial diameter of the half cut curd was measured with the help of scale.

3.3.6 Curd depth (cm)

The vertical distance between the tip of the half cut curd and the lower most button was measured with the help of scale.

3.3.7 Curd size index (cm^2)

The product of the curd diameter and the curd depth was taken as curd size index for each curd.

3.3.8 Yield per plot (kg)

The yield of curds was recorded individually per plot and converted into quintal per hectare.

3.4 Collection of Soil Samples

Soil samples at 0-15 cm depth were collected from 72 plots before transplanting of cauliflower seedlings and application of fertilizer and manure. Post-harvest soil samples were also collected after harvesting of cauliflower.

3.4.1 Processing of Soil Samples

After collection of soil samples, were air dried in shade, ground with the help of mortar and pestle, passed through 2 mm sieve and stored for further chemical analysis. Photographic view of chemical analysis in laboratory is showed in plate 5.

3.4.2 Chemical analysis of Soil Samples

3.4.2.1 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 per cent.

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

3.4.2.2 Availability indices of Phosphorus

(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}.

(d) Bray and Kurtz P-1 Method: This method estimates the relative bioavailability of ortho-phosphate (PO_4-P) in acid to neutral pH soils using a 0.025MHCl and 0.03 M NH_4F dilute acid solution. Phosphorus content is determined by spectrophotometrically at 882 nm at an acidity of 0.19M H_2SO_4 (Rodriguez *et al.*, 1994) by reacting with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony (Murphy and Riley, 1962).

Plate 5: Photographic view of chemical analysis in the laboratory

3.4.2.3 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}.

(d) **Non exchangeable K:** Boiling Nitric acid extraction method (Pratt, 1982) 2.5g of finely ground soil sample was added to a 125ml Erlen Meyer flask and 25 ml of 0.1N HNO_3 was added to it. The flask was kept on a ring stand over a gas burner. The flame was reduced when the contents were boiling and the suspension was boiled gently for 10 min. The flask was removed and the contents were poured into a filter and filtrate was received in a 100 ml volumetric flask. Wash the soil 4 times with 15 ml portions of 0.1N HNO_3. Cool the solution, dilute it to volume and mix it thoroughly. Determine K with a flam photometer using appropriate K standards prepared using 0.1N HNO_3 such that the concentration of the acid is maintained as that in the sample.

3.5 Collection of Plant Samples

Plant samples were taken from each plot. Five plants were selected from each plot and samples of curd and leaves were taken and fresh weight was recorded (Plate 6). The plant samples were first air dried and subsequently kept in paper bags and oven dried at 60°C for 48 hours and dry matter content and dry matter yield was recorded. These samples were also used for determination of quality parameter of cauliflower.

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

$$\text{Dry matter yield (q ha}^{-1}\text{)} = \text{Fresh curd yield (q ha}^{-1}\text{)} \times \text{Dry matter content (\%)}$$

3.5.1 Processing of Plant Samples

Plants samples were dried at 60°C for 48 hours in an electric oven and then the samples were ground in a ‘Wiley’ type mill and stored in plastic bags. Oxidation of organic material and release of mineral elements was done by digestion 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.

3.5.2 Chemical analysis of Plant Sample

3.5.2.1 Nitrogen

The nitrogen content (curd+ leave) was determined by Modified micro-jeldahl method (Jackson, 1967). The digestion of dried plant sample (0.2 g) is done with 10 ml of H_2SO_4 and 1 g of catalyst mixture in a digestion tube. Further, the digestion is carried on digestion assembly till the digest becomes colourless. The digested 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.

3.5.2.2 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 as described by Chapman and Parker (1961). The content was expressed as per cent in curd and leaves.

3.5.2.3 Potassium

The potassium content of the digested material was estimated by flame photometer. The content was expressed as percent potassium in curd and leaves.

3.6 Total nutrient uptake

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

Plate 6: Harvesting and Collection of plant samples

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

(c) Total nutrient uptake by plant (kg ha^{-1}) = Uptake by curd (kg ha^{-1}) + Uptake by leaves (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 curd and leaves.

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

The nutrient requirement was calculated as follows:

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

The values were reported as kg of nitrogen (N), phosphorus (P) and potassium (K) required for producing one quintal of curd. 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 make 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:

$$\text{Percent contribution of available nutrient from soil (Cs)} = \frac{\text{Total uptake of nutrient in contorl plot}}{\text{Soil test value of that nutrient in control plot}} \times 100$$

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

3.7.3 Contribution of 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 =

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

3.7.4 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 contribution of soil & FYM and divided by applied fertilizer dose in each treated plot. Take the average of such plots separately for per cent N, P and K contribution from fertilizers.

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

3.7.5 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 divided by applied fertilizer dose in each treated plot. Take the average of all such plots separately for per cent N, P and K contribution from fertilizers.

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

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

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 doses of nitrogen, phosphorus and potassium for targeted yields were worked out as follows:

Without FYM

$$FN = (NR/Cf) \times 100T - (Cs/Cf) \times SN$$

$$FP_2O_5 = (NR/Cf) \times 2.29 \times 100T - (Cs/Cf) \times 2.29 \times SP$$

$$FK_2O = (NR/Cf) \times 1.21 \times 100T - (Cs/Cf) \times 1.21 \times SK$$

With FYM

$$FN = (NR/Cf^*) \times 100T - (CS/Cf^*) \times SN - (Cfym/Cf^*) \times M$$

$$FP_2O_5 = (NR/Cf^*) \times 2.29 \times 100T - (CS/Cf^*) \times 2.29 \times SP - (Cfym/Cf^*) \times 2.29 \times M$$

$$FK_2O = (NR/Cf^*) \times 1.21 \times 100T - (CS/Cf^*) \times 1.21 \times SK - (Cfym/Cf^*) \times 1.21\ M$$

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 = Per cent contribution of concerned nutrient from fertilizer without FYM

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

CS = Per cent contribution of concerned nutrient from soil

Cfym = Per cent 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 Quality parameters of cauliflower:

Curd samples were analyzed for total phenolic, flavonoids and ascorbic acid. After the collection, sample was left to dry under shade and after some time kept in oven for drying. Finally, samples were ground into a fine powder using a mortar and pestle.

3.9.1 Determination of total phenolic and flavonoids content

Preparation of sample

Exact amount of 1.5 g of sample was weighed and underwent for extraction with 85% methanol which is acidifies to pH 2.0 with the addition of 6N HCl along with the constant agitation using magnetic stirrer for the duration of 30 minutes, for the analysis of antioxidant activity**.** The supernatant was decanted and the residue was re-extracted for complete removal of phenolic and flavonoid compounds. The procedure was repeated two times and then mixture of three supernatants was centrifuged at 6000 rpm for 15 min. The supernatants was collected and filtered through Whatman No. 1 filter paper, resulting finally into 50 ml crude extract. The extracted sample was stored at -20°C for phenolic and flavonoid activity.

Total phenol content: The Total Phenol content was determined according to the method given by Singleton *et al.* (1999) using Folin- ciocalteu reagent.

Principle: Polyphenol in plant extract reacts with specific redox reagent (Folin-ciocalteu reagent) to form blue chromophore constituted by a phosphotungustic-phosphomolybdenum complex. The blue color was measured at 750 nm.

Reagent Preparations:

- **Gallic acid (GA) standard solution** (100 mg %)

  Stock solution: 100 mg Gallic acid was dissolved in 100 ml distilled water.

  Working solution: 1 ml stock solution was taken and volume was made up 20 ml with D/W.

- **Folin- ciocalteu (FC) reagent (50%):** 1:1 dilution with distilled water

- **Sodium carbonate (7.5%):** 7.5 g Na_2CO_3 was dissolved in 100 ml distilled water

Procedure:

Sample: A known aliquot of sample was taken and volume was made upto1.5 ml with distilled water. After this, 0.5 ml of Folin- ciocalteu reagent was added. Also 10 ml of 7.5% Na_2CO_3 was added and incubated at 37°C for 60 minutes. The resulting blue color was read at 750 nm against blank.

Standard: Standard series of known concentration of gallic acid (5-20 µg) was prepared. Aliquots of 0.1, 0.2, 0.3, 0.4 ml was taken and volume was made up to 5 ml with D/W and treated same as sample.

Blank: Blank was prepared by taking 1.5 ml of D/W and treated same as sample.

Calculations:

Total Phenol (mg GAE/100g):

$$\frac{\text{std. conc.}}{\text{std. O. D.}} * \frac{\text{std. O. D.}}{\text{aliquot taken}} * \frac{\text{volume made up}}{\text{sample taken}} * \frac{100}{1000}$$

3.9.2 Total flavonoid content

Total flavonoid content was determined according to the method given by Zhishen *et al.* (1999).

Reagent Preparation:

- **Rutin standard solution (10 mg %):** Dissolve 10 mg Rutin in 100 ml methanol.
- **Sodium Nitrite (5 g %):** Dissolve 5 g $NaNO_2$ in 100 ml distilled water
- **Aluminium Chloride (10 g %):** Dissolve 10 g $AlCl_3 . 6H_2O$ in 100 ml distilled water
- **Sodium Hydroxide (1N)**: Dissolve 4 g NaOH in 100 ml D/W and standardized with oxalic acid.

Procedure:

Sample: A known aliquot of sample was taken and volume was made upto 5 ml with distilled water. A 0.3 ml of 5% $NaNO_2$ was added and after 5 min, 0.6 ml of $AlCl_3$ was added and mixed well. After 6 min, 2 ml of 1N NaOH was added and mixed. Then 2.1

ml D/W was added to make volume up to 10 ml. The absorbance of resulting pink color was read at 510 nm against blank.

Standard: Standard series of known concentration of Rutin (50-200 µg) was prepared. Aliquots of 0.5, 1.0, 1.5, 2.0 ml was prepared and volume was made up to 5 ml with distilled water and treated same as sample.

Blank: Blank was prepared by taking 5 ml of distilled water and treated same as sample.

Calculations:

Total flavonoid content (mg RE/100g):

$$\frac{\text{std. conc.}}{\text{std. O. D.}} * \frac{\text{sample O. D.}}{\text{Aliquot taken}} * \frac{\text{volume made up}}{\text{sample taken}} * \frac{100}{1000}$$

3.9.3 Ascorbic acid (mg/100g)

2, 6-dichlorophenol-indophenol visual titration method was used to estimate ascorbic acid content in Cauliflower, This method given by Ranganna (1977).

acid content in the sample was calculated by following formula:

Ascorbic acid content (mg/100g)

$$= \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up} \times 1000}{\text{Volume of aliquot taken} \times \text{Weight of sample taken}} \times 10$$

3.9.4 Protein content of curd (%)

Micro-Kjeldhal method was used to estimate protein content. Nitrogen content in the sample was computed by using following formula:

$$\text{Nitrogen (\%)} = \frac{\text{Sample titre} - \text{Blank titre} \times 100 \times N \times 14}{\text{Weight of sample (g)} \times 1000}$$

Protein content was calculated by following conversion formula:

Protein (%) = 6.25 × Nitrogen (%)

3.10 Verification trials

The adjustment equations generated from experiment-1 were utilized for validation in verification trial. The verification trial on cauliflower was conducted at CRC in next year 2016-17. In this trial ten treatments (Table 3.7) with three replications were studied under RBD. The layout of the experiment given in fig 3.5.

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

Treatments	Notation
Control	T1
General recommendation Dose	T2
Yield Target 250 q ha^{-1}	T3
Yield Target 300 q ha^{-1}	T4
Yield Target 250 q ha^{-1}+ FYM 10t ha^{-1}	T5
Yield Target 250 q ha^{-1}+ FYM 20t 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
FYM 10t ha^{-1}	T9
FYM 20t ha^{-1}	T10

The yield and various observations recorded from this experiment were recorded. The information generated from this experiment was used for calculation of economics analysis of target yield approach.

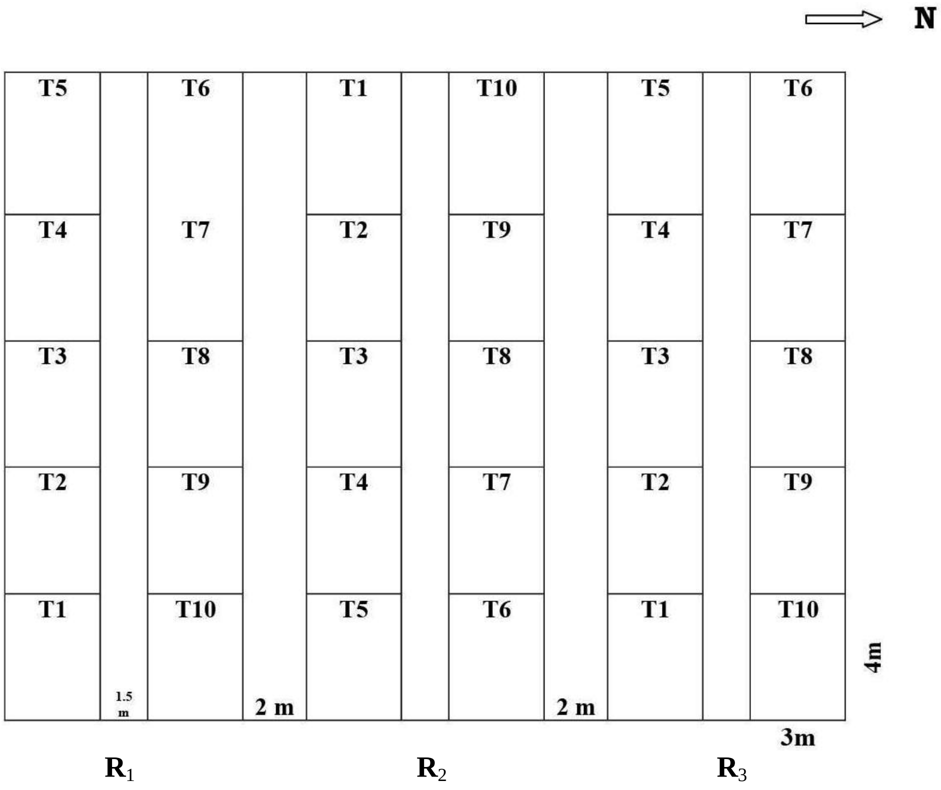


Fig. 3.5: Layout of verification experiment

3.11 Follow up trial

Follow up trial on Cauliflower was conducted at farmer's field at Golapaar, Haldwani during 2016-17. In this trial seven treatments (Table 3.8) with three replications were studied under RBD. The layout of the experiment given in fig 3.6.

Table 3.8: Fertilizers and FYM treatments in follow up trial of cauliflower

Treatments	Notation
Control	T1
Farmer practice	T2
General recommendation Dose	T3
Yield Target 250 q ha^{-1}	T4
Yield Target 250 q ha^{-1}+ FYM 10t ha^{-1}	T5
Yield Target 300 q ha^{-1}	T6
Yield Target 300 q ha^{-1}+ FYM 10t ha^{-1}	T7

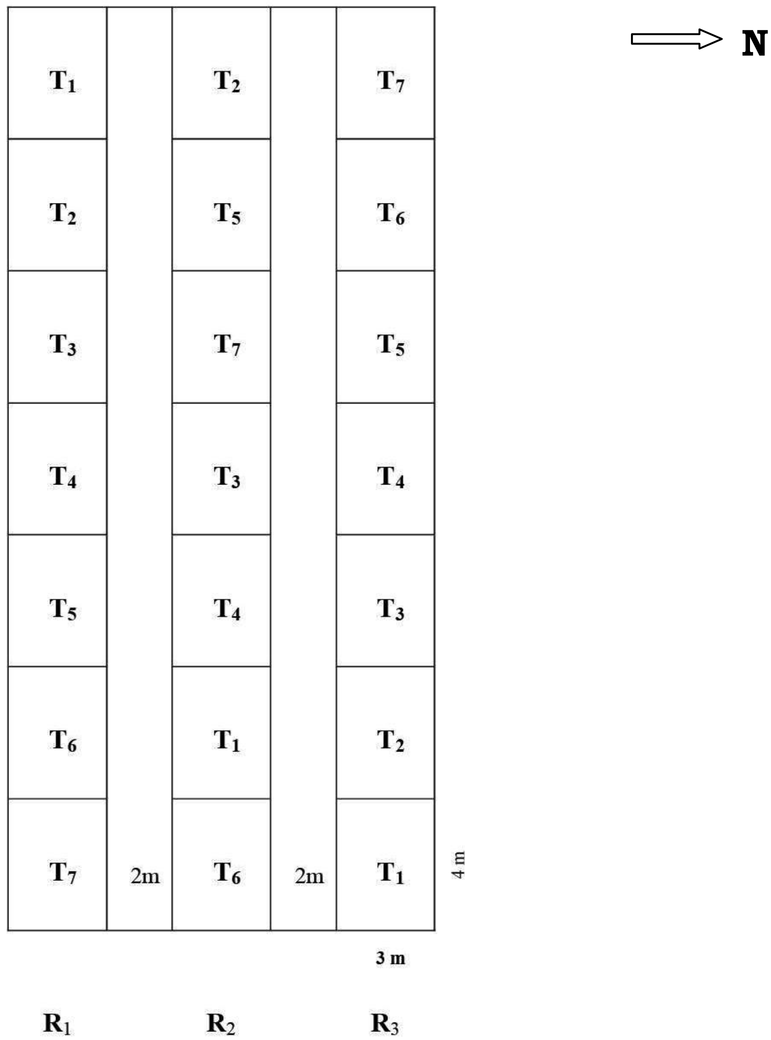


Fig. 3.6: Layout of follow up trial

The yield obtained from this experiment was recorded. The information generated from this experiment was used for economics analysis of this trial and demonstration of importance of target yield approach to farmers.

3.12 Statistical analysis

The data of fertilizer requirement and nutrient use efficiency experiments were statistically analyzed as per standard design of AICRP on ‘Soil Test Crop Response Correlation Project’. Observations recorded during field experiments on various characters were analyzed statistically by adopting fisher’s method of analysis of variance and correlations as outlined by the Gomez and Gomez (1984).

Results and Discussion

RESULTS AND DISCUSSION

The results obtained with respect to the various soil and plant characteristics have been presented with the help of suitable tables and figures and discussed with possible explanations and evidences in this chapter with a view to find out the causes and effects among different treatments. The trend observed compared with the work of other scientists and explained with proper reasoning of experimental results.

4.1 Soil analysis

4.1.1 Fertility gradient experiment

A field experiment was conducted as per the technical programme of AICRP on soil test crop response (STCR). To evaluate a meaningful regression between soil test value of various plots and crop response to fertilizer, possible large variations in fertility levels of different strips of selected field was created. The experimental success is entirely depends on the creation of the 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 cauliflower in the preceding crop season preparatory trial had conducted by growing exhaust crop maize (var. Kanchan). Experimental soil was Sandy loam classified as *AquicHapludoll* having pH 6.8, EC 0.20 (dSm^{-1}), Organic carbon 0.89%, Alkaline $KMnO_4$-N 152.89, Olsen's-P 17.21 and Ammonium Acetate-K 260.61 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 6.00 to 7.55 with an average of 6.58. pH in strip I ranged from 6.00 - 7.12 with an average of 6.92. While in strip II, the pH ranged from 6.01 to 7.29 with an average of 6.63. Range of pH in strip III varied from 6.00 to 7.55 with an average of 6.58. The average value of pH was lowest in strip III 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 0.20 dSm^{-1}. EC in strip I ranged from 0.12 to 0.26 dSm^{-1} with an average of 0.20 dSm^{-1}. While in strip II, the EC ranged from 0.15 to 0.27 dSm^{-1} with an average of 0.20 dSm^{-1}. Range of EC in strip III varied from 0.13 to 0.32 dSm^{-1} with an average of 0.24 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 0.48-1.35 per cent with an average of 0.89 per cent. Organic carbon content in strip I ranged from 0.53-1.08 per cent with an average of 0.82 per cent. While in strip II, the organic carbon content ranged from 0.48-1.32 per cent with an average of 0.91 per cent. Range of organic carbon content in strip III varied from 0.60-1.35 per cent with an average of 0.94 per cent. 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 137.98 to 200.98 kg N ha^{-1} with average value of 160.98 kg N ha^{-1}. Strip wise values ranged from 137.98 to 175.62 with an average of 160.46 in strip I, 137.98 to 200.70 with an average of 160.98 in strip II and 150.53 to 175.62 with an average of 161.50 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 15.01 to 22.12 kg P ha^{-1} with an average value of 18.47 kg P ha^{-1}. Strip wise range varied from 15.01 to 21.33 with an average value of 17.66 kg ha^{-1} in strip I, 15.01 to 20.93 with an average value of 17.97 kg P ha^{-1} in strip II and 17.77 to 22.12 with an average of 19.80 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 99.68 to 365.12 kg ha^{-1} with an average of 281.81 kg K ha^{-1} for the entire experimental field. Values ranged from 99.68 to 342.72 in strip I with an average value of 265.63 kg K ha^{-1}, 104.16 to 365.12 in strip II with an average value of 277.34 kg K ha^{-1} and 254.24 to 339.36 kg K ha^{-1} in strip III with an average value of 302.49 kg K ha^{-1}. The average value of Potassium was lowest in strip I and the highest in strip III. Such type of trend in soil fertility has also been reported many workers in STCR experiment (Sati *et al*., 2010, Gautam *et al*., 2013, Rawat *et al*., 2015, Pande and Singh, 2016 on Mollisols of Uttarakhand).

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

Sl. No.	Parameters	Strip I	Strip II	Strip III	Whole field
1.	pH (1:2 soil water suspension)	6.00-7.12 (6.92)	6.01-7.29 (6.63)	6.00-7.55 (6.58)	6.00-7.55 (6.58)
2.	Electrical conductivity (dSm^{-1})	0.12-0.26 (0.20)	0.15-0.27 (0.20)	0.13-0.32 (0.24)	0.12-0.32 (0.20)
3.	Organic carbon (%)	0.53-1.08 (0.82)	0.48-1.32 (0.91)	0.60-1.35 (0.94)	0.48-1.35 (0.89)
4.	Available nitrogen (kg N ha^{-1})	137.98-175.62 (160.46)	137.98-200.70 (160.98)	150.53-175.62 (161.50)	137.98-200.98 (160.98)
5.	Available phosphorus (kg P ha^{-1})	15.01-21.33 (17.66)	15.01-20.93 (17.97)	17.77-22.12 (19.80)	15.01-22.12 (18.47)
6.	Available potassium (kg K ha^{-1})	99.68-342.72 (265.63)	104.16-365.12 (277.34)	254.24-339.36 (302.49)	99.68-365.12 (281.81)

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 available nutrients, i.e. Nitrogen (SN), Phosphorous (SP) and 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**	0.7929	160.98	6.48
SP	<0.01**	0.6611	18.47	8.11
SK	<0.01**	0.7026	281.82	14.54

The data in table 4.2 clearly show that 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_4-OAc-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 and K 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 Chatterjee (2008), Firdous (2010), Rawat (2014) and Kumar (2016) in the Mollisol of Uttarakhand.

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, Mehlich-1 or Bray P-1 method and neutral normal NH_4OA_C, AB-DTPA, Mehlich-1 or Non-exchangeable-K method to determine, available nitrogen, phosphorus and potassium in or Bray P-1 method and neutral normal NH_4OA_C, AB-DTPA, Mehlich-1 or Non-exchangeable-K method to determine, available nitrogen, phosphorus and potassium in soil, respectively (Appendix VI). Availability indices of N, P and K were determined by regression equations using curd yield as dependent and soil test values, fertilizer doses as independent variables. Data in table 4.3 show that value of R^2 in combination of different availability indices of nitrogen, phosphorus and potassium.

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

Sl. No.	Equation	R^2	Soil Test Method
For Available Nitrogen			
1.	Yield = 0.2091 + 0.2246 * SN + 4.9436 * SP - 0.2242 * SK + 2.5999 * FN + 1.5678 * FP - 2.8917 * FK + 0.0020 * FN² - 0.0354 * FP² + 0.0156 * FK² - 0.0087 * FNSN - 0.0303 * FPSP + 0.0071 * FKSK	0.8008**	Alkaline $KMnO_4N$ Olsen's P NH_4OAc- K
2.	Yield = 21.6012 + 34.5172 * SN + 4.7302 * SP - 0.2599 * SK + 1.3095 * FN + 1.4906 * FP - 2.9729 * FK + 0.0015 * FN² - 0.0376 * FP² + 0.0151 * FK² - 0.0274 * FNSN - 0.0264 * FPSP + 0.0073 * FKSK	0.7964**	OC % Olsen's P NH_4OAc-K
For Available Phosphorus			
1.	Yield = 0.2091 + 0.2246 * SN + 4.9436 * SP - 0.2242 * SK + 2.5999 * FN + 1.5678 * FP - 2.8917 * FK + 0.0020 * FN² - 0.0354 * FP² + 0.0156 * FK² - 0.0087 * FNSN - 0.0303 * FPSP + 0.0071 * FKSK	0.8008**	Alkaline $KMnO_4N$ Olsen's P NH_4OAc-K
2.	Yield = - 3.8150 + 0.2302 * SN + 4.5949 * SP - 0.2316 * SK + 2.6277 * FN + 2.9724 * FP - 3.0432 * FK + 0.0021 * FN² - 0.0355 * FP² + 0.0158 * FK² - 0.0089 * FNSN - 0.0931 * FPSP + 0.0075 * FKSK	0.7983**	Alkaline $KMnO_4N$ ABDTPA-P NH_4OAc- K
3.	Yield = - 12.0858 + 0.2302 * SN + 4.5949 * SP - 0.2316 * SK + 2.6277 * FN + 3.1399 * FP - 3.0432 * FK + 0.0021 * FN² - 0.0355 * FP² + 0.0158 * FK² - 0.0089 * FNSN - 0.0931 * FPSP + 0.0075 * FKSK	0.7983**	Alkaline $KMnO_4N$ Mehlich-P NH_4OAc- K
4.	Yield = 48.4421 + 0.1967 * SN + 4.7867 * SP - 0.2456 * SK + 2.5749 * FN + 2.4127 * FP - 3.1329 * FK + 0.0022 * FN² - 0.0350 * FP² + 0.0158 * FK² - 0.0086 * FNSN - 0.1260 * FPSP + 0.0078 * FKSK	0.7975**	Alkaline $KMnO_4N$ Bray-P NH_4OAc- K
For Available Potassium			
1.	Yield = 0.2091 + 0.2246 * SN + 4.9436 * SP - 0.2242 * SK + 2.5999 * FN + 1.5678 * FP - 2.8917 * FK + 0.0020 * FN² - 0.0354 * FP² + 0.0156 * FK² - 0.0087 * FNSN - 0.0303 * FPSP + 0.0071 * FKSK	0.8008**	Alkaline $KMnO_4N$ Olsen's P NH_4OAc-K
2.	Yield = 46.2479 + 0.3585 * SN + 4.5101 * SP - 0.2525 * SK + 2.9972 * FN + 2.2375 * FP - 4.1002 * FK + 0.0016 * FN² - 0.0356 * FP² + 0.0183 * FK² - 0.0106 * FNSN - 0.1009 * FPSP + 0.0082 * FKSK	0.7947**	Alkaline $KMnO_4N$ Olsen's P ABDTPA- K
3.	Yield = - 28.5247 + 0.1451 * SN + 5.4258 * SP + 0.0275 * SK + 2.8251 * FN + 2.4437 * FP + 0.5443 * FK + 0.0016 * FN² - 0.0422 * FP² + 0.0231 * FK² - 0.0096 * FNSN - 0.0962 * FPSP - 0.0053 * FKSK	0.7935**	Alkaline $KMnO_4N$ Olsen's P Mehlich- K
4.	Yield = 8.3586 + 0.4694 * SN + 4.7830 * SP - 0.2035 * SK + 3.2590 * FN + 2.2037 * FP - 3.0720 * FK + 0.0015 * FN² - 0.0380 * FP² + 0.0209 * FK² - 0.0121 * FNSN - 0.0910 * FPSP + 0.0048 * FKSK	0.7915**	Alkaline $KMnO_4N$ Olsen's P Non Exchangeable-K

Various soil test methods were evaluated for their suitability under field conditions (Velayutham *et al*., 1985). 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 alternately one method each time keeping the method of other nutrient constant. Mosi and Lakshminarayanan (1985) reported that such a screening procedure is useful in selecting the most appropriate testing procedure. Generally, organic carbon and alkaline $KMnO_4$ methods for N, Olsen's method for P and ammonium acetate method for K were found suitable to predict the available nutrients in the soil.

On the basis of the R^2 value derived from regression equations, the alkaline $KMnO_4$– N is superior over organic carbon per cent (Table 4.3). Per cent organic carbon and alkaline-$KMnO_4$ nitrogen both can be used equally as indices for N availability in Mollisol. Similarly, Per cent organic carbon and alkaline-$KMnO_4$ nitrogen were found to be equally good indices for N availability in wheat grown soil in most of the Indian soils (coordinators report, STCR, 1985-93). Sati (2008) observed that organic carbon and alkaline-$KMnO_4$ methods were equally suitable for evaluation of available nitrogen for yellow Sarson in Pantnagar, Uttarakhand. Upadhayay (2012) observed that organic carbon and alkaline-$KMnO_4$ methods were equally suitable for evaluation of available nitrogen in Mollisols of Uttarakhand. Similar findings were also reported by Laxminarayana and Rajgopoal, (2000), Rao *et al*. (2002) and Kumar (2016). Thus considering suitability, simplicity and cost. The organic carbon and alkaline-$KMnO_4$ oxidizable nitrogen methods seemed to be promising for testing available nitrogen in Mollisols.

The Olsen's P (R^2=0.8008) is superior to AB-DTPA P (R^2= 0.7983), Mehlich-I P (R^2= 0.7983) and Bray-P (R^2= 0.7975) but statistically they are at par. This indicates that all the four methods can be taken as an index of soil available phosphorus. Singh (1973) observed that, Olsen's method is highly correlated with phosphorus uptake and percentage yield response using wheat as a test crop in alluvial soils for Uttar Pradesh. Olsen's extractable phosphorus have significant positive correlation with yield and uptake of crops as observed by Pathak *et al*. (1975), Thakur *et al*. (1977), Lakshminarasimhan *et al*. (1978) and Sharma and Parmar (1998). Enamul *et al.* (2013) found the mean extractable P in the order of Olsen > Mehlich-3 > Bray and Kurtz-1.

Significantly higher correlation was found between Olsen-P and mehlich-3-P (r=0.924**) and Bray and Kurtz-1-P (r=0.929**). 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 in soil.

The neutral normal NH_4OAC (R^2 = 0.8008**) is superior to Mehlich K (R^2= 0.7935**), AB-DTPA K (R^2 = 0.7947**) and Non exchangeable K (R^2= 0.7915**) but statistically at par with later. Sachan *et al*. (1971) reported that neutral normal NH_4OAC method had highly significant correlation with yield of mustard. Neutral normal ammonium acetate method of potassium extraction worked well in Mollisol using wheat as a test crop (Singh *et al*., 1969 and Sachan *et al*., 1972). However, there is a need for refinement of soil test method for potassium (Ramamoorthy and Paliwal, 1965 and Sekhon and Velayutham, 1978). From the above observations, it can be suggested that both organic carbon method and alkaline-$KMnO_4$ method for soil available nitrogen, Olsen's method for soil available phosphorus and neutral ammonium NH_4OAC method for soil available potassium can be taken as indices for determining N, P and K in Mollisol of Uttarakhand.

4.3 Growth parameters of Cauliflower and their correlation

Five plants were randomly selected for all the observation and take an average of it. Strip wise and plot wise growth parameters of cauliflower given in appendix IV while range and average of growth parameters is given in table 4.4.

4.3.1 Number of leaves per plant

Number of leaves of experimental field ranged from 12 to 20 with an average of 17. Average number of leaves recorded 17 in strip III, strip II and in strip I.

4.3.2 Gross plant weight (Kg)

Gross plant weight (kg) of cauliflower ranged from 0.52 to 6.17 with an average of 2.64. Average Gross plant weight (kg) recorded in strip III (2.99 kg) was followed by strip II (2.62 kg) and in strip I (2.26 kg).

4.3.3 Marketable curd weight (Kg)

Marketable curd weight (kg) ranged from 0.22 to 2.48 with an average of 1.15. Average marketable curd weight (kg) recorded in strip III (1.30 kg) was followed by strip II (1.18 kg) and in strip I (0.99 kg).

4.3.4 Net curd weight (Kg)

Net curd weight (kg) ranged from 0.11 to 1.27 with an average of 0.59. Average net curd weight (kg) recorded in strip III (0.59 kg) was followed by strip II (0.67 kg) and in strip I (0.52 kg).

4.3.5 Curd diameter (cm)

Curd diameter (cm) ranged from 8 to 32 with an average of 14. Average curd diameter (cm) recorded 14 in strip III, strip II and in strip I.

4.3.6 Curd depth (cm)

Curd depth (cm) ranged from 5 to 12 with an average of 9. Average curd diameter (cm) recorded 9 in strip III, strip II and in strip I.

4.3.7 Curd size index (cm^2)

Curd size index (cm^2) ranged from 45 to 264 with an average of 133. Averagecurd size index (cm^2) recorded in strip II (139 cm^2) was followed by strip III (131 cm^2) and in strip I (129 cm^2).

Table 4.4: Range and average of growth parameters of Cauliflower

Sl. No.	Growth parameters	Strip I	Strip II	Strip III	Whole
1.	Number of leaves per plant	14-19 (17)	12-20 (17)	14-20 (17)	12- 20 (17)
2.	Gross plant weight (Kg)	0.52-3.88 (2.26)	0.59-5.27 (2.62)	0.82-6.17 (2.99)	0.52-6.17 (2.64)
3.	Marketable curd weight (Kg)	0.22-1.56 (0.99)	0.25-2.35 (1.18)	0.33-2.48 (1.30)	0.22-2.48 (1.15)
4.	Net curd weight (Kg)	0.11-0.92 (0.52)	0.12-1.27 (0.67)	0.17- 1.21 (0.59)	0.11- 1.27 (0.59)
5.	Curd diameter (cm)	8- 32 (14)	9- 18 (14)	10-19 (14)	8- 32 (14)
6.	Curd depth (cm)	7- 11 (9)	5- 12 (9)	7- 11 (9)	5- 12 (9)
7.	Curd size index (cm^2)	55- 264 (129)	45- 208 (139)	65- 212 (131)	45- 264 (133)

4.3.8 Correlation among curd yield, applied nutrients and growth parameters of cauliflower

Various correlation worked out in present investigation is presented in appendix V. Among them significant and high values correlation are presented in table 4.5. The curd yield of cauliflower significantly correlated with applied nitrogen (0.696**). Similarly Curd yield was also significantly correlated with growth parameter of cauliflower, gross plant weight (0.816**), marketable curd weight (0.823**), net curd weight (0.782**), curd depth (0.735**) and curd size index (0.668**). Applied nitrogen also shows positive and significant correlation with growth parameter of cauliflower, number of leaves (0.754**), gross plant weight (0.869**), marketable curd weight (0.870**), net curd weight (0.862**), curd depth (0.853**) and curd size index (0.712**).

Growth parameter of cauliflower, number of leaves were significantly correlated with gross plant weight (0.719**), marketable curd weight (0.748**), net curd weight (0.752**) and curd depth (0.729**).Gross plant weight of cauliflower is significantly correlated with marketable curd weight (0.986**), net curd weight (0.914**), curd depth (0.870**) and curd size index (0.775**).

Marketable curd weight of cauliflower is positively correlated with net curd weight (0.937**), curd depth (0.891**) and curd size index (0.790**). Net curd weight of cauliflower is significantly correlated with curd depth (0.924**) and curd size index (0.834**).

Diameter of curd is significantly correlated with curd size index (0.913**) and Curd depth of cauliflower is positively correlated with curd size index (0.872**). Thus, from the correlation studies it can be concluded that curd yield of cauliflower was positively and significantly correlated with different parameters of cauliflower. There was a highly significant correlation between applied N, P, and K, uptake and growth parameter of cauliflower. Similar findings were also reported by Ahirwar *et al.* (2015) and Kumar (2016).

Table 4.5:- Significant correlation among curd yield, applied nutrient and growth parameters of cauliflower

Sl. No.	Parameters	Correlation with	Value of correlation
1.	Yield		
a.	Curd yield	Applied nitrogen	0.696**
		Gross plant weight	0.816**
		Marketable curd weight	0.823**
		Net curd weight	0.782**
		Curd depth	0.735**
		Curd size index	0.668**
2.	Applied nutrient		
a.	Nitrogen	Number of leaves	0.754**
		Gross plant weight	0.869**
		Marketable curd weight	0.870**
		Net curd weight	0.862**
		Curd depth	0.853**
		Curd size index	0.712**
3.	Growth parameters		
a.	Number of leaves	Gross plant weight	0.719**
		Marketable curd weight	0.748**
		Net curd weight	0.752**
		Curd depth	0.729**
b.	Gross plant weight	Marketable curd weight	0.986**
		Net curd weight	0.914**
		Curd depth	0.870**
		Curd size index	0.775**
c.	Marketable curd weight	Net curd weight	0.937**
		Curd depth	0.891**
		Curd size index	0.790**
d.	Net curd weight	Curd depth	0.924**
		Curd size index	0.834**
e.	Curd diameter	Curd size index	0.913**
f.	Curd depth	Curd size index	0.872**

4.4 Yield and nutrient content of Cauliflower

Strip wise and plot wise fresh and dry matter yield with N, P and K content of curd given in appendix VII & VIII while range and average of experimental field is given in table 4.6.

4.4.1 Fresh yield

Fresh yield of plant (q ha^{-1}) of experimental field ranged from 50.00 ($N_0P_2K_2OM_2$) to 615.00 ($N_3P_2K_3OM_1$) with an average of 244.61. Average plant yield recorded in strip III (282.57 q ha^{-1}) was followed by strip II (239.86 q ha^{-1}) and in strip I (211.39 q ha^{-1}). Curd yield (q ha^{-1}) of experimental field ranged from 36.67 ($N_3P_2K_1OM_0$) to 413.33 ($N_3P_2K_3OM_1$) with an average of 192.41 q ha^{-1}. Average curd yield recorded in strip III (215.97q ha^{-1}) was followed by strip II (196.60 q ha^{-1}) and in strip I (164.65 q ha^{-1}). Yield can be predicted with total uptake of N, P and K (77 per cent) (Appendix X). It is clearly indicated that combine use of inorganic fertilizer with FYM in most of the cases is better for increase in yield. Similar results were also reported by Thilagam (2011), Kumar *et al*. (2013), Shree *et al.* (2014), Prabhakar *et al.* (2015) and Singh *et al*. (2018) in cauliflower.

4.4.2 Dry matter yield

Dry matter yield of plant (q ha^{-1}) in experimental field varied from 9.17 ($N_0P_2K_2OM_0$) to 76.88 ($N_3P_2K_3OM_1$) with an average 38.06 q ha^{-1}. Average Dry matter yield of plant recorded in order of strip III (39.79 q ha^{-1}) was followed by strip II (38.80 q ha^{-1}) and strip I (35.60 q ha^{-1}). However, dry matter yield of curd (q ha^{-1}) in experimental field varied from 4.67 ($N_0P_0K_0OM_2$) to 50.00 ($N_3P_3K_3OM_1$) with an average 21.06 q ha^{-1}. Average dry matter yield of curd recorded in order of strip III (24.06 q ha^{-1}) was followed by strip II (19.75 q ha^{-1}) and strip I (19.37 q ha^{-1}). Similar results also reported by Manhas and Gill (2010) and Kumar (2016).

Table 4.6: Range and average fresh and dry matter yield and nutrient content of Cauliflower

Particulars	Strip I	Strip II	Strip III	Whole field
Plant				
Fresh Yield ($q\ ha^{-1}$)	50.00-386.67 (211.39)	55.00-486.67 (239.86)	81.67-615.00 (282.57)	50.00-615.00 (244.61)
Dry Matter yield($q\ ha^{-1}$)	9.17-69.72 (35.60)	9.64-71.60 (38.80)	14.48-76.88 (39.79)	9.17-76.88 (38.06)
N Content (%)	1.33-2.66 (1.92)	1.26-2.24 (1.76)	1.47-2.31 (1.86)	1.26-2.66 (1.85)
P Content (%)	0.10-0.13 (0.11)	0.09-0.12 (0.11)	0.09-0.13 (0.11)	0.09-0.13 (0.11)
K Content (%)	0.23-0.56 (0.38)	0.22-0.53 (0.36)	0.27-0.62 (0.41)	0.22-0.62 (0.38)
Curd				
Fresh Yield ($q\ ha^{-1}$)	36.67-260.00 (164.65)	41.67-391.67 (196.60)	55.00-413.33 (215.97)	36.67-413.33 (192.41)
Dry Matter yield ($q\ ha^{-1}$)	5.40-41.23 (19.37)	4.67-35.00 (19.75)	6.88-50.00 (24.06)	4.67-50.00 (21.06)
N Content (%)	1.47-3.22 (2.73)	1.47-3.15 (2.60)	1.33-3.22 (2.69)	1.33-3.22 (2.67)
P Content (%)	0.06-0.10 (0.08)	0.06-0.09 (0.07)	0.06-0.09 (0.08)	0.06-0.10 (0.08)
K Content (%)	0.45-3.84 (1.32)	0.42-2.30 (1.26)	0.45-3.71 (1.22)	0.42-3.84 (1.27)

4.4.3 Nitrogen content

Nitrogen content of plant (%) in experimental field varied from 1.26 to 2.66 with an average 1.85 %. Average N content of plant recorded in order of strip I (1.92 %) was followed by strip III (1.86 %) and strip II (1.76 %). However, N content of curd (%) in experimental field varied from 1.33) to 3.22 with an average 2.67 %. Average N content of curd recorded in order of strip I (2.73 %) was followed by strip III (2.69 %) and strip II (2.60 %).

4.4.4 Phosphorus content

Phosphorus content of plant (%) in experimental field varied from 0.09 to 0.13 with an average 0.11 %. Average P content of plant recorded in each strip (0.11%). However, P content of curd (%) in experimental field varied from 0.06 to 0.10 with an average 0.08 %. Average P content of curd recorded in order of strip I and III (0.08 %) was followed by strip II (0.07 %).

4.4.5 Potassium content

Potassium content of Plant (%) in experimental field varied from 0.22 to 0.62 with an average 0.38 %. Average K content of plant recorded in order of strip III (0.41 %) was followed by strip I (0.38 %) and strip II (0.36 %). However, K content of curd (%) in experimental field varied from 0.42 to 3.84 with an average 1.27 %. Average K content of curd recorded in order of strip I (1.32 %) was followed by strip II (1.26 %) and strip III (1.22%). Similar results were also reported by Gyanendra *et al*. (2002), Brahma *et al*. (2002) Kadam and Sahane (2002) Karthikeyan *et al.* (2009) and Kumar (2016).

4.5 Nutrient uptake by cauliflower

Strip wise and plot wise nitrogen, phosphorus and potassium uptake of cauliflower given in appendix IX while range and average of experimental field is given in table 4.7.

4.5.1 Nitrogen Uptake

Nitrogen uptake (kg ha^{-1}) by the plant in experimental field varied from 16.04 ($N_1P_1K_1OM_0$) to 172.20 ($N_3P_2K_3OM_1$) with an average 71.78 kg ha^{-1}. Average nitrogen uptake recorded in order of strip III (76.29 kg ha^{-1}) followed by strip II (75.28 kg ha^{-1}) and strip I (63.76 kg ha^{-1}). However, nitrogen uptake (kg ha^{-1}) by the curd in experimental field varied from 13.23 ($N_1P_1K_1OM_0$) to 136.50 ($N_3P_3K_3OM_1$) with an average 57.28 kg ha^{-1}. Average nitrogen uptake by the curd recorded in order of strip III (65.88 kg ha^{-1}) followed by strip II (54.79 kg ha^{-1}) and strip I (51.18 kg ha^{-1}). Therefore, total nitrogen uptake (kg ha^{-1}) by the crop in experimental field varied from 29.27 ($N_1P_1K_1OM_0$) to 298.20 ($N_3P_2K_3OM_1$) with an average 129.06 kg ha^{-1}. Average nitrogen uptake recorded in order of strip III (142.17 kg ha^{-1}) followed by strip II (130.07 kg ha^{-1}) and strip I (114.94 kg ha^{-1}).

Addition of N significantly enhanced its uptake over control. The lower uptake of N in control plots may be due to lower yield obtained in these plots. These results validate the finding of Gupta *et al*. (2002) for cauliflower and Sharma and Arya (2001) for cabbage. It was also reported by Singh *et al*. (2005), that an increase in the levels of nutrients increased the uptake of nutrients due to increase in growth attributing characters. Combined application of FYM and NPK dose significantly enhanced the N uptake by cauliflower as compared to NPK alone. Beneficial effect of FYM on N uptake was also reported by Chand *et al*. (2001) and Datt *et al*. (2003).

4.5.2 Phosphorus uptake

Phosphorus uptake (kg ha^{-1}) by the plant in whole field varied from 0.88 ($N_1P_1K_1OM_0$) to 10.15 ($N_3P_2K_3OM_1$) with an average 4.26 kg ha^{-1}. Average phosphorus uptake recorded in order of strip II (4.47 kg ha^{-1}) followed by strip III (4.39 kg ha^{-1}) and strip I (3.94 kg ha^{-1}). However, phosphorus uptake (kg ha^{-1}) by the curd in experimental field varied from 0.38 ($N_0P_0K_0OM_0$) to 4.58 ($N_3P_3K_3OM_1$) with an average 1.62 kg ha^{-1}. Average phosphorus uptake by the curd recorded in order of strip III (1.85 kg ha^{-1}) followed by strip II (1.58 kg ha^{-1}) and strip I (1.44 kg ha^{-1}). Therefore, total phosphorus uptake (kg ha^{-1}) by the crop in experimental field varied from 1.30 ($N_1P_1K_1OM_0$) to 13.45 ($N_3P_2K_3OM_1$) with an average 5.89 kg ha^{-1}. Average phosphorus uptake recorded in order of strip III (6.24 kg ha^{-1}) was followed by strip II (6.04 kg ha^{-1}) and strip I (5.38 kg ha^{-1}). These results corroborate the finding of Bhatt *et al*. (2002), Shreeniwas *et al*. (2000) and Kanwar *et al*. (2002).

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).

Table 4.7: Range and average nutrient uptake of Cauliflower in different strips:

Uptake (kg ha^{-1})	Strip I	Strip II	Strip III	Whole field
Plant				
Nitrogen	16.04-146.42 (63.76)	18.21-137.59 (75.28)	27.38-172.20 (76.29)	16.04-172.20 (71.78)
Phosphorus	0.88-7.97 (3.94)	1.01-8.42 (4.47)	1.78-10.15 (4.39)	0.88-10.15 (4.26)
Potassium	4.17-21.75 (12.27)	3.24-38.55 (14.32)	5.90-31.52 (16.03)	3.24-38.55 (14.20)
Curd				
Nitrogen	13.23-106.78 (51.18)	14.70-98.28 (54.79)	20.69-136.50 (65.88)	13.23-136.50 (57.28)
Phosphorus	0.42-3.40 (1.44)	0.38-2.86 (1.58)	0.51-4.58 (1.85)	0.38-4.58 (1.62)
Potassium	5.13-81.22 (24.37)	3.45-88.83 (25.20)	7.39-72.50 (27.04)	3.45-88.83 (25.54)
Total (Plant +Curd)				
Nitrogen	29.27-232.29 (114.94)	33.24-233.14 (130.07)	48.40-298.20 (142.17)	29.27-298.20 (129.06)
Phosphorus	1.30-11.37 (5.38)	1.39-10.93 (6.04)	2.44-13.45 (6.24)	1.30-13.45 (5.89)
Potassium	10.03-95.31 (36.64)	6.69-108.26 (39.51)	15.09-98.90 (44.09)	6.69-108.26 (39.74)

4.5.3 Potassium uptake

Potassium uptake (kg ha^{-1}) by the plant in whole field varied from 3.24 ($N_0P_0K_0OM_0$) to 38.55 ($N_2P_2K_3OM_1$) with an average 14.20 kg ha^{-1}. Average potassium uptake recorded in order of strip III (16.03 kg ha^{-1}) followed by strip II (14.32 kg ha^{-1}) and strip I (12.27 kg ha^{-1}). However, potassium uptake (kg ha^{-1}) by the curd in experimental field varied from 3.45 ($N_0P_0K_0OM_0$) to 88.83 ($N_2P_2K_0OM_2$) with an average 25.54 kg ha^{-1}. Average potassium uptake by the curd recorded in order of strip III (27.04 kg ha^{-1}) followed by strip II (25.20 kg ha^{-1}) and strip I (24.37 kg ha^{-1}). Therefore, total potassium, uptake (kg ha^{-1}) by the crop in experimental field varied from 6.69 ($N_0P_0K_0OM_0$) to 108.26 ($N_2P_2K_0OM_2$) with an average 39.74 kg ha^{-1}. The order of average potassium uptake recorded in order of strip III (44.09 kg ha^{-1}) > strip II (39.51 kg ha^{-1}) >strip I (36.64 kg ha^{-1}).

Increase in potassium uptake was observed in almost all the integrated nutritional treatments over the sole chemical fertilization. Similar results were reported by Bahadur *et al.* (2004) in cabbage. This might be due to enhancement in K availability by shifting the equilibrium among the forms of K from relatively exchangeable K to soluble K forms in the soil.

Wani *et al*. (2011) observed that uptake of nutrients (NPK) by the cauliflower plants significantly increased with individual and combined application of organic manures and/or inorganic fertilizers over control. There was a consistent increase in nutrient uptake with each increment in NPK fertilizer along with a constant level of FYM (Datt *et al*. 2003).

In general, the amount of nutrient uptake in cauliflower was in the order of phosphorus < potassium< nitrogen. Ranges and averages of uptake of N, P and K with varying levels of FYM for cauliflower are presented in table 4.7. Average nutrient uptake of N, P and K followed the following trend among the strips:

Strip III > Strip II > Strip I.

N, P and K uptake in different strips in relation to FYM observed following trend

$F_2 > F_1 > F_0$

Uptake of N, P and K in control plots with varying levels of FYM showed the following trend (Table 4.8):

Table 4.8: 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	$N_0P_0K_0OM_2$	186.14	7.87	80.99	**35**	181.97	7.40	58.23	**58**	56.80	2.85	40.51
22	$N_0P_0K_0OM_1$	162.37	7.58	57.55	**47**	145.91	6.03	28.70	**72**	55.68	2.77	19.63
7	$N_0P_0K_0OM_0$	35.65	1.85	11.02	**41**	33.24	1.39	6.69	**67**	48.40	2.44	15.09

Data in table 4.8 clearly indicate that in control plots ($N_0P_0K_0OM_0$) uptake of N, P and K increases with increasing level of FYM.

The above trend shows that uptake of nutrients by the crop followed the trend accordance with the yield of the crop and fertility of the strip resulted from the addition of fertilizers in gradient stabilizing experiment. Crop growth and yield is also determined by the presence in the soil of sufficient quantities of nutrients in the available form for their uptake. Nutrient uptake is associated with external medium ion concentration and distribution. Organic manure application increased the soil solution concentration of nutrient ions.

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 increase in microbial population which favors soil environment. In FYM treated plots with chemical fertilizer, uptake of nitrogen increased due to growth promoting hormones, 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) and Rawat *et al.* (2015).

The increase in the uptake of nutrients by vegetable crops with application of NPK along with FYM is obvious as it is considered as a storehouse of plant nutrients, which provide optimum nutrients for crop. These results are consistent with Vachhani and Patel (1991) findings. The increased uptake of nutrients under integrated nutrient management was also due to the addition of nutrient supplies and a proliferous root system developed under balanced plant nutrition, resulting in more water and nutrients absorption and adequate soil physical environment (Grewal and Trehan 1979; Miller *et al.,* 1987). Similar results were also reported by Datt *et al*. (2003) and Wani *et al*. (2011).

4.6 Basic data for the calculation of fertilizer dose for targeted yields of Cauliflower (*Brassica oleracea* L var. botrytis)

Experimental data of curd yield, nutrient uptake, available nutrients in initial soil samples of test crop applied dosed of N, P and K nutrients through fertilizers and farmyard manure were used to compute basic parameters viz., the nutrient requirement for producing one quintal of cauliflower (NR), the per cent 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 cauliflower are presented in table 4.9.

The nutrient requirement for the production of one-quintal cauliflower was 0.70 kg of Nitrogen, 0.03 kg of Phosphorus (P) and 0.23 kg of Potassium (K). Per cent contribution of nitrogen, Phosphorus and Potassium from soil was 33.20, 13.84 and 8.13, respectively. Contribution from fertilizer as percentage of its nutrient content was 75.27, 15.62 and 54.68 without FYM and 82.44, 16.50 and 55.63 with FYM for nitrogen, phosphorus and potassium, respectively. Contribution from farmyard manure as percentage of its nutrient content was 45.62, 2.19 and 13.5 for nitrogen, phosphorus and potassium, respectively. These data are close conformity with results of John, (2004) on cabbage and Thilagam and Natesan (2009) on cauliflower. These results indicate that nutrient contribution from fertilizer sources is greater than that from soil or organic sources. These findings are in agreement with Muralidharudu *et al*. (2007) on potato, turmeric, garlic, pumpkin and ladies finger; Saxena *et al*. (2008) for onion, Chatterjee *et al*. (2010) for potato crop, Muralidharudu *et al*. (2011a) on brinjal, tomato, radish, chilly, carrot and fenugreek, Gogoi and Mishra (2015) on pumpkin, Pande and singh (2016) on cabbage and Arya *et al*. (2017) for tomato.

Table 4.9: Basic data for calculating fertilizer doses with and without FYM for targeted yield of Cauliflower

Sl. No	Particulars	Without FYM			With FYM		
		N	P	K	N	P	K
1.	Nutrient requirement (kg q^{-1})	0.70	0.03	0.23	0.70	0.03	0.23
2.	Contribution of available nutrient from soil (%)	33.20	13.84	8.13	33.20	13.84	8.13
3.	Contribution from applied fertilizer (%)	75.27	15.62	54.68	82.44	16.50	55.63
4.	Nutrients contribution from applied FYM (%)	-	-	-	45.62	2.19	13.50

4.7 Fertilizer adjustment equations:

Soil test based fertilizer recommendation equations for nitrogen, phosphorus and potassium were developed for desired target yields of cauliflower with and without FYM using the basic data (Table 4.9) are presented in table 4.10.

Table 4.10: Soil test based fertilizer adjustment equations for targeted yield of Cauliflower

Without FYM	With FYM
FN = 0.93T - 0.44SN	FN = 0.849T - 0.402SN - 0.553FYM-N
FP_2O_5 = 0.439T - 2.02SP	FP_2O_5 = 0.416T - 1.91SP - 0.291FYM-P
FK_2O = 0.508T - 0.179SK	FK_2O = 0.500T - 0.176SK - 0.293FYM-K

T= yield target (q ha^{-1}), SN= Alkaline $KMnO_4$-N (kg ha^{-1}), SP= Olsen's- P (kg ha^{-1}), SK= Amm. Ac. - K (kg ha^{-1}),FYM-N =Amount of N applied through FYM (kg ha^{-1}), FYM-P= Amount of P applied through FYM (kg ha^{-1}) and FYM-K= 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.

These fertilizer prescription equations can be adopted only under the following situations:

a. The equations should be used for similar and allied soils occurring in a particular agro- eco region.

b. Targets chosen should not be unduly high or low and should be within the range of experimental yields obtained.

c. Prescription equations must be used within the experimental range of soil test values and cannot be extrapolated.

4.8 Nitrogen, phosphorus and potassium doses for different yield targets of cauliflower with and without combination of FYM

Fertilizer adjustment equations for calculating fertilizer doses with and without FYM are given in table 4.10. These equations were developed with the help of basic data. The fertilizer doses of nitrogen, phosphorus and potassium at different soil test value and yield targets are given in table 4.11, (without use of FYM), table 4.12, (with 10 t FYM) and table 4.13 (with 20 t FYM).

4.8.1 Without using FYM

Nutrient doses for different yield targets were calculated with the help of targeted yield equations. Ready reckoners of N, P_2O_5 and K_2O doses are given in table 4.11 and also presenting in the form of bar diagram in fig 4.1 to 4.3.

Since curd yield in the present investigation varied from 36.67 to 413.33 q ha^{-1} with an average of 192.41 q ha^{-1}. Therefore, 200, 250 and 300 q ha^{-1} yield targets were selected for nutrient doses calculations. The soil test value of nitrogen ranged from 137.98 to 200.98 kg ha^{-1}, phosphorus ranged from 15.01 to 22.12 kg ha^{-1} and potassium ranged from 99.68 to 365.12 kg ha^{-1}. Therefore, soil test values considered within these ranges to calculate nutrient doses for targeted yield of cauliflower.

Data in table 4.11 indicated that nitrogen doses were 142, 188 and 235 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 100 kg ha^{-1} of alkaline $KMnO_4$-N. While these values were 120, 166 and 213 at soil test value150 kg ha^{-1} of alkaline $KMnO_4$-N on the same yield targets. Fertilizer Phosphorus doses were 68, 90 and 112 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 10 kg ha^{-1} of Olsen's Phosphorus. While these values were 48, 69 and 91 at soil test value 20 kg ha^{-1} of Olsen's Phosphorus on the same yield target.

Potassium fertilizer doses were 83, 108 and 134 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 100 kg ha^{-1} NH_4OAC-K. While these values were 48, 73 and 98 at soil test value 300 kg ha^{-1} NH_4OAC-K on the same yield target. It means fertilizer doses increases with increasing yield target, however it decreases with increasing soil test value. Similar trend was also reported by Santhi *et al*. (2002) for onion on Inceptisols, Rawat *et al*. (2015) for Okra, Pande *et al*. (2016) for cabbage and Arya *et al*. (2017) for tomato on Mollisols.

Table 4.11: Nitrogen, phosphorus and potassium doses for different yield targets of Cauliflower without using FYM

Soil test value (kg ha^{-1})	Yield target of cauliflower (q ha^{-1})		
	200	**250**	**300**
Alkaline $KMnO_4$- N	**Fertilizer – N (kg ha^{-1})**		
100	142	188	235
125	131	177	224
150	120	166	213
175	109	155	202
Olsen's-P	**Fertilizer – P_2O_5 (kg ha^{-1})**		
10	68	90	112
15	58	80	102
20	48	69	91
25	37	59	81
Amm. Ac.-K	**Fertilizer – K_2O (kg ha^{-1})**		
100	83	108	134
200	65	91	116
300	48	73	98
400	30	55	80

FN = 0.93T - 0.44SN

FP_2O_5 = 0.439T - 2.02SP

FK_2O = 0.508T - 0.179SK

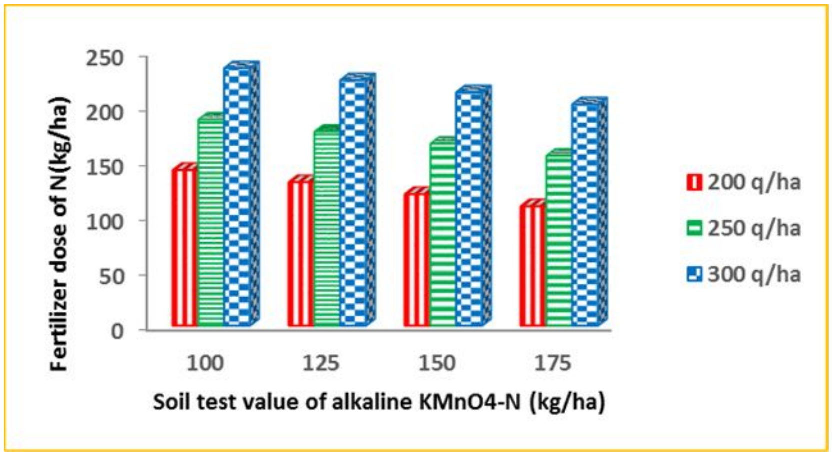


Fig 4.1: Nitrogen doses of Cauliflower at different soil test values and yield targets

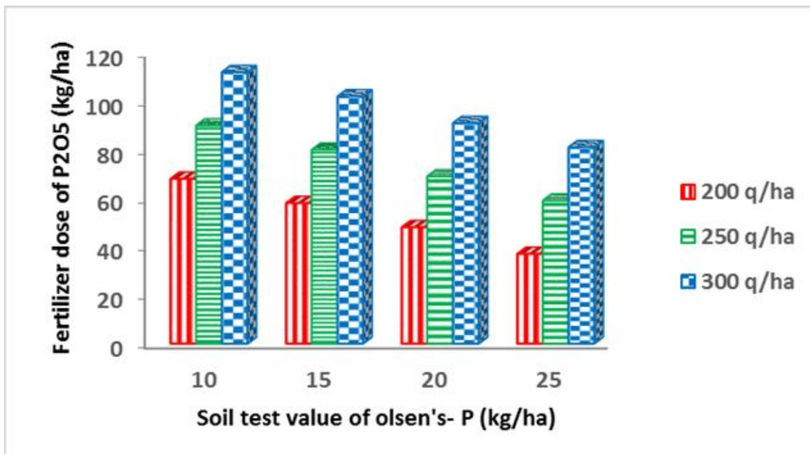


Fig 4.2: Phosphorus doses of Cauliflower at different soil test values and yield targets

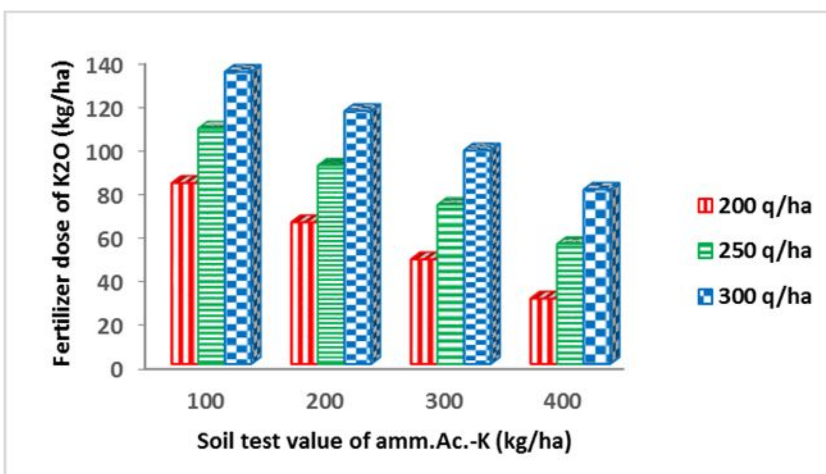


Fig 4.3: Potassium doses of Cauliflower at different soil test values and yield targets

4.8.2 Fertilizer doses with conjoint use of FYM

4.8.2.1 Fertilizer doses with 10 t FYM ha^{-1}

Nutrient requirements for different yield targets were calculated with the help of targeted yield equations. The ready reckoners of Nitrogen, phosphorus and potassium requirements are given in table 4.12 and also presenting in the form of bar diagram i.e. fig (4.4 to 4.6).

Data in table 4.12 indicated that nitrogen doses were 115, 158 and 200 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 100 kg ha^{-1} of alkaline $KMnO_4$- N. While these values were 95, 137 and 180 at soil test value150 kg ha^{-1} of alkaline $KMnO_4$-N on the same yield target. Fertilizer Phosphorus doses were 61, 81 and 102 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 10 kg ha^{-1} of Olsen's Phosphorus. While these value were 41, 62 and 83 at soil test value 20 kg ha^{-1} of Olsen's Phosphorus on the same yield target.

Potassium fertilizer doses were 74, 98 and 123 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 100 kg ha^{-1} NH_4OAC-K. While these values were 39, 63 and 88 at soil test value 300 kg ha^{-1} NH_4OAC-K on the same yield target. It means fertilizer doses increases with increasing yield target, however it decreases with increasing soil test value. It is also clear from the table 4.12 that fertilizer doses decreased at all the soil test values and yield targets by used of FYM with fertilizer as compared with table 4.11. Similar trend was also reported by Santhi *et al*. (2002) for onion on Inceptisols, Rawat *et al*. (2015) for Okra, Pande *et al*. (2016) for cabbage and Arya *et al*. (2017) for tomato on Mollisols.

Table 4.12: Nitrogen, phosphorus and potassium doses for different yield targets of Cauliflower with10 t FYM ha^{-1}

Soil Test Values ($kg\ ha^{-1}$)	Yield Target of cauliflower ($q\ ha^{-1}$)		
	200	**250**	**300**
Alkaline $KMnO_4$- N	**Fertilizer – N ($kg\ ha^{-1}$)**		
100	115	158	200
125	105	148	190
150	95	137	180
175	85	127	170
Olsen's P	**Fertilizer – P_2O_5 ($kg\ ha^{-1}$)**		
10	61	81	102
15	51	72	93
20	41	62	83
25	32	53	73
Amm.Ac.-K	**Fertilizer – K_2O ($kg\ ha^{-1}$)**		
100	74	98	123
200	56	81	106
300	39	63	88
400	21	46	71

FN = 0.849T - 0.402SN - 0.553FYM-N

FP_2O_5 = 0.416T - 1.91SP - 0.291FYM-P

FK_2O= 0.500T - 0.176SK - 0.293FYM-K

Note: In present study FYM contain 0.57%N, 0.32%P_2O_5 and 0.58%K_2O

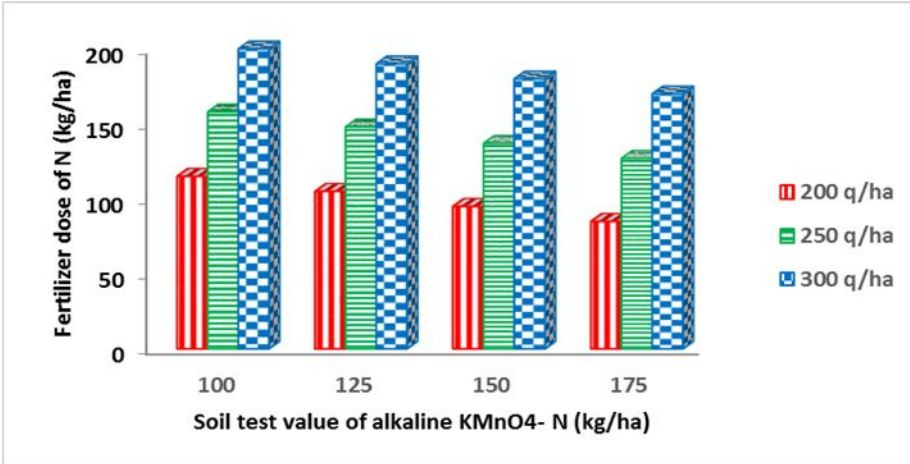


Fig. 4.4: Nitrogen doses of Cauliflower at different soil test values and yield targets with 10 t FYM

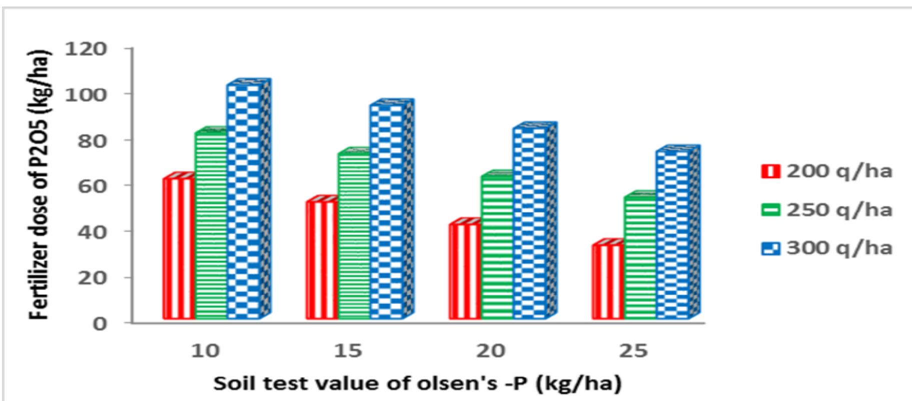


Fig. 4.5: Phosphorus doses of Cauliflower at different soil test values and yield targets with 10 t FYM

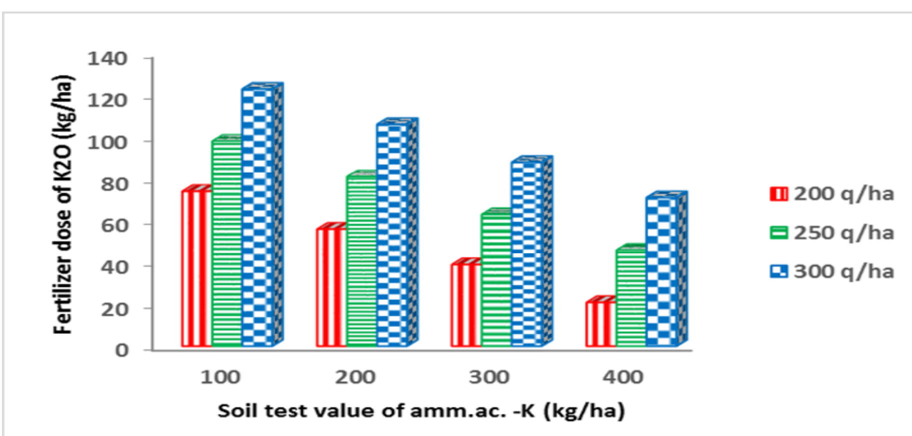


Fig. 4.6: Potassium doses of Cauliflower at different soil test values and yield targets with 10 t FYM

4.8.2.2 Fertilizer with 20 t FYM ha^{-1}

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 doses are given in table 4.13 and also presenting in the form of bar diagram in fig. (4.7 to 4.9).

Data in table 4.13 indicated that nitrogen doses were 101, 143 and 186 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 100 kg ha^{-1} of alkaline $KMnO_4$- N. While these values were 81, 123 and 166 at soil test value150 kg ha^{-1} of alkaline $KMnO_4$-N on the same yield target. Fertilizer Phosphorus doses were 57, 78 and 99 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 10 kg ha^{-1} of Olsen's Phosphorus. While these value were 38, 59 and 79 at soil test value 20 kg ha^{-1} of Olsen's Phosphorus on the same yield target.

Potassium fertilizer doses were 65, 90 and 115 at 200, 250 and 300 q ha^{-1} yield targets, respectively at soil test value 100 kg ha^{-1} NH_4OAC-K. While these values were 31, 55 and 80 at soil test value 300 kg ha^{-1} NH_4OAC-K on the same yield target. Similar trend was also reported by Santhi *et al*. (2002) for onion on Inceptisols, Rawat *et al*. (2015) for Okra, Pande *et al*. (2016) for cabbage and Arya *et al*. (2017) for tomato on Mollisols.

Table 4.13: Nitrogen, phosphorus and potassium doses for different yield targets of Cauliflower with 20 t FYM ha^{-1}

Soil Test Values (kg ha^{-1})	Yield Target of cauliflower (q ha^{-1})		
	200	**250**	**300**
Alkaline $KMnO_4$- N	**Fertilizer – N (kg ha^{-1})**		
100	101	143	186
125	91	133	176
150	81	123	166
175	71	113	155
Olsen's P	**Fertilizer – P_2O_5 (kg ha^{-1})**		
10	57	78	99
15	47	68	89
20	38	59	79
25	28	49	70
Amm.Ac.-K	**Fertilizer – K_2O (kg ha^{-1})**		
100	65	90	115
200	48	73	98
300	31	55	80
400	13	38	63

Note: In present study FYM contain 0.57%N, 0.32%P_2O_5 and 0.58%K_2O

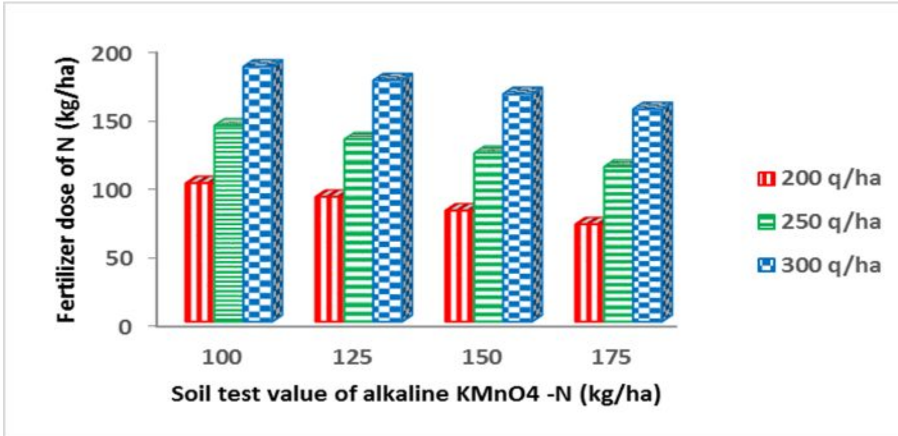


Fig. 4.7: Nitrogen doses of Cauliflower at different soil test values and yield targets with 20 t FYM

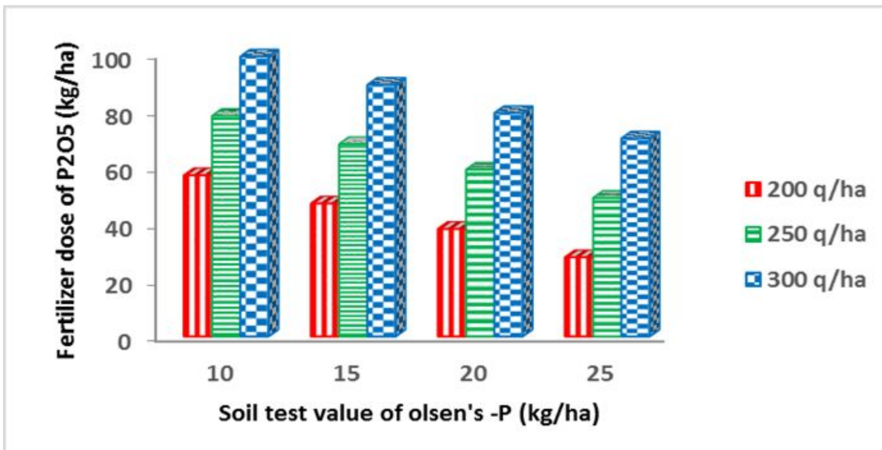


Fig. 4.8: Phosphorus doses of Cauliflower at different soil test values and yield targets with 20 t FYM

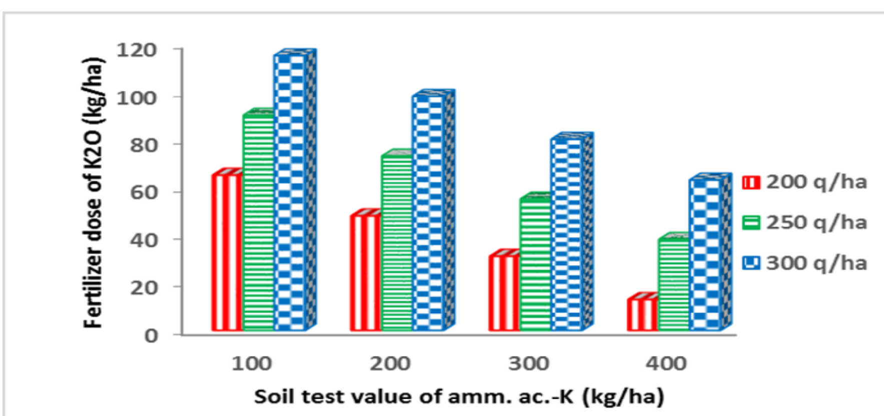


Fig. 4.9: Potassium doses of Cauliflower at different soil test values and yield targets with 20 t FYM

Thus data presented in table no 4.11, 4.12 and 4.13 clearly indicated that N, P and K doses increases with increasing the yield target of cauliflower. However, it decreases with increasing soil test value. Similar finding were reported by Thilagam and Natesan (2009) and Regar and Singh (2014). The application of chemical fertilizer with FYM in integrated manner has beneficial effect by several ways in terms of increasing soil fertility and improving physical condition of soil and higher fertilizer use efficiencies. As evident from table 4.12 and 4.13 that FYM has contributed as per dose of FYM and composition of FYM used. Therefore, its used is suggested for optimum yield and saving of chemical fertilizer. Moreover it also maintain soil physical and biological properties and sustained soil fertility. Lower yield target may be considered for a poor resource farmers to obtain maximum profit per unit cost spent on fertilizer, whereas, a higher yield target for a resourceful farmers who are interested for maximum potential production per unit area. Hence, for maintaining soil fertility, it is necessary to choose appropriate yield targets and fertilizer use practices that achieve the twin objectives of high yield and maintenance of soil fertility. Thus the target yield approach of fertilizer recommendation ensures nutrient balancing to suit the situations involving different yield goals, soil fertility and resources of the farmer **(**Dev *et al*. 1985). Several workers have used this approach of fertilizer prescription Patil, (1985), Acharya *et al*. (1988), Arya, (2003), Sati *et al*. (2010), Gautam *et al*. (2013), Rawat *et al*. (2015) and Pande *et al*. (2016).

4.9 Fertilizer equivalence of FYM for cauliflower

Fertilizer equivalence of FYM in the present investigation was calculated by taking differences in fertilizer doses of nutrient in question with and without FYM at a given soil test value and target yield. The average saving of fertilizer by 10.0 tonnes FYM were 29.34 kg ha^{-1} N, 7.58 kg ha^{-1} P_2O_5 and 9.53 kg ha^{-1} K_2O along with the experimental soil test value and yield targets (Table 4.14).

Table 4.14: Fertilizer equivalence of FYM (10 t ha^{-1}) under different yield targets and soil test value of Cauliflower.

Soil test values (kg/ha)	Yield target (q ha^{-1})				Fertilizer equivalence of one t FYM (kg ha^{-1})
	200	**250**	**300**	**Average**	
Alkaline $KMnO_4$ N	**N fertilizer equivalence (kg ha^{-1})**				
100	26.73	30.78	34.82	**30.78**	**3.08**
125	25.77	29.82	33.86	**29.82**	**2.98**
150	24.81	28.86	32.90	**28.86**	**2.89**
175	23.86	27.90	31.95	**27.90**	**2.79**
Average	**25.29**	**29.34**	**33.38**	**29.34**	**2.93**
Olsen's P	**P_2O_5 fertilizer equivalence (kg ha^{-1})**				
10	7.22	8.38	9.54	**8.38**	**0.83**
15	6.69	7.85	9.01	**7.85**	**0.78**
20	6.15	7.31	8.47	**7.31**	**0.73**
25	5.62	6.78	7.94	**6.78**	**0.67**
Average	**6.42**	**7.58**	**8.74**	**7.58**	**0.75**
Amm. Ac.-K	**K_2O fertilizer equivalence (kg ha^{-1})**				
100	9.55	9.98	10.41	**9.98**	**0.99**
200	9.25	9.68	10.11	**9.68**	**0.96**
300	8.95	9.38	9.81	**9.38**	**0.93**
400	8.65	9.08	9.51	**9.08**	**0.90**
Average	**9.10**	**9.53**	**0.95**	**9.53**	**0.95**

Data presented in table 4.14 and 4.15 are clearly show 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 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. Average saving of N, P_2O_5 and K_2O were 29.34, 7.58 and 9.53 kg ha^{-1}, respectively by use of 10 tonnes FYM with chemical fertilizer. Further by taking 20 tonnes of FYM the average saving of fertilizer were 43.73 kg ha^{-1} N, 11.22 kg ha^{-1} P_2O_5 and 17.68 kg ha^{-1} K_2O along within the experimental soil test values and yield targets. From these value it is clear that saving of N, P_2O_5 and K_2O from FYM was more at 20 tonnes FYM as compared to 10 tonnes FYM. The values of per cent saving of N, P_2O_5 and K_2O were 0.25, 0.066 and 0.092 respectively by addition of FYM (Table 4.15). Since applied FYM containing 0.57% N, 0.32% P and 0.58% K. Therefore, contribution of FYM was about 50% for N and 20% for P & K to cauliflower. The probable reason low mineralization potential of FYM during winter season when crop was grown. Similar results were also reported by Santhi *et al*. (2002) for onion on Inceptisols and Pande *et al*. (2016) for cabbage in Mollisols.

Thilagam and Natesan (2009) also reported that application of FYM at 15 t ha^{-1} together with chemical fertilizer resulted in a saving of 35, 10.9 and 23.3 kg ha^{-1} N, P and K, respectively, in cauliflower. 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. Similar result were 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 2.93, 0.75 and 0.95 kg ha^{-1} respectively. Similar type of findings were also reported by Santhi *et al*. (2011) and Jadhav *et al*. (2013) in beet root and tomato crop respectively.

Table 4.15: Fertilizer equivalence of FYM (20 t ha^{-1}) under different yield targets and fertility level of cauliflower.

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})
	Yield target (q ha^{-1})					
	15	**20**	**25**	**Average**		
Alkaline $KMnO_4$ N	**N fertilizer equivalence (kg ha^{-1})**					
100	41.12	45.17	49.21	**45.17**	2.26	2.67
125	40.16	44.21	48.25	**44.21**	2.21	2.60
150	39.20	43.25	47.29	**43.25**	2.16	2.53
175	38.24	42.29	46.33	**42.29**	2.11	2.45
Average	**39.68**	**43.73**	**47.77**	**43.73**	2.19	2.56
Olsen's P	**P_2O_5 fertilizer equivalence (kg ha^{-1})**					
10	10.86	12.02	13.18	**12.02**	0.60	0.72
15	10.33	11.49	12.65	**11.49**	0.57	0.68
20	9.80	10.96	12.12	**10.96**	0.55	0.64
25	9.26	10.42	11.58	**10.42**	0.52	0.60
Average	**10.06**	**11.22**	**12.38**	**11.22**	0.56	0.66
Amm. Ac.-K	**K_2O fertilizer equivalence (kg ha^{-1})**					
100	17.70	18.13	18.56	**18.13**	0.91	0.95
200	17.40	17.83	18.26	**17.83**	0.89	0.93
300	17.10	17.53	17.96	**17.53**	0.88	0.91
400	16.80	17.23	17.66	**17.23**	0.86	0.88
Average	**17.25**	**17.68**	**18.11**	**17.68**	0.88	0.92

4.10 Curd yield response

Response of a particular applied nutrient at middle doses of other nutrients had been worked out. Curd yield (q ha^{-1}) at different doses of nitrogen and FYM with middle dose of P and K were taken and then averaged. Similarly response of P and K were also worked out. Response of N, P and K are presented in table 4.16 and also shown in figure 4.10. A photographic view of response of different doses of N, P and K on cauliflower growth is presented in plate 7, 8 and 9, respectively.

4.10.1 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 100.00, 142.22 and 80.37 kg kg^{-1}, respectively. Average response 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 50 q ha^{-1}. So the increment was 100.00 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 92.22 q ha^{-1}. So the Increment was 184.45 kg kg^{-1} of over successive dose of N. Decreasing of yield was 21.67 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. Similar type of findings were also reported by Raut and Kedar (1981), Sharma and Arora (1987), Singh and Sharma (1990) and Bashyal (2011) in cauliflower and Ingle and Jadhao (1997) in cabbage.

4.10.2 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 74.45, 40.56 and 20.37 kg kg^{-1}, respectively. The yield was increased up to 150 kg but maximum increase was at 100 kg P_2O_5 ha^{-1}. 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 37.22 q ha^{-1}. So the increment was 74.45 kg kg^{-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 3.33 q ha^{-1}. So the Increment was 6.66 kg kg^{-1} yield per kg of over successive dose of P_2O_5. Decreasing of yield was 10.00 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. Similar type of findings were also reported by Khurana *et al*. (1990) and Kunwar and Pandey (1994) in cauliflower and Samant *et al*. (1993) in cabbage.

N_0

N_{50}

N_{100}

N_{150}

Plate 7: Response of different doses of nitrogen on growth of cauliflower

Plate 8: Response of different doses of phosphorus on growth of cauliflower


K_0



K_{50}



K_{100}

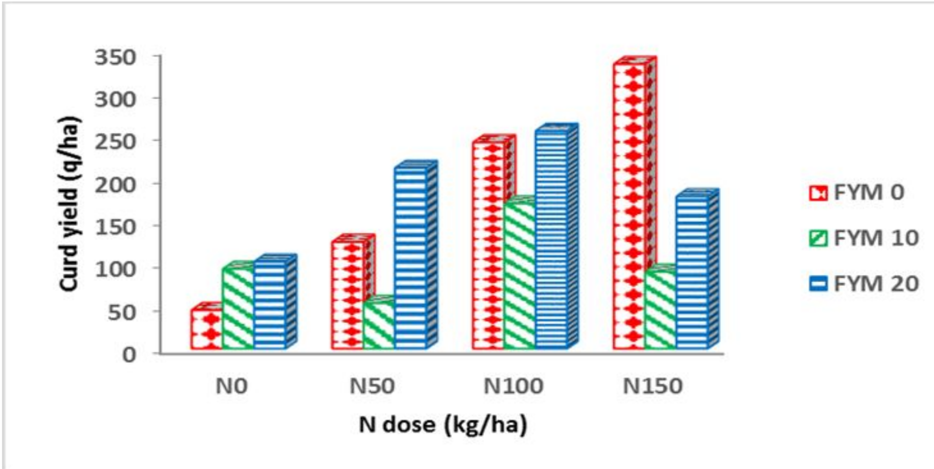


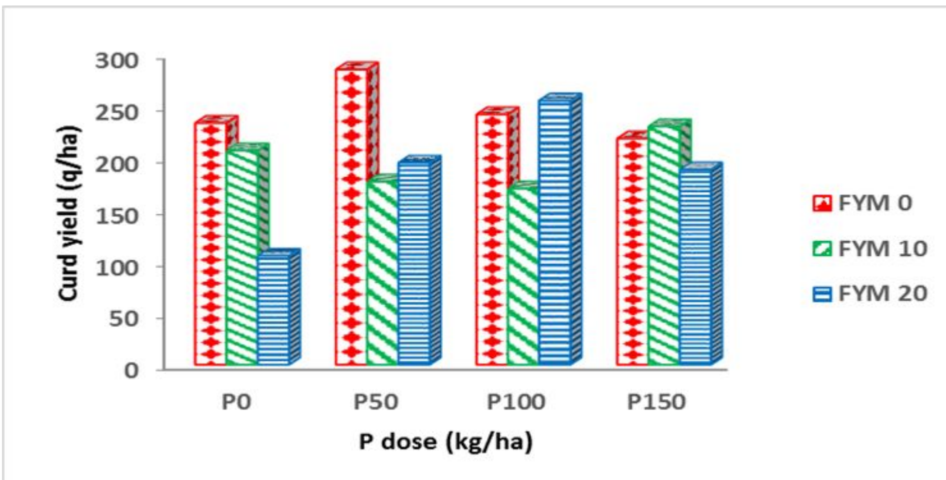
K_{150}


Plate 9: Response of different doses of potassium on growth of cauliflower

Table 4.16: Response of Nitrogen, Phosphorus and Potassium at different level of FYM on curd yield of Cauliflower.

Fertilizer dose kg/ha	Curd yield (q/ha)				Response kg per kg of nutrient	
	FYM 0	FYM 10	FYM 20	Average	Over N 0	Over successive dose
N0	45.00	93.33	101.67	**80.00**	0	0
N50	125.00	53.33	211.67	**130.00**	100.00	100.00
N100	241.67	170.00	255.00	**222.22**	142.22	184.45
N150	333.33	90.00	178.33	**200.55**	80.37	-43.34
Average	**186.25**	**101.67**	**186.67**			
P0	233.33	206.67	105.00	**181.67**	0	0
P50	285.00	176.67	195.00	**218.89**	74.45	74.45
P100	241.67	170.00	255.00	**222.22**	40.56	6.66
P150	218.33	230.00	188.33	**212.22**	20.37	-20.00
Average	**244.58**	**195.83**	**185.83**			
K0	228.33	211.67	205.00	**215.00**	0	0
K50	196.67	241.67	216.67	**218.33**	6.67	6.67
K100	241.67	170.00	255.00	**222.22**	7.22	7.78
K150	241.67	236.67	178.33	**218.89**	2.59	-6.67
Average	**227.09**	**215.00**	**213.75**			





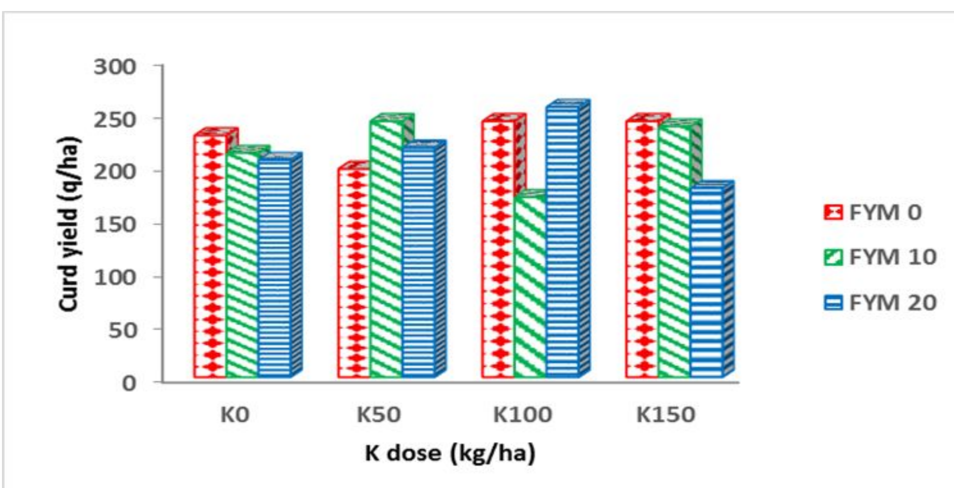


Fig. 4.10: Response of Nitrogen, phosphorus and potassium at different level of FYM on Curd yield of Cauliflower.

4.10.3 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 6.67, 7.22 and 2.59 kg kg^{-1}, respectively. It was increasing with application of potassium however maximum increase was at 100 kg K_2O ha^{-1}. 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 3.33 q ha^{-1}. So the increment was 6.67 kg yield per kg of potassium 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 3.89 q ha^{-1}. So the Increment was 7.78 kg yield per kg of over successive dose of K_2O. Decreasing of yield was 3.33 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. Similar type of findings were also reported by yong *et al*. (1994) in broccoli, Baghel and Singh (1995) in cauliflower and Tarata *et al*. (1995) in cabbage.

4.11 Multiple regressions for different functions

Ramamoorthy *et al*. (1967) suggested a realistic and more practical approach for prescribing fertilizer doses based on soil test values for attaining either maximum yield or maximum profit, based on the creation of artificial fertility gradients (Inductive approach). In this approach, Ramamoorthy (1974) established a significant relationship between soil test values, fertilizer doses and crop yield by fitting multiple quadratic regression with linear soil and fertilizer nutrient terms and soil and fertilizer nutrient interaction terms. By conducting gradient experiment, a range of soil test values are created in one and the same field for minimizing interference of other factors affecting crop yield and relate them through multiple regression with curvilinear response function.

The multiple regression equation represents a relationship between curd yield as dependent variable and soil test values, fertilizer doses, interaction between soil test values, fertilizer doses and between fertilizer nutrients as well as FYM as independent variables through a multiple quadratic type regression equation.

Specific location recommendations for fertilizers are possible for soils with varying fertility, farmers' resource conditions and targeted yield levels for similar soil classes and environment (Ahmed *et al*., 2002). For these equations, the soil test values used were alkaline $KMnO_4$-N Olsen-P and normal ammonium acetate-K kg ha^{-1} as the recommended soil test method for Uttarakhand Mollisol (Sachan *et al*., 1982). Dose of fertilizer used as nutrients 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:

Yield = - 81.0978 + 0.4808 * SN + 6.5874 * SP - 0.1156 * SK + 2.9951 * FN + 2.7889 * FP - 1.9370 * FK + 0.0016 * FN^2 - 0.0365 * FP^2 + 0.0190 * FK^2 - 0.0107 * FNSN - 0.0927 * FPSP + 0.0028 * FKSK - 33.1806 * ON - 18.8769 * OP + 38.4936 * OK………………… **R^2= 0.8315 ****

Where,

Y = Curd 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, Alkaline $KMnO_4$-N as an index (kg ha^{-1})

SP = Soil test value for phosphorus by Olsen's-P as an index (kg ha^{-1})

SK = Soil test value for potassium, Neutral normal NH_4OAc-K as an index (kg ha^{-1}).

ON = Nitrogen through FYM (kg ha^{-1})

OP = Phosphorus through FYM (kg ha^{-1})

OK = Potassium through FYM (kg ha^{-1})

** Significant at 1 % level.

* Significant at 5 % level.

In this model, each fertilizer nutrient has three terms- viz. linear, quadratic and interaction term with soil nutrients as shown above. These terms occurs either with + or – sign. There are eight possible response types out of them, the +-- response type alone follows the law of diminishing returns and provides a basis for optimization of fertilizer doses.

The model where the soil test, levels of fertilizer nutrient, FYM and yield data of cauliflower crop was fitted had high and significant coefficient of predictability (0.8315). Sharma *et al*. (2005) found highly significant R^2 values of 0.88 and 0.91 for multiple regression equations on *Haplustept* in broccoli. Types of responses identified in the present investigation were: (++-), (+--) and (-++) for N, P and K, respectively, and presented in table 4.17.

Table 4.17: Response type obtained by regression equation

R^2 value	Nutrient	Response Type
0.8315**	Nitrogen	++-
	Phosphorus	+--
	Potassium	-++

The response type obtained for nitrogen was ++- shows that at lower soil test values, there is a continuous increase in the response with increasing fertilizer dose but this response decreases with increasing soil test values upto a limit in the later when response type changes to a different pattern in which there is depression in yield upto a certain level in the fertilizer dose above which there will be a positive response to further increase in fertilizer dose.

Phosphorus 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 terms.

Potassium showed the response type '- + +' which shows that at lower soil test values, there is a decrease in yield with increasing fertilizer dose up to a limit at which a very minimum yield occurs and above which an increase in yield with increasing fertilizer dose sets in.

4.12 Post harvest Soil test values and apparent nutrient balance

Treatment and strip wise post-harvest soil values of available N, P and K are given in appendix XI and strip wise range and average of post-harvest soil test values for nitrogen, phosphorus and potassium are given in table 4.18.

Table 4.18: Range and average of the soil test values after harvest in different strips

Sl. No.	Particulars	Strip I	Strip II	Strip III	Whole field
1.	Organic carbon (%)	0.48-0.87 (0.66)	0.48-0.90 (0.72)	0.48-1.14 (0.75)	0.48-1.14 (0.71)
2.	Available nitrogen (kg N ha^{-1})	148.83-224.09 (176.43)	146.43-192.79 (174.35)	162.68-197.59 (178.85)	146.43-224.09 (176.54)
3.	Available phosphorus (kg P ha^{-1})	8.11-16.74 (12.88)	8.11-14.43 (10.76)	11.66-15.92 (13.63)	8.11-16.74 (12.42)
4.	Available potassium (kg K ha^{-1})	244.89-330.01 (293.14)	90.33-331.13 (253.97)	94.81-352.14 (264.07)	90.33-352.14 (270.39)

Organic carbon content of experimental field ranged from 0.48 to 1.14 per cent with an average of 0.71 per cent. Organic carbon content in strip I ranged from 0.48 to 0.87 per cent with an average of 0.66 per cent. While in strip II the organic carbon content ranged from 0.48 to 0.90 per cent with an average of 0.72 per cent. Range of organic carbon content in strip III varied from 0.48 to 1.14 per cent with an average of 0.75 per cent. The average value of organic carbon was highest in strip III followed by strip II and strip I, respectively.

Available Nitrogen extracted by alkaline- $KMnO_4$ method of the experimental field varied from 146.43 to 224.09 kg N ha^{-1} with an average 176.54 kg N ha^{-1}. Strip wise variation ranged from 148.83 to 224.09 with an average of 176.43 in strip I, 146.43 to 192.79 kg N ha^{-1} with an average of 174.35 kg N ha^{-1} in strip II and 162.68 to 197.59 with an average of 178.85 kg N ha^{-1} in strip III. The average value of Nitrogen was highest in strip III followed by strip I and strip II, respectively.

Available Phosphorus content of the entire experimental field ranged from 8.11 to 16.74 kg P ha^{-1} with an average value of 12.42 kg P ha^{-1}. Strip wise range varied from 8.11 to 16.74 with an average value of 12.88 kg P ha^{-1} in strip I, 8.11 to 14.43 with an average value of 10.76 kg P ha^{-1} in strip II and 11.66 to 15.92 kg P ha^{-1} with an average value of 13.63 kg P ha^{-1} in strip III. The average value of Phosphorus was highest in strip III followed by strip I and strip II, respectively.

Available Potassium extracted by neutral normal NH_4OAc method ranged from 90.33 to 352.14 kg K ha^{-1} with an average of 270.39 kg K ha^{-1} for the entire experimental field. Values ranged from 244.89 to 330.01 in strip I with an average value of 293.14 kg K ha^{-1}, 90.33 to 331.13 in strip II with an average value of 253.97 kg K ha^{-1} and 94.81 to 352.14 kg ha^{-1} in strip III with an average value of 264.07 kg K ha^{-1}. The average value of Potassium was highest in strip I followed by strip III and strip II, respectively.

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

4.12.1 Apparent nutrient balance

Apparent nutrient balance is calculated by initial soil test value and post-harvest soil test value after harvesting of cauliflower. This approach provides the basis of optimum resources utilization and balance crop nutrient management.

Organic carbon content of experimental field was 0.89% which decreases to 0.71% in post-harvest soil test value. Average organic carbon content in strip I changed from 0.82 to 0.66 per cent. While in strip II the average organic carbon content changed from 0.91 to 0.72 per cent and average organic carbon content in strip III changed from 0.94 to 0.75 per cent. Over all organic carbon content slightly decrease from initial to post soil test value (Table 4.19).

Nitrogen of experimental field changed from 160.98 to 176.54 kg N ha^{-1} of initial to post harvest soil test value respectively. Average Nitrogen in strip I changed from 160.46 to 176.43 kg N ha^{-1}. While in strip II the Nitrogen changed from 160.98 to 174.35 and average Nitrogen in strip III changed from 161.50 to 178.85 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 increase in available nitrogen 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 nitrogen to inorganic form. Maragatham and Chellumutthu (2000) reported that, the post-harvest soil of sunflower crop showed a significant build-up of soil nitrogen compared to the initial level ranging from 165 to 228 kg ha-[1] due to addition of FYM. The favorable soil conditions under FYM addition might have helped in the mineralization of soil nitrogen leading to build up of higher available nitrogen. Similar results were also found by Yanthan *et al*. (2010).

Phosphorus of experimental field changed from 18.47 to 12.42 kg P ha^{-1} of initial to postharvest soil test value respectively. Average Phosphorus in strip I changed from 17.66 to 12.88 kg P ha^{-1}. While in strip II the Phosphorus changed from 17.97 to 10.76 and average Phosphorus in strip III changed from 19.80 to 13.63 kg P ha^{-1} may be due to high P fixation capacity of particular site characteristics.

Potassium of experimental field changed from 281.81 to 270.39 kg K ha^{-1} of initial to postharvest soil test value. Average Potassium in strip I changed from 265.63 to 293.14 kg K ha^{-1}. While in strip II the Potassium changed from 277.34 to 253.97 and average Potassium in strip III changed from 302.49 to 264.07 kg K ha^{-1}. In case of phosphorous and potassium, they were decreased from initial to post harvest soil test value because applied fertilizer is fully utilized by crops and some amount of phosphorous and potassium fix in the soil due to high phosphorous and potassium fixation capacity of experimental Soil but in case of nitrogen, it was slightly increased from initial to post harvest soil test value. Applied FYM may contribute to available N, P and K content to the soil. The data on alkaline $KMnO_4$-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 Singh (2001) and Santhi *et al*. (2002) also supported the results recorded in the present study.

Table 4.19: Apparent nutrient balance during experiment

Sl. No.	Particulars	Strip I		Strip II		Strip III		Whole field	
		Initial	Post	Initial	Post	Initial	Post	Initial	Post
1	Organic carbon (%)	0.53-1.08 (0.82)	0.48-0.87 (0.66)	0.48-1.32 (0.91)	0.48-0.90 (0.72)	0.60-1.35 (0.94)	0.48-1.14 (0.75)	0.48-1.35 (0.89)	0.48-1.14 (0.71)
2	Available nitrogen (kg N ha^{-1})	137.98-175.62 (160.46)	148.83-224.09 (176.43)	137.98-200.70 (160.98)	146.43-192.79 (174.35)	150.53-175.62 (161.50)	162.68-197.59 (178.85)	137.98-200.98 (160.98)	146.43-224.09 (176.54)
3	Available phosphorus (kg P ha^{-1})	15.01-21.33 (17.66)	8.11-16.74 (12.88)	15.01-20.93 (17.97)	8.11-14.43 (10.76)	17.77-22.12 (19.80)	11.66-15.92 (13.63)	15.01-22.12 (18.47)	8.11-16.74 (12.42)
4	Available potassium (kg K ha^{-1})	254.24-339.36 (302.49)	244.89-330.01 (293.14)	99.68-342.72 (265.63)	90.33-331.13 (253.97)	104.16-365.12 (277.34)	94.81-352.14 (264.07)	99.68-365.12 (281.81)	90.33-352.14 (270.39)

4.13 Prediction of post-harvest Soil test value

After a crop is harvested, nutrient availability in the soil is greatly influenced by the initial soil nutrient status, the amount of fertilizer nutrients added, and the nature of the crop risen. To apply soil test based fertilizer recommendations, the soils are to be tested after each crop, which is not practicable. Therefore, it has become necessary to predict the soil test values after the harvest of the crop to save time and cost of soil testing. It can be done by the development of prediction equations. This provides the way for giving the fertilizer recommendations for whole cropping sequence based on initial soil test values. This is very useful because the soil of farmer's field under intensive cultivation cannot be tested for each crop for practical reasons. 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 (Table 4.20)

Table 4.20: Prediction equation of postharvest soil nutrient based on yield and uptake of Cauliflower

Based on yield	**Prediction equation**	**R^2**
1.	PHN = - 13.0369 + 0.9986 * SN - 0.0036 * FN - 0.0014 * Y	0.9821**
2.	PHP = - 6.2497 + 1.0479 * SP + 0.0079 * FP - 0.0045 * Y	0.7224**
3.	PHK = - 12.7897 + 1.0059 * SK + 0.0086 * FK - 0.0033 * Y	0.9979**
Based on uptake	**Prediction equation**	**R^2**
1.	PHN = - 13.3654 + 0.9997 * SN - 0.0076 * FN + 0.0018 * UN	0.9821**
2.	PHP = - 5.6666 + 0.9812 * SP - 0.0093 * FP + 0.0283 * UP	0.6974**
3.	PHK = - 13.3833 + 1.0069 * SK + 0.0037 * FK - 0.0034 * UK	0.9978**

** 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= curd yield.

The results showed that when curd yield was used for predicting the extent of predictability for available nitrogen, phosphorus and potassium R^2 values were 0.98, 0.72 and 0.99, respectively, while, when uptake by cauliflower was considered the values were 0.98, 0.69 and 0.99 for nitrogen, phosphorus and potassium respectively. Based on above prediction equations strip wise observed predicted post-harvest soil test value ($KMnO_4$-N, Olsen-P and NH_4OAc-K kg ha^{-1}) can be calculated. This suggests that such regression equations can be used with confidence for the prediction of available N, P and K after cauliflower for optimum level of targeted yield based fertilizer recommendation for succeeding crops.

Singh *et al.* (2015) reported the relationship amongst the post-harvest soil test values, fertilizer applied doses, initial soil test values and grain yield from treated plots for *kharif* maize crop. Appreciably large R^2 value were obtained from the equation. This suggests that regression equation can be used with confidence for the prediction of available N, P, and K after maize for making soil test based fertilizer recommendation for succeeding crops. Similar results were also found by Subba Rao *et al.* (2009), Milap-chand *et al.* (2006) and Verma *et al.* (2017) for the three major nutrients (N, P, K). The observed and predicted post-harvest soil test values were compared by Paired t- Test. The results clearly show that the deviations were quite small/very negligible and both actual and predicted soil test values of available nitrogen, phosphorus and potassium were in good agreement with each other. This test shows that that predicted and observed value were non-significant. This clearly shows the validity of the post harvest soil test value equations. 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. Prediction equations were also developed by Bera *et al*. (2006) in rice, Mishra *et al*. (2015) for chickpea, Coumaravel *et al*. (2016) for maize, Gangola *et al*. (2017) for maize-chickpea sequence and Kumar *et al*. (2018) for turmeric.

Strip and plot wise observed and predicted soil test value on the basis of yield is given in appendix XI, respectively. Range and average of observed and predicted post harvested soil test values are given in table 4.21.

Table 4.21: Predicted and observed value of Post-harvest soil test value

Particulars	Strip I		Strip II		Strip III	
	Observed	predicted	Observed	predicted	Observed	predicted
Available nitrogen (kg N ha^{-1})	176.43	176.59	174.35	175.91	178.85	177.13
Available phosphorus (kg P ha^{-1})	12.88	12.02	10.76	11.55	13.63	13.70
Available potassium (kg K ha^{-1})	293.14	291.28	253.97	254.09	264.07	265.81

4.14 Verification trial (Phase III)

The verification trials are important since the results obtained on research farm are required to be tested for their validity for their use. 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 profitability of the soil test based fertilizer recommendation than general recommended dose.

Verification trial on cauliflower was conducted during 2016-17 to verify the adjustment equations (Table 4.10) generated the test crop experiments during 2015-16. In this trial ten treatments with three replications were taken under RBD. The average curd yield of each treatment is given below in table 4.22 and also presented in Fig 4.11. Photographic view of cauliflower growth under different treatments is presented in plate10.

Plate10: Photographic view of verification trial on cauliflower

Table 4.22: Yield of cauliflower under various treatments

Treatment	Yield (q/ha)
T1=Control	127.94
T2=GRD (100:60:60)	148.17
T3=Target Yield I-250 q ha-1(145:80:102)	175.40
T4=Target Yield II -300 q ha-1(190:103:128)	202.50
T5= Target Yield I- 250 q ha-1(118:74:93 +10 t ha-1FYM)	185.93
T6= Target Yield I- 250 q ha-1(103:70:85+20 t ha-1FYM)	209.26
T7= Target Yield II-300 q ha-1(160:95:118+10 t ha-1FYM)	238.89
T8= Target Yield II-300 q ha-1(146:90:110+20 t ha-1FYM)	218.82
T9=10 t ha-1FYM	162.22
T10=20 t ha-1FYM	160.33
CD at 5%	12.71
S.Em.±	4.28
CV	4.05

On the basis of above table, it is clearly indicated that target yield approach treatments both chemical and under INM mode are significantly superior over general recommended dose (GRD). Similarly INM mode of fertilizer recommendation (T7) at the rate of 10 t ha^{-1} FYM is significantly better than chemical mode of fertilizer with same yield targets (T4).

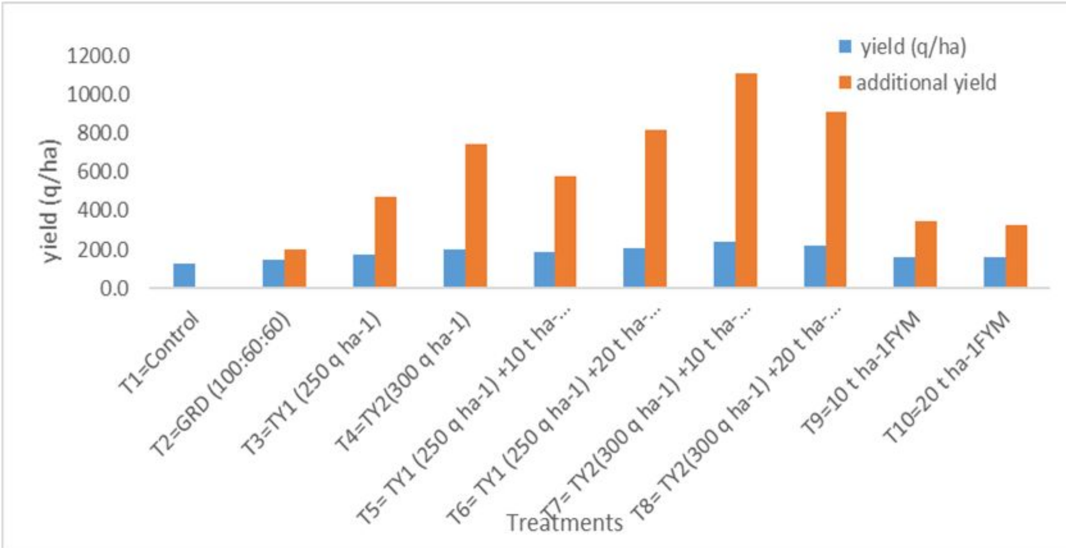


Fig.4.11: Cauliflower yield comparison between Control, G.R.D and STCR based fertilizer recommendations

Economic analysis of verification trial showed that all the treatments are superior over GRD as well as control. Net benefit was highest with 300 q ha^{-1} yield target with 10 t ha^{-1} FYM. Target yield 300 q ha^{-1} with 10 t ha^{-1} FYM is superior over chemical mode of fertilizer yield target.

Data in table 4.23 indicated that the B/C ratio was higher where fertilizer recommended through STCR (inorganic) as compared to general recommended dose. Response ratio was better in both the yield targets both under chemical/INM modes over GRD. Similarly response ratio was better in integrated targets as compared to chemical mode of targets in the experiment.

The relatively higher RR recorded under STCR under 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 use of organic sources of nutrients (Rao and Srivastava 1999). Similar result was also reported by Sharma *et al.* (2005), Yanthan *et al.* (2010), Thilagam (2011), Pande *et al*. (2016) and Dhinesh *et al.* (2017).

Table 4.23: Economics of Verification Trial on cauliflower

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 Ratio
Control	0-0-0	12794	0.0	0.0	0	0.0	0	0
GRD	100-60-60	14817	2022.7	20226.7	5681.8	14544.9	2.6	9.2
TY1 (250 q ha^{-1})	145-80-102	17540	4745.8	47457.8	8321.9	39135.9	4.7	14.5
TY2(300 q ha^{-1})	190-103-128	20250	7456.2	74562.1	10660.8	63901.3	6.0	17.7
TY1 (250 q ha^{-1}) +10 t ha^{-1}FYM)	118-74-93	18593	5798.6	57985.9	22472.5	35513.4	1.6	20.3
TY1 (250 q ha^{-1}) +20 t ha^{-1}FYM)	103-70-85	20926	8131.9	81319.3	36885.6	44433.7	1.2	31.5
TY2(300 q ha^{-1}) +10 t ha^{-1}FYM	160-95-118	23889	11094.9	110948.9	24653.6	86295.3	3.5	29.7
TY2(300 q ha^{-1}) +20 t ha^{-1}FYM	146-90-110	21882	9088.2	90881.9	39030.9	51851.0	1.3	26.3
10 t ha^{-1}FYM	0-0-0	16222	3428.2	34282.2	15000	19282.2	1.3	380.9
20 t ha^{-1}FYM	0-0-0	16033	3239.3	32393.3	30000	2393.3	0.1	180.0

Cost of cauliflower= 10 Rs. /kg

FYM cost= Rs.150/q, N, P_2O_5 and K_20 cost (Rs. /kg) = 11.65, 47.54 and 27.74 Rs. /kg

4.14.1 Effect of soil fertility and fertilizer on quality of cauliflower

A judicious use of organic manure and fertilizer is effective not only in maintaining crop productivity and soil health, but also in improving crop composition of quality. There are several reports which show that the combined and sole application of organic manures and biofertilizers increase yield and influence quality attributes in vegetables (Bahadur *et al*. 2006).

It is well known that quality of cauliflower was affected by soil fertility and applied fertilizer. Therefore, following quality parameters were studied for this purpose in the curd samples collected during verification trial which was conducted as per detail mentioned in 4.22.

Table 4.24: Quality parameters of cauliflower

Treatment	Protein content	Ascorbic Acid (mg/100g)	Total phenols	Flavonoids
T1=Control	9.19	40.08	38.14	3.12
T2=GRD (100:60:60)	13.25	50.76	39.52	3.63
T3=TY1 (250 q ha-1)	14.00	48	40.05	3.68
T4=TY2(300 q ha-1)	12.50	42.50	44.21	3.73
T5= TY1 (250 q ha-1) +10 t ha-1FYM)	14.63	48.65	44.67	4.06
T6= TY1 (250 q ha-1) +20 t ha-1FYM)	15.75	49.93	45.06	4.52
T7= TY2(300 q ha-1) +10 t ha-1FYM	19.69	45.05	47.08	4.65
T8= TY2(300 q ha-1) +20 t ha-1FYM	17.00	46.93	45.98	4.56
T9=10 t FYM ha^{-1}	10.75	55.05	44.9	4.29
T10=20 t FYM ha^{-1}	10.44	58.53	43.2	4.33
CD at 5%	0.539	1.86	2.00	0.152
S.Em.±	0.181	0.628	0.673	0.513
CV	2.29	2.24	2.69	2.19

All the quality parameter of cauliflower, i.e. Protein content, Ascorbic acid, Total phenols and flavonoids in different treatments were significantly superior over control.

Ascorbic acid content was significantly superior in only FYM treatments than other treatment. The highest ascorbic acid content (58.53) in curd was obtained with the treatment T10 (20 t FYM ha^{-1}). The lowest (40.08) ascorbic acid was recorded with control. These findings are in close agreement with those earlier reported by Singh (2004) in cauliflower, Guo *et al*. (2004) in cabbage and Sable and Bhamare (2007) in cauliflower. Protein content was significantly superior in all the treatments except only FYM treatment. The highest protein content (19.69) in curd was obtained with the treatment T7 (TY2 (300 q ha^{-1}) +10 t ha^{-1}FYM. The lowest (9.19) protein content was recorded with control. Therefore, organic crop would be expected to maintain higher vitamin 'C' and carbohydrates and less protein as reported by Bahadur *et al*. (2003) in broccoli.

Total phenol content was significantly superior in all the treatments over GRD. The highest total phenol (47.08) content was obtained with the treatment T7 (TY2 (300 q ha^{-1}) +10 t ha^{-1} FYM). The lowest total phenol (38.14) was recorded with control. Flavonoids content was significantly superior in integrated nutrient & FYM treated plots over chemical fertilizer treatment. The highest flavonoids (4.65) contents was obtained with the treatment T7 (TY2 (300 q ha^{-1}) +10 t ha^{-1} FYM) and the lowest flavonoids (3.12) was recorded with control. Overall results indicated that under integrated nutrient management and organic treatments with higher rate of FYM applications showed better antioxidant capacity compared to cauliflower grown in control and using only chemical fertilizers. Similar results were reported by Young *et al*. (2005), Dangour *et al*. (2009) and Shankar *et al.* (2012). From this study it is evident that cauliflower grown with integrated nutrient system or organic system produced higher antioxidant qualities than crop grown with chemical fertilizers only.

4.15 Follow up trial

Follow up trial on Cauliflower were conducted at farmer's field in district of Nainital during 2016-17 to verify the adjustment equations (Table 4.10) generated the test crop experiments during 2015-16. These trials were conducted at three locations as replication with seven treatments as listed in table 4.25 and also presented in Fig 4.12. Average of three locations presented in this table and photographic view of cauliflower growth under different treatments is presented in plate11.

Table 4.25: Yield of cauliflower under various treatments

Treatment	**Yield (q/ha)**
T1- Control	113.0
T2= FP	166.7
T3= GRD	190.7
T4= TY1 (250 q ha^{-1})	223.0
T5= TY_1 (250 q ha^{-1})+ FYM 10 t ha^{-1}	298.1
T6= TY_2 (300 q ha^{-1})	245.9
T7= TY_2 (300 q ha^{-1})+ FYM 10 t ha^{-1}	215.6
CD at 5%	**8.72**
S.Em.±	**2.83**
CV	**2.42**

On the basis of above table, it is clearly indicated that target yield approach treatments both chemical and under INM mode are significantly superior over general recommended dose (GRD). Similarly INM mode of fertilizer recommendation (T5) at the rate of 10 t ha^{-1} FYM is significantly better than chemical mode of fertilizer with same yield targets (T4).

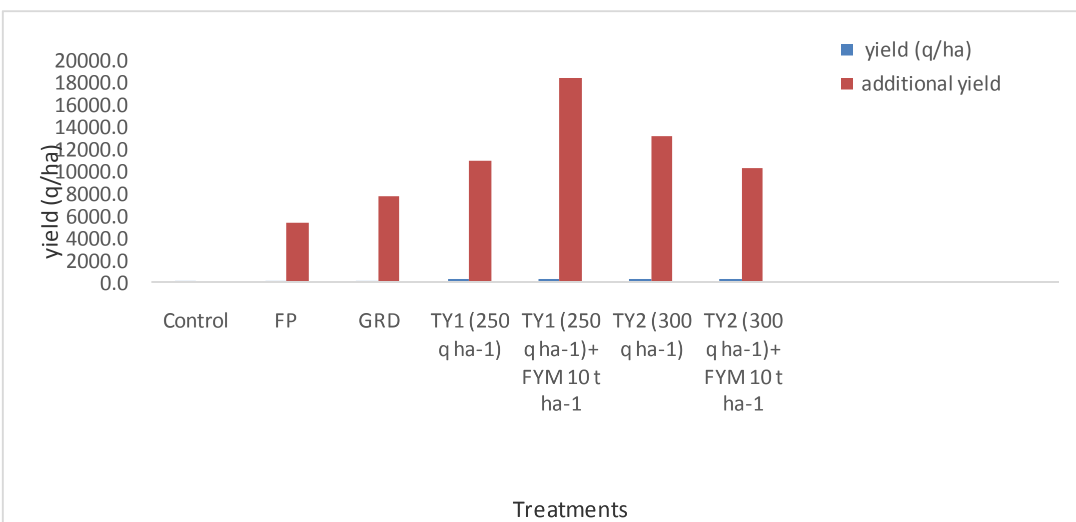


Fig.4.12: Cauliflower yield comparison between control, FP and STCR based fertilizer recommendations

Plate 11:Photographic view of follow up trial on cauliflower

Table 4.26: Economics of Follow up trials at farmer's field for cauliflower

Treatment	Fertilizer doses(kg/ha)			Fresh curd yield(q/ha)	Response ratio	Net return (Rs.)	B:C ratio
Control	0	0	0	113.0	-	-	-
FP	-	-	-	166.7	-	53706.7	-
GRD	100	60	60	190.7	35.4	72098.9	12.7
TY1 (250 q ha^{-1})	148	76	90	223.0	35.0	102169.2	13.0
TY_1 (250 q ha^{-1})+ FYM 10 t ha^{-1}	120	67	80	298.1	69.4	163385.7	7.5
TY_2 (300 q ha^{-1})	194	98	117	245.9	32.5	122801.3	12.1
TY_2 (300 q ha^{-1})+ FYM 10 t ha^{-1}	162	90	106	215.6	28.7	78533.7	3.3

Cost of cauliflower= 10 Rs. /kg, FYM cost= Rs.150/q, N, P_2O_5 and K_2O cost (Rs. /kg) = 11.65, 47.54 and 27.74 Rs. /kg

These treatments were compared with general recommended dose and farmer's practice treatments. Curd yield, net benefit and response ratio was highest in treatment where fertilizer was applied on the basis of 250 q ha^{-1} target yield with 10 t ha^{-1} FYM than the farmer's practice and general recommended dose treatments. Kumar *et al.* (2013) have reported that integration of organic and inorganic fertilizers application significantly increased the yield in broccoli over inorganic fertilizers alone. Kumar and Chaudhary (2002) reported the yield increase of 27 q ha^{-1} in cauliflower cv. Pusa snowball-1 with application of FYM @ 25 t ha^{-1} + 100 per cent NPK in comparison to application of 100 per cent NPK alone. This might be due to balanced supply of nutrients from fertilizer, efficient utilization of applied fertilizer nutrients in the presence of FYM.

Benefit cost ratio was found highest with yield target 250 q ha^{-1}. There was also increase in profit over farmer's practice with increasing yield targets from 250 to 300 q ha^{-1} (Table 4.26). Chand *et al.* (2006) also observed that fertilizer application based on yield targets give higher yields, net return and B/C ratio over the farmers practice for mustard and rapeseed crop. The present study also suggests that STCR based recommendations for cauliflower are better for the efficient and economic use of fertilizers than the inorganic fertilizers alone.

Efficient nutrient management is a prerequisite for achieving maximum yield in cauliflower with good curd quality. Neither the chemical fertilizers alone nor the organic manures exclusively sustain the productivity of cauliflower but a judicious combination of both along with their efficient management for sustaining the productivity.

4.16 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). In view of the research gaps to document GPS based soil test data base for all the nutrients based on multistage stratified random sampling technique, and to provide on line fertilizer recommendations, the preparation of GPS and GIS based soil fertility maps for selected districts in different states of the country was carried out during 2010-2013 by the Indian Institute of Soil Science, Bhopal and all the Cooperating centers of AICRP with an ultimate aim of transferring the generated soil test crop response based site specific IPNS recommendations to the farmers. This information will be beneficial to the researchers, planners, and policy makers, extension workers of the State Department of Agriculture, fertilizer industries and farmers. Accordingly Santhi *et al*. (2016) have prepared GPS and GIS based soil fertility maps for nine selected districts of Tamil Nadu and suggested district wise action plan. Muralidharudu *et al*., 2011, prepared GIS based soil fertility maps of different states of India including Uttarakhand.

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 4.13).

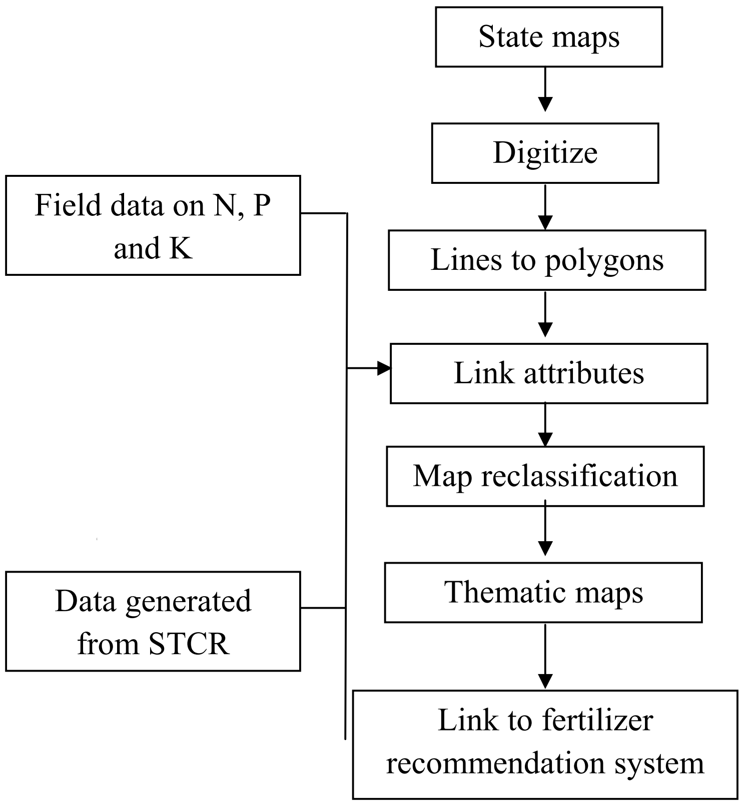


Fig 4.13: Flow chart for online recommendation of fertilizer for cauliflower

Summary and Conclusion

Chapter 5 SUMMARY AND CONCLUSION

The present investigation was conducted at Vegetable Research Centre (29° N latitude, 79° 27' E longitudes and an altitude of 217 m above the mean sea level) during 2015-16 and at Crop Research Centre (29^0 N latitude, $79^0$29' E longitudes and an altitude of 243.84 m above the mean sea level) during 2016-17 of G.B. Pant University of Agriculture and Technology Pantnagar, Udham Singh Nagar (Uttarakhand). 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 created by dividing experimental field into three equal strips and applying graded doses of fertilizers in these strips and growing of exhaust crop maize (var. Kanchan). In the second phase i.e. next season test crop Cauliflower (var. Snowball-16) was grown by dividing each strip into 24 plots having 21 treated and 3 control. 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, 30, 60 and 90 kg P_2O_5 ha^{-1}) and four levels of potassium (0, 30, 60 and 90 kg K_2O ha^{-1}) at different fertility levels of cauliflower was studied. Verification trial, i.e. second experiment was conducted during 2016-17 to validate the fertilizer adjustment equations developed in first experiment with ten treatments and three replications, having combinations of inorganic and organic sources. Follow up trial, i.e. third experiment was also conducted on farmer's field at golapaar, Haldwani during 2016-17.

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 and curd yield were utilized to develop basic data and thereafter fertilizer adjustment equations for targeted production of cauliflower. Experiment wise findings of the present investigations are summarized below:

Experiment I

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 0.48-1.35 per cent with an average of 0.89 per cent, Alkaline $KMnO_4$ extractable nitrogen ranged from 137.98 to 200.98 kg N ha^{-1} with average value of 160.98 kg N ha^{-1}, Olsen's phosphorus ranged from 15.01 to 22.12 kg P ha^{-1} with an average value of 18.47 kg P ha^{-1} and neutral normal NH_4OAc extractable potassium ranged from 99.68 to 365.12 kg ha^{-1} with an average of 281.81 kg K ha^{-1}.

2. Statistically it was established that there was difference in available N, P & K status of the experimental field.
3. Various growth parameters and their correlation worked out in present investigation. Number of leaves of cauliflower in experimental field ranged from 12 to 20 with an average of 17. Average number of leaves recorded 17 in strip III, strip II and in strip I.
4. Gross plant weight (kg) of cauliflower ranged from 0.52 to 6.17 with an average of 2.64. Average Gross plant weight (kg) recorded in strip III (2.99 kg) was followed by strip II (2.62 kg) and in strip I (2.26 kg).
5. Marketable curd weight (kg) ranged from 0.22 to 2.48 with an average of 1.15. Average marketable curd weight (kg) recorded in strip III (1.30 kg) was followed by strip II (1.18 kg) and in strip I (0.99 kg).
6. Net curd weight (kg) ranged from 0.11 to 1.27 with an average of 0.59. Average net curd weight (kg) recorded in strip III (0.59 kg) was followed by strip II (0.67 kg) and in strip I (0.52 kg).
7. Curd diameter (cm) ranged from 8 to 32 with an average of 14. Average curd diameter (cm) recorded 14 in strip III, strip II and in strip I.
8. Curd depth (cm) ranged from 5 to 12 with an average of 9. Average curd diameter (cm) recorded 9 in strip III, strip II and in strip I.
9. Curd size index (cm^2) ranged from 45 to 264 with an average of 133. Average curd size index (cm^2) recorded in strip II (139 cm^2) was followed by strip III (131cm^2) and in strip I (129cm^2).

10. The curd yield of cauliflower significantly correlated with applied nitrogen (0.696**), gross plant weight (0.816**), marketable curd weight (0.823**), net curd weight (0.782**), curd depth (0.735**) and curd size index (0.668**).

11. Applied nitrogen shows positive and significant correlation with number of leaves (0.754**), gross plant weight (0.869**), marketable curd weight (0.870**), net curd weight (0.862**), curd depth (0.853**) and curd size index (0.712**).

12. Number of leaves were significantly correlated with gross plant weight (0.719**), marketable curd weight (0.748**), net curd weight (0.752**) and curd depth (0.729**).

13. Gross plant weight of cauliflower is significantly correlated with marketable curd weight (0.986**), net curd weight (0.914**), curd depth (0.870**) and curd size index (0.775**).

14. Marketable curd weight of cauliflower is positively correlated with net curd weight (0.937**), curd depth (0.891**) and curd size index (0.790**).

15. Net curd weight of cauliflower is significantly correlated with curd depth (0.924**) and curd size index (0.834**).

16. Diameter of curd is significantly correlated with curd size index (0.913**) and Curd depth of cauliflower is positively correlated with curd size index (0.872**).

17. Fresh yield of plant (q ha^{-1}) of experimental field ranged from 50.00 to 615.00 with an average of 244.61. Average plant yield recorded in strip III (282.57 q ha^{-1}) was followed by strip II (239.86 q ha^{-1}) and in strip I (211.39 q ha^{-1}).

18. Dry matter yield of plant (q ha^{-1}) in experimental field varied from 9.17 to 76.88 with an average 38.06 q ha^{-1}. Average dry matter yield of plant recorded in order of strip III (39.79 q ha^{-1}) was followed by strip II (38.80 q ha^{-1}) and strip I (35.60 q ha^{-1}).

19. Curd yield (q ha^{-1}) of experimental field ranged from 36.67 to 413.33 with an average of 192.41 q ha^{-1}. Average curd yield recorded in strip III (215.97 q ha^{-1}) was followed by strip II (196.60 q ha^{-1}) and in strip I (164.65 q ha^{-1}).

20. Dry matter yield of curd (q ha^{-1}) in experimental field varied from 4.67 to 50.00 with an average 21.06 q ha^{-1}. Average dry matter yield of curd recorded in order of strip III (24.06 q ha^{-1}) was followed by strip II (19.75 q ha^{-1}) and strip I (19.37 q ha^{-1}).

21. Fresh and dry matter yield of cauliflower plant and curd followed the same trend as of initial fertility of soil.

22. The average N, P and K content of plant (%) were found 1.85, 0.11 and 0.38 %, respectively. While, in curd, the average N, P and K content were found 2.67, 0.08 and 1.27 %, respectively.

23. N, P and K contents in both plant and curd of cauliflower were in order of N>K>P.

24. The Nitrogen uptake (kg ha^{-1}) by the crop in experimental field varied from 29.27 to 298.20 with an average 129.06 kg ha^{-1}. Average nitrogen uptake recorded in order of strip III (142.17 kg ha^{-1}) followed by strip II (130.07 kg ha^{-1}) and strip I (114.94 kg ha^{-1}).

25. The Phosphorus uptake (kg ha^{-1}) by the crop in experimental field varied from 1.30 to 13.45 with an average 5.89 kg ha^{-1}. Average phosphorus uptake recorded in order of strip III (6.24 kg ha^{-1}) was followed by strip II (6.04 kg ha^{-1}) and strip I (5.38 kg ha^{-1}).

26. The Potassium, uptake (kg ha^{-1}) by the crop in experimental field varied from 6.69 to 108.26 with an average 39.74 kg ha^{-1}. Average potassium uptake recorded in order of strip III (43.07 kg ha^{-1}) was followed by strip II (39.51 kg ha^{-1}) and strip I (36.64 kg ha^{-1}).

27. N, P and K uptake by cauliflower in order of strip III> strip II >strip I.

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

29. For the production of one quintal curd yield, cauliflower required 0.70 kg of nitrogen, 0.03 kg of phosphorus (P) and 0.23 kg of potassium (K).

30. The contribution of soil in supplying available nitrogen, phosphorus and potassium of their soil test value for the crop was 33.20, 13.84 and 8.13 per cent, respectively.

31. Per cent contribution of applied FYM for nitrogen, phosphorus and potassium were 45.62, 2.19 and 13.50, respectively.

32. Contribution from fertilizer as percentage was 82.44, 16.50 and 55.63, with FYM and 75.27, 15.62 and 54.68 without FYM for nitrogen, phosphorus and potassium, respectively.

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

34. 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.

35. 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 10 tonne FYM were 2.56 kg ha^{-1} N, 0.66 kg P_2O_5 ha^{-1} and 0.92 kg K_2O ha^{-1} along with the experimental soil test value and yield targets.

36. Fertilizer equivalence of FYM for N, P_2O_5 and K_2O was higher with 10 tonne FYM as compared to 20 tonne FYM.

37. Maximum yield response was observed i.e. 142.22, 74.45, 7.22 kg kg^{-1} for N, P_2O_5 and K_2O, respectively, with 100 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}.

38. Quadratic type multiple regression equation developed by curd yield as a dependent variable and soil test value, applied fertilizer doses, their interaction and also FYM as independent variables. From R^2 (0.831**) value, it can be observed that 83.1 per cent variation in curd yield can be predicted.

39. From the present study, it can be concluded that both organic carbon and alkaline-$KMnO_4$ methods were equally suitable for evaluation of available nitrogen. Olsen's and AB-DTPA-P methods for soil available phosphorus and neutral ammonium NH_4OA_C and AB-DTPA K methods for soil available potassium can be taken as indices for determining N, P and K in Mollisol of Uttarakhand. AB-DTPA as universal extractant can be adopted by soil testing laboratories for extraction as it can extract both P and K and various micronutrients too from the soil.

40. 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.

41. The values (R^2) of prediction equations based on yield for available N, P and K found 0.98**, 0.72** and 0.99**, respectively.

Experiment II

42. Verification trial was conducted to test the validity of fertilizer adjustment equations. Results of this trial clearly indicate significant superiority of targeted yield approach over general fertilizer recommendations. The trend of INM treatments of target yields showed significantly superior over chemical mode of fertilizer application. Economic analysis of verification trial indicated that B/C ratio was higher in chemical fertilizer treatments as compare to INM treatments. However, net benefit of fertilizer was the highest in INM treatments with 300 q/ha yield target using 10 tonne FYM.

43. All the quality parameter of cauliflower, i.e. protein content, ascorbic acid, total phenols and flavonoids in different treatments were significantly superior over control.

44. Ascorbic acid content was significantly superior only in FYM treatments than other treatments.

45. Protein content was significantly superior in all the treatments except only FYM treatment.

46. Total phenol content was significantly superior in all the treatments over GRD.

47. Flavonoids content was significantly superior in integrated nutrient & FYM treated plots over chemical fertilizer treatment.

Experiment III

48. Follow up trial was conducted to test the validity of fertilizer adjustment equations at farmer's field. Results of this trial clearly indicate the superiority of targeted yield approach over general fertilizer recommendations. The present study also suggests that STCR based recommendations for cauliflower are better for the efficient and economic use of fertilizers than the General fertilizer recommendations.

Conclusions drawn from the present study

In *tarai* region of Mollisol of Uttarakhand maximum yield response of cauliflower was obtained at 100 Kg N ha^{-1}, 50 Kg P_2O_5 ha^{-1} and 100 Kg K_2O ha^{-1}. Integrated fertilizer use on the basis of soil test value for target yield proved significantly superior over general fertilizer recommendation. Fertilizer prescription equations both under chemical and INM mode developed for cauliflower at desired yield targets and fertility status may be 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.

Future Thrust

1. There is need to develop fertilizer prescription equation using drip irrigation for enhancing nutrient use efficiency.

2. To overcome effect of season over the year there is need to develop model by including various factors (soil, climate, varieties, management etc), so that recommendations may become useful for changing scenario of climate, management and varieties.

3. There is need to develop DSS by integrating GPS/GIS-based soil fertility maps with STCR prescription equations for wide use of STCR based recommendations for remote areas.

4. There is need to popularize this approach among soil testing labs, farmers and other stake holders.
5. Development and validation of more universal extractants/methods of soil testing and their calibration for different crops to be used by soil testing labs.

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Appendices

APPENDIX I

Weekly weather parameters during the course of experimentation 2015-16

Month	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)	Sun Shine (hrs.)	Wind velocity (km/hr)	Evaporation (mm)
	Max	Min	0712 am	1412 pm				
1 Oct-7 Oct 2015	32.89	20.16	82.71	50.57	0.00	9.49	2.11	4.73
8 Oct- 14 Oct	32.50	20.34	82.57	51.71	0.00	7.46	2.37	4.59
15 Oct-21 Oct	31.47	19.29	86.43	51.00	0.00	5.11	3.06	3.54
22 Oct-28 Oct	31.19	13.87	88.14	47.86	0.00	8.69	2.97	3.97
29 Oct-4 Nov	28.96	13.69	90.00	43.43	0.83	6.21	2.90	3.04
5 Nov- 11 Nov	27.97	12.10	90.57	43.14	0.29	6.59	3.01	2.53
12 Nov-18 Nov	29.00	11.89	90.71	38.43	0.00	7.79	2.83	2.67
19 Nov-25 Nov	27.71	11.26	92.14	41.29	0.00	7.16	1.63	2.29
26 Nov- 2 Dec	26.66	12.63	91.14	46.14	0.00	3.66	2.69	2.09
3 Dec- 9 Dec	24.59	10.21	95.86	49.43	0.00	1.79	2.31	1.61
10 Dec-16 Dec	21.07	10.29	93.71	64.43	0.00	2.11	4.30	1.26
17 Dec-23 Dec	20.53	4.56	95.71	50.14	0.00	5.34	2.53	1.49
24 Dec-30 Dec	20.40	4.71	94.71	47.43	0.00	5.91	3.11	1.44
31 Dec-6 Jan 2016	23.91	6.69	92.57	38.29	0.00	6.51	2.63	1.54
7 Jan-13 Jan	22.41	7.17	93.43	49.00	0.00	4.20	3.33	1.73
14 Jan- 20 Jan	17.93	6.39	94.14	59.29	0.00	2.60	3.94	1.36
21 Jan-27 Jan	17.50	4.76	93.71	59.71	0.00	2.69	3.90	1.36
28 Jan-3 Feb	22.10	6.77	95.29	45.14	0.00	4.57	4.91	1.77
4 Feb-10 Feb	22.97	7.89	93.43	48.00	0.00	5.43	4.16	2.51
11 Feb-17 Feb	26.06	8.91	85.14	32.14	0.00	7.11	4.16	2.89
18 Feb-24 Feb	26.46	11.99	84.86	44.43	0.36	4.10	7.43	2.99
25 Feb- 2 Mar	28.39	11.76	87.57	36.86	0.00	7.37	3.07	2.94
3 Mar-9 Mar	30.60	13.36	86.14	36.14	0.00	8.21	5.74	3.94
10 Mar-16Mar	29.14	13.60	83.14	37.43	0.15	7.44	7.66	4.70

APPENDIX II

Weekly weather parameters during the course of experimentation 2016-17

Month	Temperature (^0C)		Relative Humidity (%)		Rainfall (mm)	Sun Shine (hrs.)	Wind velocity (km/hr)	Evaporation (mm)
	Max	Min	0712 am	1412 pm				
1 Oct-7 Oct 2016	32.66	24.93	88.00	66.29	0.00	3.87	2.41	2.99
8 Oct- 14 Oct	32.17	19.87	88.71	61.00	0.00	5.90	2.90	2.86
15 Oct-21 Oct	31.60	17.19	80.00	47.14	0.00	7.67	2.26	2.84
22 Oct-28 Oct	31.19	13.84	90.14	37.00	0.00	7.70	2.13	2.81
29 Oct-4 Nov	30.41	13.51	84.86	38.71	0.00	7.93	1.89	2.56
5 Nov- 11 Nov	28.99	11.36	90.29	36.14	0.00	7.86	2.61	2.43
12 Nov-18 Nov	28.34	10.59	90.86	37.43	0.00	8.13	2.13	2.76
19 Nov-25 Nov	26.61	9.80	93.43	40.00	0.00	7.31	2.23	1.94
26 Nov- 2 Dec	26.13	11.33	92.57	49.71	0.00	4.16	2.60	1.79
3 Dec- 9 Dec	23.43	11.51	95.00	60.00	0.00	4.11	3.07	1.30
10 Dec-16 Dec	19.96	9.91	94.43	63.00	0.00	2.23	2.70	1.13
17 Dec-23 Dec	23.13	6.50	94.57	47.86	0.00	6.14	2.34	1.83
24 Dec-30 Dec	22.91	8.87	93.57	55.29	1.60	6.03	3.61	1.73
31 Dec-6 Jan 2017	23.24	8.84	92.29	52.86	0.00	7.13	2.61	1.76
7 Jan-13 Jan	18.29	5.46	92.71	57.86	2.17	5.54	5.21	1.47
14 Jan- 20 Jan	18.64	6.50	94.71	58.00	0.00	4.39	4.09	1.20
21 Jan-27 Jan	23.16	8.41	93.14	55.86	3.94	5.86	5.07	1.64
28 Jan-3 Feb	20.30	8.87	92.43	59.14	2.83	4.57	3.73	1.74
4 Feb-10 Feb	23.24	9.21	92.71	49.29	0.00	5.77	5.23	1.93
11 Feb-17 Feb	24.80	8.54	91.00	46.86	0.00	7.96	2.83	1.73
18 Feb-24 Feb	27.01	10.99	91.14	45.14	0.00	6.07	4.54	2.36
25 Feb- 3 Mar	26.99	9.29	87.71	40.71	0.11	8.33	4.73	2.84
4 Mar-10 Mar	23.24	9.21	92.71	49.29	0.00	5.77	5.23	1.93
11 Mar-17 Mar	24.80	8.54	91.00	46.86	0.00	7.96	2.83	1.73

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.	N2P1K2OM1	137.98	16.98	99.68	1.05
2.	N3P3K1OM1	150.53	15.40	316.96	0.60
3.	N1P2K2OM1	137.98	15.01	339.36	0.75
4.	N3P2K2OM1	175.62	15.80	235.20	0.59
5.	N2P1K1OM0	163.07	17.77	340.48	0.87
6.	N2P2K1OM0	163.07	18.56	302.40	0.93
7.	N0P0K0OM0	163.07	19.35	311.36	0.87
8.	N1P1K1OM0	175.62	15.40	315.84	1.05
9.	N3P3K3OM2	150.53	16.98	208.32	0.72
10.	N3P1K1OM2	163.07	18.96	172.48	0.75
11.	N0P0K0OM2	175.62	15.01	331.52	0.60
12.	N2P3K3OM2	163.07	15.80	228.48	0.57
13.	N0P2K2OM2	150.53	18.17	290.08	0.83
14.	N3P2K3OM2	150.53	20.14	240.80	0.53
15.	N1P1K2OM2	175.62	18.96	216.16	0.84
16.	N3P3K2OM2	163.07	17.77	241.92	0.83
17.	N3P2K1OM0	150.53	15.40	254.24	1.02
18.	N2P0K2OM0	175.62	16.59	222.88	0.93
19.	N1P2K1OM0	150.53	18.17	228.48	0.98
20.	N2P2K3OM0	163.07	21.33	299.04	0.87
21.	N2P2K0OM1	150.53	20.14	266.56	0.69
22.	N0P0K0OM1	163.07	20.93	275.52	0.78
23.	N2P2K2OM1	175.62	17.77	294.56	0.86
24.	N2P3K2OM1	163.07	17.38	342.72	1.08
Mean		**160.46**	**17.66**	**265.63**	**0.82**

STRIP-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.	N3P2K1OM1	175.62	18.17	333.76	1.05
2.	N2P2K3OM1	163.07	17.38	338.24	1.29
3.	N2P0K2OM1	150.53	18.56	318.08	0.89
4.	N1P2K1OM1	163.07	15.40	328.16	0.93
5.	N2P3K3OM0	175.62	16.59	322.56	0.71
6.	N3P1K1OM0	150.53	18.56	365.12	1.32
7.	N3P2K3OM0	163.07	20.54	310.24	0.48
8.	N0P2K2OM0	137.98	15.80	231.84	0.80
9.	N2P2K2OM2	163.07	16.98	252.00	0.90
10.	N2P3K2OM2	150.53	18.96	266.56	0.98
11.	N0P0K0OM2	150.53	18.17	265.44	0.83
12.	N2P1K2OM2	163.07	19.75	273.28	1.05
13.	N3P3K1OM2	163.07	18.56	294.56	0.98
14.	N3P2K2OM2	200.70	17.77	272.16	0.78
15.	N1P2K2OM2	175.62	18.96	266.56	0.65
16.	N2P2K0OM2	150.53	20.14	280.00	1.32
17.	N0P0K0OM0	137.98	20.93	245.28	1.08
18.	N1P1K2OM0	163.07	18.96	264.32	0.95
19.	N3P3K2OM0	150.53	18.56	252.00	0.83
20.	N3P3K3OM0	163.07	17.38	104.16	0.75
21.	N2P1K1OM1	163.07	18.17	253.12	0.69
22.	N2P2K1OM1	175.62	15.01	266.56	1.13
23.	N0P0K0OM1	150.53	15.80	271.04	0.60
24.	N1P1K1OM1	163.07	16.19	281.12	0.90
Mean		**160.98**	**17.97**	**277.34**	**0.91**

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.	N2P3K3OM1	175.62	18.96	328.16	1.26
2.	N3P2K3OM1	150.53	21.33	293.44	1.17
3.	N3P1K1OM1	163.07	22.12	339.36	1.28
4.	N3P3K3OM1	150.53	19.75	318.08	1.14
5.	N2P1K2OM0	150.53	18.56	297.92	1.02
6.	N2P2K2OM0	163.07	20.54	268.80	0.99
7.	N2P3K2OM0	150.53	19.35	337.12	1.19
8.	N3P3K1OM0	163.07	21.72	316.96	0.98
9.	N2P1K1OM2	175.62	18.56	267.68	0.89
10.	N0P0K0OM2	163.07	20.93	301.28	0.75
11.	N2P2K1OM2	150.53	19.35	286.72	0.95
12.	N1P2K1OM2	175.62	18.17	315.84	0.83
13.	N1P1K1OM2	150.53	20.14	339.36	0.77
14.	N2P0K2OM2	163.07	21.72	254.24	0.86
15.	N2P2K3OM2	150.53	19.35	334.88	0.60
16.	N3P2K1OM2	163.07	20.54	303.52	0.75
17.	N3P2K2OM0	175.62	18.96	277.76	1.01
18.	N1P2K2OM0	150.53	19.75	303.52	0.77
19.	N0P0K0OM0	175.62	19.35	301.28	0.63
20.	N2P2K0OM0	163.07	21.33	286.72	0.63
21.	N1P1K2OM1	150.53	19.75	314.72	0.75
22.	N0P2K2OM1	163.07	18.96	293.44	1.13
23.	N3P3K2OM1	175.62	18.17	308.00	0.83
24.	N0P0K0OM1	163.07	17.77	271.04	1.35
Mean		**161.50**	**19.80**	**302.49**	**0.94**

APPENDIX IV
Range and average of growth parameters of Cauliflower
Strip I

Plot No.	Treatment	No. of leaves	Gross plant wt. (kg)	Mar. Curd wt. (kg)	N curd wt. (kg)	Curd dia. (cm)	Curd depth (cm)	Curd size index (cm^2)
1.	N2P1K2OM1	19	2.05	0.76	0.40	11.62	8.74	101.56
2.	N3P3K1OM1	18	3.28	1.20	0.59	14.16	9.7	137.35
3.	N1P2K2OM1	18	1.35	0.64	0.32	12.14	8.52	103.43
4.	N3P2K2OM1	18	3.88	1.56	0.61	14.84	10.1	149.88
5.	N2P1K1OM0	19	2.58	1.06	0.54	13.76	9	123.84
6.	N2P2K1OM0	17	2.72	1.18	0.61	14.26	9.62	137.18
7.	N0P0K0OM0	14	0.79	0.32	0.11	8.4	6.5	54.60
8.	N1P1K1OM0	17	1.08	0.54	0.34	12.42	8.24	102.34
9.	N3P3K3OM2	19	3.25	1.40	0.92	15.52	10.28	159.55
10.	N3P1K1OM2	18	3.36	1.48	0.80	14.86	10.56	156.92
11.	N0P0K0OM2	14	0.65	0.28	0.18	9.74	7.56	73.63
12.	N2P3K3OM2	17	1.05	0.53	0.38	12.36	8.38	103.58
13.	N0P2K2OM2	14	0.52	0.22	0.12	8.8	6.62	58.26
14.	N3P2K3OM2	17	3.14	1.40	0.68	13.94	9.74	135.78
15.	N1P1K2OM2	15	1.12	0.52	0.24	10.62	7.9	83.90
16.	N3P3K2OM2	18	3.22	1.29	0.79	15.08	9.76	147.18
17.	N3P2K1OM0	17	2.75	1.35	0.76	14.9	10	149.00
18.	N2P0K2OM0	15	2.82	1.37	0.63	14.1	9.44	133.10
19.	N1P2K1OM0	18	1.84	1.02	0.47	12.84	9.04	116.07
20.	N2P2K3OM0	17	3.00	1.38	0.73	14.1	10.5	148.05
21.	N2P2K0OM1	17	2.91	1.27	0.64	14.64	10.32	151.08
22.	N0P0K0OM1	15	0.92	0.37	0.25	32.2	8.2	264.04
23.	N2P2K2OM1	18	3.19	1.42	0.77	15.4	10.92	168.17
24.	N2P3K2OM1	18	2.68	1.15	0.63	14	10	140.00
Mean		**17**	**2.26**	**0.99**	**0.52**	**14**	**9**	**129**

Strip II

Plot No.	Treatment	No. of leaves	Gross plant wt. (kg)	Mar. Curd wt. (kg)	N curd wt. (kg)	Curd dia. (cm)	Curd depth (cm)	Curd size index (cm^2)
1.	N3P2K1OM1	19	4.17	1.96	1.09	17.1	11.1	189.81
2.	N2P2K3OM1	17	3.47	1.55	0.81	15.9	10.3	163.77
3.	N2P0K2OM1	15	2.72	1.24	0.71	14.9	10.08	150.19
4.	N1P2K1OM1	17	2.08	0.88	0.47	13.6	9.5	129.20
5.	N2P3K3OM0	17	2.82	1.20	0.72	15.1	10.94	165.19
6.	N3P1K1OM0	20	4.25	1.95	1.12	17.3	11.8	204.14
7.	N3P2K3OM0	19	4.35	1.99	1.06	16.8	11.86	199.25
8.	N0P2K2OM0	12	0.60	0.27	0.17	10.2	6.5	66.30
9.	N2P2K2OM2	18	2.28	1.07	0.75	15	9.5	142.50
10.	N2P3K2OM2	16	2.29	1.13	0.65	15.3	10	153.00
11.	N0P0K0OM2	15	0.66	0.30	0.14	9.9	5.8	57.42
12.	N2P1K2OM2	17	1.58	0.63	0.44	13.06	8.2	107.09
13.	N3P3K1OM2	17	2.90	1.40	0.84	15.7	10.1	158.57
14.	N3P2K2OM2	19	3.30	1.53	1.01	16.7	10.36	173.01
15.	N1P2K2OM2	15	1.25	0.61	0.32	12.24	7.44	91.07
16.	N2P2K0OM2	20	2.54	1.23	0.70	15	10.16	152.40
17.	N0P0K0OM0	15	0.59	0.25	0.12	8.7	5.18	45.07
18.	N1P1K2OM0	16	1.53	0.68	0.45	12.9	8.42	108.62
19.	N3P3K2OM0	20	5.27	2.35	1.27	17.5	11.9	208.25
20.	N3P3K3OM0	18	4.46	1.95	1.04	17.34	10.78	186.93
21.	N2P1K1OM1	19	3.35	1.50	0.82	15.56	10.04	156.22
22.	N2P2K1OM1	17	3.32	1.45	0.74	15.02	10.18	152.90
23.	N0P0K0OM1	15	1.40	0.51	0.26	10.9	6.58	71.72
24.	N1P1K1OM1	15	1.67	0.68	0.44	12.72	8.36	106.34
Mean		**17**	**2.62**	**1.18**	**0.67**	**14**	**9**	**139**

Strip III

Plot No.	Treatment	No. of leaves	Gross plant wt.(kg)	Mar. Curd wt. (kg)	N curd wt. (kg)	Curd dia. (cm)	Curd depth (cm)	Curd size index (cm^2)
1.	N2P3K3OM1	19	3.83	1.85	0.94	15.68	10.54	165.27
2.	N3P2K3OM1	19	6.17	2.48	1.21	18.54	11.46	212.47
3.	N3P1K1OM1	20	4.79	2.00	0.85	16.06	10.1	162.21
4.	N3P3K3OM1	17	5.13	2.25	0.77	14.7	10.06	147.88
5.	N2P1K2OM0	18	3.89	1.71	0.72	15.2	10.62	161.42
6.	N2P2K2OM0	16	3.20	1.45	0.57	14.84	9.56	141.87
7.	N2P3K2OM0	16	3.21	1.31	0.64	14.6	9.14	133.44
8.	N3P3K1OM0	17	4.00	1.70	0.68	15.94	10.1	160.99
9.	N2P1K1OM2	17	2.40	1.14	0.49	13.84	8.88	122.90
10.	N0P0K0OM2	15	0.82	0.33	0.18	10.58	7.08	74.91
11.	N2P2K1OM2	18	2.99	1.30	0.63	13.76	8.84	121.64
12.	N1P2K1OM2	16	1.47	0.67	0.34	13.16	7.94	104.49
13.	N1P1K1OM2	18	1.70	0.75	0.46	12.9	8.32	107.33
14.	N2P0K2OM2	17	2.80	1.17	0.50	13.42	8.36	112.19
15.	N2P2K3OM2	18	2.57	1.19	0.53	14.1	8.5	119.85
16.	N3P2K1OM2	20	3.61	1.72	0.64	14.8	10.22	151.26
17.	N3P2K2OM0	20	4.27	2.00	1.00	16.8	10.1	169.68
18.	N1P2K2OM0	17	1.71	0.75	0.35	13.1	8.34	109.25
19.	N0P0K0OM0	14	1.05	0.40	0.17	9.92	6.54	64.88
20.	N2P2K0OM0	20	3.34	1.37	0.74	15.48	9.54	147.68
21.	N1P1K2OM1	15	2.24	0.93	0.50	13.26	9.34	123.85
22.	N0P2K2OM1	15	1.25	0.56	0.26	11.66	7.46	86.98
23.	N3P3K2OM1	18	4.00	1.45	0.63	14.84	10.02	148.70
24.	N0P0K0OM1	15	1.35	0.62	0.30	11.7	7.72	90.32
Mean		**17**	**2.99**	**1.30**	**0.59**	**14**	**9**	**131**

APPENDIX V

Correlation between important parameter of cauliflower

	Curd Yield	SN	SP	SK	OC	FN	FP	FK	UN	UP	UK	No. of leaves	Gross Plant Wt.	Marketable Curd Wt.	Net Curd Wt.	Curd Diameter	Curd Depth	Curd Size Index
Curd Yield	1	NS	0.262*	NS	NS	0.696**	0.445**	0.403**	0.428**	0.401**	0.265*	0.618**	0.816**	0.823**	0.782**	0.455**	0.735**	0.668**
SN		1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SP			1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SK				1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
OC					1	NS	NS	NS	NS	NS	NS	NS	0.236*	NS	NS	NS	NS	NS
FN						1	0.582**	0.449**	0.249*	0.259*	NS	0.754**	0.869**	0.870**	0.862**	4.7000	0.853**	0.712**
FP							1	0.545**	NS	NS	NS	0.424**	0.483**	0.487**	0.508**	0.239*	0.542**	0.408**
FK								1	NS	NS	NS	NS	0.405**	0.414**	0.422**	NS	0.431**	0.299*
UN									1	0.951**	0.724**	0.348**	0.412**	0.402**	0.328**	0.298*	0.335**	0.351**
UP										1	0.748**	0.354**	0.409**	0.393**	0.331**	0.315**	0.365**	0.373**
UK											1	NS	0.244*	0.254*	NS	NS	NS	0.232*
No. of leaves												1	0.719**	0.748**	0.752**	0.467**	0.729**	0.664**
Gross Plant Wt.													1	0.986**	0.914**	0.528**	0.870**	0.775**
Marketable Curd Wt.														1	0.937**	0.534**	0.891**	0.790**
Net Curd Wt.															1	0.576**	0.924**	0.834**
Curd Diameter																1	0.610**	0.913**
Curd Depth																	1	0.872**
Curd Size Index																		1

APPENDIXVI

P and K Soil test value extracted by different methods

Strip I

Plot No.	Treatments	AB-DTPA P	Mehlich-I P	Bray-P	AB-DTPA K	Mehlich-I K	Non- Exchangeable -K
1.	N2P1K2OM1	20.67	22.47	11.17	358.94	371.29	376.18
2.	N3P3K1OM1	19.88	21.68	10.38	393.44	376.90	381.79
3.	N1P2K2OM1	21.06	22.86	11.57	386.98	399.33	348.90
4.	N3P2K2OM1	17.90	19.70	8.41	350.78	363.13	368.02
5.	N2P1K1OM0	19.09	20.89	9.59	397.92	383.65	388.54
6.	N2P2K1OM0	21.06	22.86	11.57	368.80	381.15	386.04
7.	N0P0K0OM0	23.04	24.84	13.54	367.89	380.24	385.13
8.	N1P1K1OM0	18.30	20.10	8.80	365.87	378.22	383.11
9.	N3P3K3OM2	19.48	21.28	9.99	367.68	380.03	384.92
10.	N3P1K1OM2	21.46	23.26	11.96	350.78	363.13	368.02
11.	N0P0K0OM2	20.67	22.47	11.17	386.72	399.07	300.98
12.	N2P3K3OM2	22.25	24.05	12.75	383.52	395.87	350.98
13.	N0P2K2OM2	21.06	22.86	11.57	381.28	393.63	398.52
14.	N3P2K3OM2	20.27	22.07	10.78	354.24	366.59	371.48
15.	N1P1K2OM2	21.46	23.26	11.96	381.28	393.63	398.52
16.	N3P3K2OM2	22.64	24.44	13.14	383.52	395.87	328.98
17.	N3P2K1OM0	23.43	25.23	13.93	357.76	370.11	375.00
18.	N2P0K2OM0	21.56	23.36	12.06	383.52	395.87	387.90
19.	N1P2K1OM0	21.16	22.96	11.67	381.28	393.63	298.07
20.	N2P2K3OM0	19.98	21.78	10.48	366.72	379.07	383.96
21.	N2P2K0OM1	20.77	22.57	11.27	394.72	389.56	394.45
22.	N0P0K0OM1	17.61	19.41	8.11	373.44	385.79	390.68
23.	N2P2K2OM1	18.40	20.20	8.90	388.00	378.54	383.43
24.	N2P3K2OM1	18.79	20.59	9.30	351.04	363.39	368.28
Mean		**20.50**	**22.30**	**11.00**	**374.01**	**382.40**	**370.91**

STRIP-II

Plot No.	Treatments	AB-DTPA P	Mehlich-I P	Bray-P	AB-DTPA K	Mehlich-I K	Non-Exchangeable -K
1.	N3P2K1OM1	19.58	21.38	10.09	300.98	313.33	318.22
2.	N2P2K3OM1	18.00	19.80	8.51	396.96	398.56	367.98
3.	N2P0K2OM1	17.61	19.41	8.11	373.20	385.55	390.44
4.	N1P2K1OM1	17.70	19.50	8.20	315.20	327.55	332.44
5.	N2P3K3OM0	19.67	21.47	10.18	312.72	325.07	329.96
6.	N3P1K1OM0	20.46	22.26	10.97	373.20	385.55	390.44
7.	N3P2K3OM0	21.25	23.05	11.76	382.16	394.51	399.40
8.	N0P2K2OM0	17.30	19.10	7.81	386.64	398.99	389.07
9.	N2P2K2OM2	18.88	20.68	9.39	279.12	391.50	396.39
10.	N2P3K2OM2	20.86	22.66	11.36	243.28	355.89	360.78
11.	N0P0K0OM2	16.91	18.71	7.41	402.32	378.40	383.29
12.	N2P1K2OM2	17.70	19.50	8.20	299.28	311.63	316.52
13.	N3P3K1OM2	20.07	21.87	10.57	360.88	373.23	378.12
14.	N3P2K2OM2	22.04	23.84	12.54	311.60	323.95	328.84
15.	N1P2K2OM2	20.86	22.66	11.36	286.96	356.89	361.78
16.	N2P2K0OM2	19.67	21.47	10.18	312.72	325.07	329.96
17.	N0P0K0OM0	17.30	19.10	7.81	325.04	337.39	342.28
18.	N1P1K2OM0	18.49	20.29	8.99	291.88	304.23	309.12
19.	N3P3K2OM0	20.07	21.87	10.57	297.48	309.83	314.72
20.	N3P3K3OM0	23.23	25.03	13.73	368.04	380.39	385.28
21.	N2P1K1OM1	22.04	23.84	12.54	335.56	347.91	352.80
22.	N2P2K1OM1	22.83	24.63	13.33	344.52	356.87	361.76
23.	N0P0K0OM1	19.67	21.47	10.18	363.56	375.91	380.80
24.	N1P1K1OM1	19.28	21.08	9.78	372.12	384.47	389.36
Mean		**19.64**	**21.44**	**10.15**	**334.81**	**355.94**	**358.74**

STRIP-III

Plot No.	Treatments	AB-DTPA P	Mehlich-I P	Bray-P	AB-DTPA K	Mehlich-I K	Non-Exchangeable -K
1.	N2P3K3OM1	20.86	22.66	11.36	398.65	378.90	383.79
2.	N3P2K3OM1	23.23	25.03	13.73	366.78	379.13	357.90
3.	N3P1K1OM1	24.02	25.82	14.52	387.08	399.43	376.02
4.	N3P3K3OM1	21.65	23.45	12.15	397.16	350.87	355.76
5.	N2P1K2OM0	20.46	22.26	10.28	391.56	379.13	384.02
6.	N2P2K2OM0	22.44	24.24	12.25	394.56	347.91	352.80
7.	N2P3K2OM0	21.25	23.05	11.07	379.24	391.59	396.48
8.	N3P3K1OM0	23.62	25.42	13.43	300.84	313.19	318.08
9.	N2P1K1OM2	20.46	22.26	10.28	321.00	333.35	338.24
10.	N0P0K0OM2	23.93	25.73	13.74	335.56	347.91	352.80
11.	N2P2K1OM2	22.35	24.15	12.17	334.44	346.79	351.68
12.	N1P2K1OM2	21.17	22.97	10.98	342.28	354.63	359.52
13.	N1P1K1OM2	23.14	24.94	12.95	394.56	354.34	359.23
14.	N2P0K2OM2	24.72	26.52	14.53	372.16	384.51	389.40
15.	N2P2K3OM2	22.35	24.15	12.17	366.56	378.91	383.80
16.	N3P2K1OM2	23.54	25.34	13.35	380.00	392.35	397.24
17.	N3P2K2OM0	21.96	23.76	11.77	345.28	357.63	362.52
18.	N1P2K2OM0	22.75	24.55	12.56	364.32	376.67	381.56
19.	N0P0K0OM0	22.35	24.15	12.17	352.00	364.35	369.24
20.	N2P2K0OM0	24.33	26.13	14.14	302.56	314.91	319.80
21.	N1P1K2OM1	22.75	24.55	12.56	351.12	363.47	368.36
22.	N0P2K2OM1	21.96	23.76	11.77	364.56	376.91	381.80
23.	N3P3K2OM1	21.17	22.97	10.98	369.04	381.39	386.28
24.	N0P0K0OM1	20.77	22.57	10.59	379.12	391.47	396.36
Mean		**22.38**	**24.18**	**12.31**	**362.10**	**364.99**	**367.61**

APPENDIX VII

Strip and treatment wise fresh and dry matter yield of plant and curd

Strip I

Plot No.	Treatments	Plant Fresh yield ($q\ ha^{-1}$)	Plant Drymatter yield ($q\ ha^{-1}$)	Curd Fresh yield ($q\ ha^{-1}$)	Curd Drymatter yield ($q\ ha^{-1}$)
1.	N2P1K2OM1	215.00	44.20	176.67	18.93
2.	N3P3K1OM1	346.67	36.13	196.67	19.67
3.	N1P2K2OM1	118.33	35.24	53.33	8.89
4.	N3P2K2OM1	386.67	28.57	90.00	10.00
5.	N2P1K1OM0	253.33	39.71	233.33	35.00
6.	N2P2K1OM0	256.67	44.23	246.67	27.41
7.	N0P0K0OM0	78.33	45.38	46.67	4.67
8.	N1P1K1OM0	90.00	9.17	88.33	8.28
9.	N3P3K3OM2	308.33	40.33	228.33	24.46
10.	N3P1K1OM2	313.33	32.22	200.00	24.00
11.	N0P0K0OM2	61.67	13.64	126.67	13.57
12.	N2P3K3OM2	86.67	23.28	260.00	31.20
13.	N0P2K2OM2	50.00	46.88	211.67	26.46
14.	N3P2K3OM2	290.00	43.70	61.67	7.71
15.	N1P1K2OM2	100.00	20.00	236.67	29.58
16.	N3P3K2OM2	321.67	43.67	191.67	18.70
17.	N3P2K1OM0	233.33	15.11	36.67	5.09
18.	N2P0K2OM0	241.67	22.67	233.33	31.11
19.	N1P2K1OM0	136.67	64.04	86.67	13.00
20.	N2P2K3OM0	270.00	69.72	215.00	29.32
21.	N2P2K0OM1	273.33	41.11	225.00	28.13
22.	N0P0K0OM1	91.67	46.75	106.67	10.00
23.	N2P2K2OM1	295.00	22.25	170.00	24.29
24.	N2P3K2OM1	255.00	26.40	230.00	24.64
Mean		**211.39**	**35.60**	**164.65**	**19.35**

Strip II

Plot No.	Treatments	Plant Fresh yield (q ha^{-1})	Plant Drymatter yield (q ha^{-1})	Curd Fresh yield (q ha^{-1})	Curd Drymatter yield (q ha^{-1})
1.	N3P2K1OM1	368.33	41.81	326.67	24.50
2.	N2P2K3OM1	320.00	69.33	258.33	24.22
3.	N2P0K2OM1	246.67	26.30	206.67	22.14
4.	N1P2K1OM1	200.00	71.60	146.67	18.33
5.	N2P3K3OM0	270.00	56.30	200.00	18.75
6.	N3P1K1OM0	383.33	57.04	325.00	29.85
7.	N3P2K3OM0	393.33	17.80	331.67	30.85
8.	N0P2K2OM0	55.00	30.00	45.00	5.40
9.	N2P2K2OM2	201.67	57.81	178.33	19.81
10.	N2P3K2OM2	193.33	50.13	188.33	17.66
11.	N0P0K0OM2	60.00	9.64	85.00	9.11
12.	N2P1K2OM2	158.33	27.08	105.00	11.14
13.	N3P3K1OM2	250.00	21.43	233.33	22.76
14.	N3P2K2OM2	295.00	48.33	255.00	21.25
15.	N1P2K2OM2	106.67	27.27	101.67	11.86
16.	N2P2K0OM2	218.33	61.86	205.00	19.84
17.	N0P0K0OM0	56.67	35.00	41.67	5.68
18.	N1P1K2OM0	141.67	27.88	113.33	13.22
19.	N3P3K2OM0	486.67	17.08	391.67	41.23
20.	N3P3K3OM0	418.33	32.40	325.00	27.86
21.	N2P1K1OM1	308.33	42.05	250.00	24.39
22.	N2P2K1OM1	311.67	11.46	241.67	24.79
23.	N0P0K0OM1	148.33	49.17	50.00	6.52
24.	N1P1K1OM1	165.00	42.50	113.33	13.22
Mean		**239.86**	**38.80**	**196.60**	**19.75**

Strip III

Plot No.	Treatments	Plant Fresh yield (q ha^{-1})	Plant Drymatter yield (q ha^{-1})	Curd Fresh yield (q ha^{-1})	Curd Drymatter yield (q ha^{-1})
1.	N2P3K3OM1	330.00	36.67	308.33	31.62
2.	N3P2K3OM1	615.00	76.88	413.33	40.00
3.	N3P1K1OM1	465.00	60.00	333.33	40.40
4.	N3P3K3OM1	480.00	63.16	375.00	50.00
5.	N2P1K2OM0	363.33	54.50	285.00	35.63
6.	N2P2K2OM0	291.67	34.03	241.67	25.89
7.	N2P3K2OM0	316.67	30.65	218.33	17.70
8.	N3P3K1OM0	383.33	58.08	283.33	33.06
9.	N2P1K1OM2	210.00	28.64	190.00	21.11
10.	N0P0K0OM2	81.67	18.85	103.33	11.23
11.	N2P2K1OM2	281.67	50.70	216.67	22.81
12.	N1P2K1OM2	133.33	28.07	111.67	14.57
13.	N1P1K1OM2	158.33	29.69	125.00	13.89
14.	N2P0K2OM2	271.67	42.89	195.00	18.28
15.	N2P2K3OM2	230.00	43.13	198.33	23.80
16.	N3P2K1OM2	315.00	54.78	286.67	28.67
17.	N3P2K2OM0	378.33	39.14	333.33	33.33
18.	N1P2K2OM0	160.00	16.67	125.00	15.63
19.	N0P0K0OM0	108.33	16.25	55.00	6.88
20.	N2P2K0OM0	328.33	48.64	228.33	24.46
21.	N1P1K2OM1	218.33	29.11	155.00	24.80
22.	N0P2K2OM1	115.00	19.17	93.33	8.89
23.	N3P3K2OM1	425.00	60.71	241.67	24.17
24.	N0P0K0OM1	121.67	14.48	66.67	9.72
Mean		**282.57**	**39.79**	**215.97**	**24.06**

APPENDIX VIII

Strip and treatment wise N, P and K content (%) in plant and curdof cauliflower

STRIP-I

Plot no.	Treatments	Nitrogen		Phosphorus		Potassium	
		Plant	Curd	Plant	Curd	Plant	Curd
1.	N2P1K2OM1	1.82	2.24	0.12	0.08	0.51	0.62
2.	N3P3K1OM1	1.68	2.80	0.12	0.07	0.56	1.19
3.	N1P2K2OM1	1.33	1.47	0.12	0.07	0.41	0.77
4.	N3P2K2OM1	1.68	3.15	0.11	0.08	0.35	1.29
5.	N2P1K1OM0	2.17	2.94	0.12	0.07	0.30	1.42
6.	N2P2K1OM0	2.1	2.52	0.12	0.07	0.26	0.77
7.	N0P0K0OM0	2.31	2.10	0.12	0.09	0.52	3.84
8.	N1P1K1OM0	2.17	3.15	0.12	0.09	0.55	2.11
9.	N3P3K3OM2	2.38	2.73	0.12	0.08	0.30	1.48
10.	N3P1K1OM2	2.66	2.31	0.12	0.06	0.28	0.65
11.	N0P0K0OM2	1.89	3.22	0.11	0.08	0.34	0.74
12.	N2P3K3OM2	2.1	2.73	0.10	0.10	0.40	1.34
13.	N0P2K2OM2	2.03	3.01	0.11	0.08	0.36	1.67
14.	N3P2K3OM2	1.68	3.15	0.11	0.07	0.24	0.86
15.	N1P1K2OM2	1.54	2.59	0.11	0.08	0.37	2.11
16.	N3P3K2OM2	2.17	2.94	0.13	0.10	0.31	3.03
17.	N3P2K1OM0	1.75	3.01	0.10	0.09	0.39	0.53
18.	N2P0K2OM0	1.47	2.94	0.11	0.09	0.23	0.81
19.	N1P2K1OM0	1.82	2.73	0.12	0.08	0.32	1.76
20.	N2P2K3OM0	1.96	2.45	0.11	0.09	0.33	1.16
21.	N2P2K0OM1	1.61	3.01	0.10	0.07	0.45	0.91
22.	N0P0K0OM1	1.75	2.80	0.11	0.06	0.51	0.82
23.	N2P2K2OM1	1.89	3.01	0.11	0.07	0.33	1.42
24.	N2P3K2OM1	2.03	2.45	0.12	0.10	0.43	0.45
Mean		1.92	2.73	0.11	0.08	**0.38**	1.32

STRIP II

Plot no.	Treatments	Nitrogen		Phosphorus		Potassium	
		Plant	Curd	Plant	Curd	Plant	Curd
1.	N3P2K1OM1	1.82	2.80	0.12	0.06	0.49	0.62
2.	N2P2K3OM1	1.47	1.82	0.09	0.07	0.39	0.78
3.	N2P0K2OM1	1.4	2.94	0.12	0.08	0.36	1.33
4.	N1P2K1OM1	1.4	2.31	0.12	0.07	0.41	1.72
5.	N2P3K3OM0	1.61	2.80	0.11	0.07	0.24	0.42
6.	N3P1K1OM0	1.82	2.80	0.10	0.08	0.23	0.74
7.	N3P2K3OM0	1.96	3.15	0.12	0.07	0.45	1.96
8.	N0P2K2OM0	1.75	2.45	0.10	0.08	0.53	0.95
9.	N2P2K2OM2	1.68	2.45	0.09	0.07	0.38	1.36
10.	N2P3K2OM2	1.82	2.73	0.11	0.08	0.47	1.52
11.	N0P0K0OM2	1.61	2.10	0.10	0.08	0.31	1.05
12.	N2P1K2OM2	1.4	3.01	0.10	0.07	0.42	1.3
13.	N3P3K1OM2	1.89	3.08	0.10	0.08	0.24	1.89
14.	N3P2K2OM2	1.68	3.15	0.10	0.07	0.32	0.88
15.	N1P2K2OM2	1.47	2.87	0.12	0.08	0.40	0.97
16.	N2P2K0OM2	1.26	2.24	0.10	0.06	0.35	1.43
17.	N0P0K0OM0	2.1	2.52	0.12	0.09	0.28	1.72
18.	N1P1K2OM0	1.75	2.45	0.12	0.08	0.37	1.66
19.	N3P3K2OM0	1.96	2.59	0.12	0.08	0.22	1.97
20.	N3P3K3OM0	2.1	2.73	0.11	0.08	0.30	0.86
21.	N2P1K1OM1	2.24	2.66	0.12	0.06	0.34	0.43
22.	N2P2K1OM1	2.1	2.59	0.12	0.09	0.40	1.56
23.	N0P0K0OM1	2.03	2.59	0.12	0.08	0.36	2.3
24.	N1P1K1OM1	1.96	1.47	0.12	0.07	0.26	0.78
Mean		**1.76**	2.60	0.11	0.07	**0.36**	1.26

STRIP III

Plot no.	Treatments	Nitrogen		Phosphorus		Potassium	
		Plant	Curd	Plant	Curd	Plant	Curd
1.	N2P3K3OM1	1.89	3.22	0.13	0.07	0.51	0.71
2.	N3P2K3OM1	2.24	3.15	0.13	0.08	0.41	0.68
3.	N3P1K1OM1	2.1	3.22	0.10	0.07	0.30	1.05
4.	N3P3K3OM1	2.17	2.73	0.11	0.09	0.42	1.45
5.	N2P1K2OM0	2.31	2.73	0.11	0.08	0.44	0.98
6.	N2P2K2OM0	1.47	3.15	0.13	0.08	0.35	1.98
7.	N2P3K2OM0	1.61	2.10	0.11	0.08	0.41	0.91
8.	N3P3K1OM0	1.82	3.01	0.09	0.07	0.29	0.68
9.	N2P1K1OM2	1.61	2.73	0.12	0.07	0.32	1.55
10.	N0P0K0OM2	1.47	3.01	0.12	0.07	0.62	1.15
11.	N2P2K1OM2	1.89	1.47	0.12	0.08	0.57	0.45
12.	N1P2K1OM2	1.75	2.03	0.09	0.08	0.27	0.69
13.	N1P1K1OM2	1.54	2.59	0.11	0.08	0.36	1.52
14.	N2P0K2OM2	1.68	2.59	0.10	0.07	0.40	1.4
15.	N2P2K3OM2	2.24	2.94	0.09	0.08	0.31	0.54
16.	N3P2K1OM2	1.96	1.33	0.10	0.06	0.33	0.75
17.	N3P2K2OM0	2.03	3.08	0.10	0.07	0.37	1.21
18.	N1P2K2OM0	1.68	2.24	0.12	0.09	0.35	3.71
19.	N0P0K0OM0	1.82	2.80	0.11	0.07	0.47	0.76
20.	N2P2K0OM0	2.1	2.80	0.09	0.08	0.52	0.9
21.	N1P1K2OM1	1.96	3.01	0.11	0.08	0.44	0.95
22.	N0P2K2OM1	1.75	3.01	0.10	0.09	0.40	1.45
23.	N3P3K2OM1	1.61	3.01	0.13	0.07	0.44	0.83
24.	N0P0K0OM1	1.89	2.52	0.13	0.08	0.55	2.9
Mean		**1.86**	2.69	0.11	0.08	**0.41**	1.22

Appendix IX

Strip and treatment wise uptake by plant and curd

Strip I

Plot No.	Treatment	Nutrient Uptake by plant			Nutrient Uptake by curd			Total Nutrient Uptake		
		N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
1.	N2P1K2OM1	80.44	5.37	21.75	68.60	1.58	15.19	149.04	6.95	36.94
2.	N3P3K1OM1	53.11	3.25	14.09	44.08	1.63	18.89	97.19	4.89	32.98
3.	N1P2K2OM1	49.33	4.18	12.62	65.10	1.73	29.45	114.43	5.90	42.07
4.	N3P2K2OM1	40.00	3.47	11.77	42.35	1.32	31.53	82.35	4.79	43.30
5.	N2P1K1OM0	63.93	4.53	9.69	52.50	1.29	7.88	116.43	5.82	17.56
6.	N2P2K1OM0	80.50	4.38	10.08	83.57	2.33	22.09	164.07	6.71	32.17
7.	N0P0K0OM0	21.95	1.31	4.17	13.70	0.54	6.85	35.65	1.85	11.02
8.	N1P1K1OM0	16.04	0.88	4.90	13.23	0.42	5.13	29.27	1.30	10.03
9.	N3P3K3OM2	67.76	3.75	15.17	48.55	1.31	26.95	116.31	5.06	42.11
10.	N3P1K1OM2	58.64	3.48	15.21	48.20	1.35	26.84	106.85	4.83	42.05
11.	N0P0K0OM2	98.18	5.68	20.51	97.18	2.27	60.47	186.14	7.87	80.99
12.	N2P3K3OM2	32.60	2.34	9.87	33.52	0.75	14.48	66.12	3.09	24.35
13.	N0P2K2OM2	88.59	4.50	11.16	70.11	1.78	43.02	158.71	6.28	54.18
14.	N3P2K3OM2	73.42	4.33	14.16	66.94	1.43	18.70	140.36	5.76	32.86
15.	N1P1K2OM2	29.40	2.31	8.08	34.04	0.94	11.51	63.44	3.25	19.59
16.	N3P3K2OM2	55.02	4.52	15.46	44.44	1.25	28.37	99.46	5.77	43.83
17.	N3P2K1OM0	31.73	1.77	4.29	14.32	0.49	9.77	46.05	2.26	14.06
18.	N2P0K2OM0	39.67	2.62	8.48	32.39	1.05	21.95	72.06	3.67	30.43
19.	N1P2K1OM0	125.51	7.97	14.09	106.78	3.40	81.22	232.29	11.37	95.31
20.	N2P2K3OM0	146.42	7.84	20.92	76.05	2.26	23.96	222.47	10.10	44.87
21.	N2P2K0OM1	92.09	4.87	14.14	64.88	1.57	10.49	156.97	6.44	24.63
22.	N0P0K0OM1	88.95	5.31	18.89	64.20	2.19	38.67	162.37	7.58	57.55
23.	N2P2K2OM1	45.17	2.60	8.01	23.59	0.68	20.95	68.76	3.29	28.96
24.	N2P3K2OM1	51.74	3.21	6.92	19.99	0.98	10.61	71.74	4.19	17.52
	Mean	**63.76**	**3.94**	**12.27**	**51.18**	**1.44**	**24.37**	**114.94**	**5.38**	**36.64**

Strip II

Plot No.	Treatment	Nutrient Uptake by plant			Nutrient Uptake by curd			Total Nutrient Uptake		
		N	P	K	N	P	K	N	P	K
1.	N3P2K1OM1	76.09	4.89	21.24	30.40	1.10	8.41	106.49	5.99	29.65
2.	N2P2K3OM1	116.48	8.42	38.55	67.20	1.76	28.56	183.68	10.19	67.11
3.	N2P0K2OM1	34.97	3.20	10.68	14.70	0.71	7.70	49.67	3.90	18.38
4.	N1P2K1OM1	120.30	7.84	25.06	98.28	2.53	40.25	218.58	10.37	65.31
5.	N2P3K3OM0	122.16	6.67	17.00	55.65	1.28	26.88	177.81	7.95	43.88
6.	N3P1K1OM0	119.78	7.10	14.94	49.56	1.39	15.14	169.34	8.49	30.09
7.	N3P2K3OM0	41.13	2.14	9.26	18.67	0.79	34.13	59.79	2.92	43.39
8.	N0P2K2OM0	65.10	3.74	16.50	31.50	0.90	21.10	96.60	4.64	37.60
9.	N2P2K2OM2	137.59	6.85	17.58	95.55	2.68	51.80	233.14	9.53	69.38
10.	N2P3K2OM2	133.35	5.79	14.24	63.31	1.73	17.81	196.67	7.52	32.05
11.	N0P0K0OM2	92.93	5.31	16.23	89.05	2.62	42.01	181.97	7.40	58.23
12.	N2P1K2OM2	56.88	2.76	10.73	22.61	0.81	11.10	79.48	3.57	21.82
13.	N3P3K1OM2	43.50	2.44	7.80	15.33	0.42	8.50	58.83	2.86	16.30
14.	N3P2K2OM2	81.20	5.44	11.79	98.00	2.29	26.76	179.20	7.72	38.55
15.	N1P2K2OM2	42.00	2.99	10.04	33.67	1.07	27.43	75.67	4.06	37.47
16.	N2P2K0OM2	134.23	8.07	19.42	86.20	2.86	88.83	220.43	10.93	108.26
17.	N0P0K0OM0	18.21	1.01	3.24	15.03	0.38	3.45	33.24	1.39	6.69
18.	N1P1K2OM0	40.99	3.05	6.53	71.93	2.13	19.82	112.92	5.18	26.34
19.	N3P3K2OM0	31.09	1.97	5.43	66.30	1.93	42.74	97.39	3.90	48.18
20.	N3P3K3OM0	63.50	3.50	10.63	60.38	2.18	28.59	123.88	5.68	39.21
21.	N2P1K1OM1	67.70	4.35	18.84	79.64	1.94	24.08	147.34	6.30	42.92
22.	N2P2K1OM1	20.05	1.31	5.80	21.58	0.49	6.32	41.64	1.79	12.12
23.	N0P0K0OM1	61.25	3.41	13.79	84.66	2.09	14.91	145.91	6.03	28.70
24.	N1P1K1OM1	86.28	4.91	18.28	45.81	1.82	8.41	132.09	6.73	26.69
Mean		**75.28**	**4.47**	**14.32**	**54.79**	**1.58**	**25.20**	**130.07**	**6.04**	**39.51**

Strip III

Plot No.	Treatment	Nutrient Uptake by plant			Nutrient Uptake by curd			Total Nutrient Uptake		
		N	P	K	N	P	K	N	P	K
1.	N2P3K3OM1	69.30	4.73	18.55	101.83	2.32	22.45	171.13	7.05	41.01
2.	N3P2K3OM1	172.20	10.15	31.52	126.00	3.30	27.20	298.20	13.45	58.72
3.	N3P1K1OM1	126.00	6.12	17.88	130.10	2.85	42.42	256.10	8.97	60.30
4.	N3P3K3OM1	137.05	6.63	26.40	136.50	4.58	72.50	273.55	11.21	98.90
5.	N2P1K2OM0	125.90	6.05	23.98	97.26	2.78	34.91	223.15	8.83	58.89
6.	N2P2K2OM0	50.02	4.29	11.84	81.56	2.14	51.27	131.58	6.42	63.11
7.	N2P3K2OM0	49.34	3.26	12.69	37.18	1.43	16.11	86.51	4.70	28.80
8.	N3P3K1OM0	105.71	5.40	16.73	99.50	2.33	22.48	205.20	7.73	39.21
9.	N2P1K1OM2	46.10	3.44	9.11	57.63	1.46	32.72	103.74	4.89	41.83
10.	N0P0K0OM2	29.58	2.35	11.72	28.30	0.94	32.57	56.80	2.85	40.51
11.	N2P2K1OM2	95.82	6.24	28.70	33.53	1.78	10.26	129.35	8.02	38.96
12.	N1P2K1OM2	49.12	2.65	7.58	29.57	1.18	10.05	78.69	3.83	17.63
13.	N1P1K1OM2	45.72	3.30	10.81	35.97	1.17	21.11	81.69	4.46	31.92
14.	N2P0K2OM2	72.06	4.18	17.24	47.35	1.32	25.59	119.41	5.50	42.84
15.	N2P2K3OM2	96.60	3.75	13.20	69.97	1.93	12.85	166.57	5.68	26.05
16.	N3P2K1OM2	107.37	5.51	18.08	38.13	1.72	21.50	145.50	7.23	39.58
17.	N3P2K2OM0	79.45	3.87	14.64	102.67	2.35	40.33	182.12	6.22	54.97
18.	N1P2K2OM0	28.00	2.03	5.90	35.00	1.45	57.97	63.00	3.48	63.87
19.	N0P0K0OM0	27.38	1.78	7.70	20.69	0.51	7.91	48.40	2.44	15.09
20.	N2P2K0OM0	102.15	4.60	25.10	71.04	2.06	22.83	173.19	6.65	47.93
21.	N1P1K2OM1	57.06	3.23	12.81	74.65	1.86	23.56	131.71	5.09	36.37
22.	N0P2K2OM1	33.54	1.87	7.67	26.76	0.79	12.89	60.30	2.66	20.56
23.	N3P3K2OM1	97.75	8.01	26.96	72.74	1.60	20.06	170.49	9.61	47.02
24.	N0P0K0OM1	27.70	1.83	7.94	27.22	0.66	7.39	55.68	2.77	19.63
Mean		**76.29**	**4.39**	**16.03**	**65.88**	**1.85**	**27.04**	**142.17**	**6.24**	**44.09**

APPENDIX X

Regression equation for different functions for the Cauliflower

R^2 value	Regression Equation
0.7730	Linear regression of yield on total uptake of Nitrogen, phosphorus and potassium Yield = 23.6246 + 1.1936 * UN + 2.3804 * UP + 0.0183 * UK
0.7193	Quadratic regression of total uptake of Nitrogen on fertilizer N, soil test value and interaction between soil and fertilizer nutrients Availability index- Alkaline $KMnO_4$-N UN = 103.0747 - 0.3256 * SN + 0.3119 * FN + 0.0036 * FN^2 + 0.0009 * FNSN
0.3150	Quadratic regression of total uptake of Phosphorus on fertilizer P, soil test value and interaction between soil and fertilizer nutrients Availability index- Olsen-P UP = - 1.7096 + 0.2897 * SP + 0.1115 * FP - 0.0002 * FP^2 - 0.0002 * FPSP
0.0984	Quadratic regression of total uptake of Potassium on fertilizer K, soil test value and interaction between soil and fertilizer nutrients Availability index- Amm. Ac.-K UK = 45.6791 - 0.0649 * SK + 0.0183 * FK - 0.0034 * FK^2 + 0.0017 * FKSK
0.1450	Linear regression of yield on soil test value Availability index-combination (Alkaline $KMnO_4$-N, Olsen-P and Amm. Ac.-K) Yield = 187.9481 - 1.5278 * SN + 15.2702 * SP - 0.1125 * SK
0.7589	Quadratic regression of yield on fertilizer N Yield = 59.2139 + 1.2741 * FN + 0.0018 * FN^2
0.2464	Quadratic regression of yield on fertilizer P Yield = 104.7310 + 5.5425 * FP - 0.0524 * FP^2
0.1743	Quadratic regression of yield on fertilizer K Yield = 123.6194 + 2.2596 * FK - 0.0088 * FK^2
0.7738	Linear regression of yield on soil test value and fertilizer doses Availability index-combination (Alkaline $KMnO_4$-N, Olsen-P and Amm. Ac.-K) Yield = 41.4094 - 0.5251 * SN + 5.3090 * SP + 0.0116 * SK + 1.4845 * FN - 0.3687 * FP + 0.2423 * FK
0.7738	Quadratic regression of yield on fertilizer Nitrogen, phosphorus and potassium Yield = 62.5550 + 1.3152 * FN + 0.0017 * FN^2 + 1.2238 * FP - 0.0373 * FP^2 - 1.2278 * FK + 0.0187 * FK^2

0.7909	Quadratic regression of yield on Soil test value and fertilizer dose Availability index-combination (Alkaline $KMnO_4$-N, Olsen-P and Amm. Ac.-K) Yield = 92.8287 - 0.7164 * SN + 4.8818 * SP + 0.0046 * SK + 1.2061 * FN + 0.0019 * FN^2 + 1.2891 * FP - 0.0392 * FP^2 - 1.2749 * FK + 0.0202 * FK^2
0.8008	Quadratic regression of yield on Soil test value, applied nutrient and interaction between soil and applied nutrient Availability index-combination (Alkaline $KMnO_4$-N, Olsen-P and Amm. Ac.-K) Yield = 0.2091 + 0.2246 * SN + 4.9436 * SP - 0.2242 * SK + 2.5999 * FN + 0.0020 * FN^2 + 1.5678 * FP - 0.0354 * FP^2 - 2.8917 * FK + 0.0156 * FK^2 - 0.0087 * FNSN - 0.0303 * FPSP + 0.0071 * FKSK
0.8151	Quadratic regression of yield on Soil test value, applied nutrient, interaction between soil and applied nutrient and among fertilizer nutrient Availability index-combination (Alkaline $KMnO_4$-N, Olsen-P and Amm. Ac.-K) Yield = - 15.6523 + 0.3884 * SN + 5.0354 * SP - 0.2626 * SK + 2.8504 * FN + 0.0021 * FN^2 + 4.1934 * FP - 0.0190 * FP^2 - 4.1502 * FK + 0.0024 * FK^2 - 0.0114 * FNSN - 0.0230 * FPSP + 0.0077 * FKSK - 0.0291 * FNFP + 0.0210 * FNFK - 0.0046 * FPFK
0.8315	Quadratic regression of yield on Soil test value, applied nutrient, interaction between soil and applied nutrient and FYM Availability index-combination (Alkaline $KMnO_4$-N, Olsen-P and Amm. Ac.-K) Yield = - 81.0978 + 0.4808 * SN + 6.5874 * SP - 0.1156 * SK + 2.9951 * FN + 0.0016 * FN^2 + 2.7889 * FP - 0.0365 * FP^2 - 1.9370 * FK + 0.0190 * FK^2 - 0.0107 * FNSN - 0.0927 * FPSP + 0.0028 * FKSK - 33.1806 * ON - 18.8769 * OP + 38.4936 * OK

APPENDIX XI

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	N2P1K2OM1	193.99	194.15	14.37	12.33	318.81	317.33
2	N3P3K1OM1	178.93	178.77	13.58	11.38	284.09	281.94
3	N1P2K2OM1	163.88	164.34	14.76	12.93	330.01	328.66
4	N3P2K2OM1	178.93	178.67	11.60	8.93	308.73	306.74
5	N2P1K1OM0	193.99	194.06	12.79	10.45	288.57	286.53
6	N2P2K1OM0	163.88	163.96	14.76	12.53	259.45	257.17
7	N0P0K0OM0	178.93	179.68	16.74	15.03	327.77	326.16
8	N1P1K1OM0	148.83	149.33	12.00	10.01	307.61	305.97
9	N3P3K3OM2	178.93	178.72	13.18	10.81	258.33	256.35
10	N3P1K1OM2	163.88	163.66	15.16	12.62	291.93	289.67
11	N0P0K0OM2	163.88	164.66	14.37	12.58	277.37	275.48
12	N2P3K3OM2	178.93	179.18	15.95	14.36	306.49	305.28
13	N0P2K2OM2	178.93	179.71	14.76	13.25	330.01	328.89
14	N3P2K3OM2	224.09	223.81	13.97	11.54	244.89	242.83
15	N1P1K2OM2	193.99	194.43	12.06	13.33	325.53	324.22
16	N3P3K2OM2	163.88	163.72	13.24	14.21	294.17	292.25
17	N3P2K1OM0	148.83	148.67	14.03	14.89	268.41	266.09
18	N2P0K2OM0	178.93	178.94	12.06	12.59	294.17	292.20
19	N1P2K1OM0	163.88	164.23	11.66	12.65	291.93	289.93
20	N2P2K3OM0	178.93	178.94	10.48	11.14	277.37	275.51
21	N2P2K0OM1	178.93	178.97	11.27	12.05	305.37	303.10
22	N0P0K0OM1	193.99	194.69	8.11	9.20	284.09	282.19
23	N2P2K2OM1	163.88	163.89	8.90	9.45	298.65	296.68
24	N2P3K2OM1	178.93	179.00	9.29	10.17	261.69	259.65
Mean		**176.43**	**176.59**	**12.88**	**12.02**	**293.14**	**291.28**

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	N3P2K1OM1	148.83	148.49	10.08	10.29	90.33	86.61
2	N2P2K3OM1	163.88	163.86	8.50	8.94	307.61	305.84
3	N2P0K2OM1	146.43	148.91	8.11	8.55	330.01	328.33
4	N1P2K1OM1	191.59	194.33	8.90	9.86	225.85	223.53
5	N2P3K3OM0	176.53	178.99	10.87	11.79	331.13	329.69
6	N3P1K1OM0	176.53	178.56	11.66	11.85	293.05	290.54
7	N3P2K3OM0	176.53	178.54	12.45	12.75	302.01	299.96
8	N0P2K2OM0	191.59	194.72	8.50	9.90	306.49	305.21
9	N2P2K2OM2	161.48	164.00	10.08	10.96	195.54	196.60
10	N2P3K2OM2	177.73	179.01	12.06	13.08	159.70	160.52
11	N0P0K0OM2	192.79	194.71	8.11	9.25	318.74	320.53
12	N2P1K2OM2	177.73	179.15	8.90	9.94	215.70	217.13
13	N3P3K1OM2	162.68	163.68	11.27	12.06	277.30	278.45
14	N3P2K2OM2	162.68	163.65	13.24	13.92	228.02	229.02
15	N1P2K2OM2	192.79	194.41	12.06	13.37	203.38	204.74
16	N2P2K0OM2	177.73	178.98	10.87	11.66	229.14	229.88
17	N0P0K0OM0	162.68	164.66	8.50	9.70	241.46	242.82
18	N1P1K2OM0	192.79	194.39	9.69	10.73	210.10	211.47
19	N3P3K2OM0	162.68	163.41	11.27	11.35	215.70	216.17
20	N3P3K3OM0	177.73	178.56	14.43	14.96	286.26	287.59
21	N2P1K1OM1	162.68	163.87	13.24	13.84	253.78	254.74
22	N2P2K1OM1	177.73	178.92	14.03	14.81	262.74	263.78
23	N0P0K0OM1	192.79	194.65	10.87	11.99	281.58	283.24
24	N1P1K1OM1	177.73	179.36	10.48	11.56	329.74	331.80
Mean		**174.35**	**175.91**	**10.76**	**11.55**	**253.97**	**254.09**

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	N2P3K3OM1	192.79	193.83	12.06	12.55	320.78	322.57
2	N3P2K3OM1	162.68	163.37	14.43	14.46	325.26	326.73
3	N3P1K1OM1	177.73	178.54	15.22	15.54	305.10	306.28
4	N3P3K3OM1	162.68	163.44	12.85	13.08	315.18	316.71
5	N2P1K2OM0	162.68	163.81	11.66	12.03	309.58	311.17
6	N2P2K2OM0	177.73	178.92	13.64	14.40	352.14	354.12
7	N2P3K2OM0	162.68	163.93	12.45	13.36	297.26	299.00
8	N3P3K1OM0	177.73	178.63	14.82	15.56	218.86	219.70
9	N2P1K1OM2	192.79	194.04	12.76	12.46	239.02	240.29
10	N0P0K0OM2	182.53	179.67	15.13	15.44	253.58	255.17
11	N2P2K1OM2	167.48	163.93	13.55	13.27	249.66	253.72
12	N1P2K1OM2	197.59	194.39	12.37	12.50	257.50	261.96
13	N1P1K1OM2	167.48	164.30	14.34	14.40	278.78	283.32
14	N2P0K2OM2	182.53	179.00	15.92	15.64	256.38	260.77
15	N2P2K3OM2	167.48	163.96	13.55	13.35	250.78	255.34
16	N3P2K1OM2	182.53	178.62	14.74	14.20	264.22	268.13
17	N3P2K2OM0	197.59	193.57	13.16	12.33	229.50	233.27
18	N1P2K2OM0	167.48	164.30	13.95	14.09	248.54	253.11
19	N0P0K0OM0	197.59	194.69	13.55	13.73	236.22	240.49
20	N2P2K0OM0	182.53	178.94	15.53	15.28	94.81	91.23
21	N1P1K2OM1	167.48	164.25	13.95	13.85	243.77	241.75
22	N0P2K2OM1	182.53	179.61	13.16	13.41	257.21	255.47
23	N3P3K2OM1	197.59	193.73	12.37	12.02	261.69	259.48
24	N0P0K0OM1	182.53	179.59	11.97	11.91	271.77	269.66
Mean		**178.85**	**177.13**	**13.63**	**13.70**	**264.07**	**265.81**

VITA

The authoress of the thesis, Ms. Alka Arya daughter of Mr. Sujan Arya, was born on 31th January 1989 at Haldwani (Uttarakhand). She passed her High School and Intermediate Examination conducted by Uttarakhand Board from Khalsa National Girls Inter College, Haldwani (Uttarakhand) in the year 2004 and 2006 respectively. She completed her graduation and post graduation from Govind Ballabh Pant University of Agriculture and Technology, Pantnagar in the year 2012 and 2014 respectively. Finally joined in Ph.D with major in Soil Science and minor in Vegetable Science at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar in 2015.

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Thesis title	:	**"Optimization of fertilizer doses through STCR approach for cauliflower (*Brassica oleracea* L var. botrytis) grown in Mollisols"**			
Advisor	:	**Dr. Sobaran Singh**			

ABSTRACT

Field experiments were conducted at Vegetable Research Centre during 2015-16 and at Crop Research Centre during 2016-17 of G.B. Pant University of Agriculture and Technology Pantnagar, U.S Nagar (Uttarakhand) to optimize fertilizer doses for cauliflower grown in Mollisols. The experiments were conducted as per the technical programme and methodology of AICRP on soil test crop response in soil. In first phase soil fertility gradient was created by dividing experimental field into three equal strips and applying graded doses of fertilizers in these strips and growing of exhaust crop maize (var. Kanchan). In the second phase, i.e. next season test crop cauliflower (var. Snowball-16) was grown by dividing each strip into 24 plots having 21 treated and 3 control. 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, 30, 60 and 90 kg P_2O_5 ha^{-1}) and four levels of potassium (0, 30, 60 and 90 kg K_2O ha^{-1}) at different fertility levels of cauliflower was studied. Verification trial, i.e. second experiment was conducted during 2016-17 to validate the fertilizer adjustment equations developed in first experiment. Follow up trial, i.e. third experiment was conducted on farmer's field at Golapaar, Haldwani during 2016-17.

The value of the organic carbon, Alkaline $KMnO_4$ extractable nitrogen, Olsen's phosphorus and neutral normal NH_4OAc extractable potassium in the experimental field ranged between 0.48-1.35 per cent, 137.98 to 200.98 kg N ha^{-1}, 15.01 to 22.12 kg P ha^{-1} and 99.68 to 365.12 kg K ha^{-1} respectively. Statistically it was established that there was difference in available N, P & K status in experimental field. The average curd yield of experimental field ranged from 50.00-615.00 with an average of 244.61 q ha^{-1}. Total average uptake of N, P and K were 129.06, 5.89 and 39.74 kg ha^{-1}, respectively. Nutrient requirement to produce one quintal curd yield, cauliflower required 0.70 kg of nitrogen, 0.03 kg of phosphorus (P) and 0.23 kg of potassium (K). Per cent contribution of N, P and K was 33.20, 13.84 and 8.13 from soil and 45.62, 2.19 and 13.50 from FYM, 75.27, 15.62 and 54.68 from chemical fertilizer and 82.44, 16.50 and 55.63 from conjoint use of chemical fertilizer with FYM. Coefficient of determination (R^2) was found highly significant (0.831**) between curd yield, soil test values, applied fertilizer doses, their interaction and also FYM. Maximum response to cauliflower obtained at 100 kg N, 50 kg P_2O_5 and 100 kg K_2O ha^{-1}. Curd yield was also significantly correlated with growth parameter of cauliflower. Quality parameter of cauliflower, i.e. protein content, ascorbic acid, total phenols and flavonoids in different treatments were significantly superior over control. Prediction equations were developed for available N, P and K. Results of verification and follow up trials clearly established the superiority of target yield approach over general fertilizer recommendation. Thus, with the help of above findings, fertilizer prescription equation for cauliflower was developed which may also be used for similar soil and climatic condition after verification trial.

(Sobaran Singh)
Advisor

(Alka Arya)
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सारांश

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षट्मास एवं प्रवेश वर्ष	:	प्रथम, 2015-16	**उपाधि**	:	पी॰एच॰डी॰
मुख्य विषय	:	मृदा विज्ञान	**विभाग**	:	मृदा विज्ञान
गौण विषय	:	सब्जी विज्ञान			
शोध ग्रंथ शीर्षक	:	**''एस॰टी॰सी॰आर॰ तकनीक के द्वारा मौलिसोल मृदाओ में उगाई गयी फूलगोभी (*Brassica oleracea* L. var. Botrytis) के लिए उर्वरक मात्राओं का अनुकूलन''**			
सलाहकार	:	**डॉ॰ सोबरन सिंह**			

प्रस्तुत शोध कार्य 2015-16 में सब्जी अनुसंधान केंद्र एवं 2016-17 में फसल अनुसंधान केंद्र, गो॰ ब॰ पंत कृषि एवं प्रौ॰ विश्वविद्यालय पंतनगर में मौलिसाल में उत्पादित फूलगोभी के लिए उर्वरक की मात्रा का अनुकूलन करने के लिए किया गया। शोध कार्य मृदा परीक्षण एवं फसल अनुक्रिया सहसंबंध पर अखिल भारतीय समन्वित शोध परियोजना के तकनीकी कार्यक्रम के अनुसार किया गया। पहले चरण मे प्रायोगिक क्षेत्र को तीन समान पट्टियों में बाटकर एवं उनमे श्रेणीबद्ध उर्वरक की मात्रा डालकर तथा उर्वरताहारी फसल मक्का (किस्म- कंचन) को उगाकर मृदा की उर्वरता प्रवणता को विकसित किया गया। द्वितीय चरण अर्थात अगले मौसम में प्रत्येक पट्टी को 24 खंडो मे बाटकर, परीक्षण फसल फूलगोभी (किस्म- स्नोबॉल- 16) को उगाया गया । जिसमे 21 उपचारित एवं तीन अनुपचारित खंड थे। एफ॰ वाई॰ एम॰ के तीन स्तर (0, 10 एवं 20 टन हे॰$^{-1}$), नाइट्रोजन के चार स्तर (0, 50, 100 एवं 150 किग्रा॰ नाइट्रोजन हे॰$^{-1}$), फास्फोरस के चार स्तर (0, 30, 60 एवं 90 किग्रा॰ फास्फोरस हे॰$^{-1}$) एवं पोटेशियम के चार स्तर (0, 30, 60 एवं 90 किग्रा॰ पोटाश हे॰$^{-1}$) का अध्यन फूलगोभी के विभिन्न उर्वरता स्तरों पर किया गया। मृदा परीक्षण मान, पोषक तत्व उद्ग्रहण, फूल की उपज से फूलगोभी के लिये मूलभूत आकड़े तैयार किए गये। इन आकड़ों से फूलगोभी के लिये मृदा परीक्षण मानों एवं लक्षित उपज आधारित समीकरणों का विकास किया गया। प्रथम प्रयोग में विकसित उर्वरक समायोजन समीकरणों के अध्यन के लिए 2016-17 में सत्यापन प्रयोग (द्वितीय प्रयोग) किया गया। तीसरा प्रयोग जो कि एक अनुसरण प्रयोग था, 2016-17 के दौरान किसान के खेत पर गोलपार, हल्द्वानी में किया गया।

प्रायोगिक क्षेत्र में जैव कार्बन, क्षारीय पोटेशियम परमेगनेट से निष्कर्षित नाइट्रोजन, ओल्सेन फास्फोरस एवं सामान्य उदासीन अमोनियम ऐसिटेट निष्कर्षित पोटेशियम का परिसर मान क्रमशः 0.48-1.35 प्रतिशत, 137.98- 200.98 किग्रा॰ हे॰$^{-1}$, 15.01-22.12 किग्रा॰ हे॰$^{-1}$ एवं 99.68- 365.12 किग्रा॰ हे॰$^{-1}$ के मध्य था। जोकि प्रायोगिक क्षेत्र में उपलब्ध नाइट्रोजन, फास्फोरस एवं पोटेशियम के स्तर में विभिन्नता दर्शाता है। इस प्रयोग में फूलगोभी की उपज 50.00 से 6.15 कु॰ हे॰$^{-1}$ के मध्य एवं औसत उपज 244.61 कु॰ हे॰$^{-1}$ थी। नाइट्रोजन, फास्फोरस एवं पोटेशियम का पूर्ण औसत अंतःग्रहण क्रमशः 129.06, 5.89 एवं 39.74 किग्रा॰ हे॰$^{-1}$ था। एक क्विंटल फूलगोभी की पैदावार के उत्पादन के लिए 0.70 किग्रा॰ नाइट्रोजन, 0.03 किग्रा॰ फास्फोरस एवं 0.23 किग्रा॰ पोटेशियम का प्रयोग पोषक तत्वों के रूप मे आवश्यक पाया गया।

इस परीक्षण मृदा में नाइट्रोजन, फास्फोरस, पोटेशियम का योगदान क्रमशः मिट्टी से 33.20, 13.84 एवं 8.13 प्रतिशत जबकि एफ॰ वाई॰ एम॰ से 45.62, 2.19 एवं 13.50 प्रतिशत पाया गया। प्रयोग मे लाये गए नाइट्रोजन, फास्फोरस एवं पोटेशियम उर्वरको से पोषक तत्वों के उपयोग की क्षमता क्रमशः 75.27, 15.62 एवं 54.68 प्रतिशत एवं उर्वरक और एफ॰ वाई॰ एम॰ के संयुक्त प्रयोग से नाइट्रोजन, फास्फोरस एवं पोटेशियम के उपयोग की क्षमता क्रमशः 82.44, 16.50 एवं 55.63 पायी गयी।

फूलगोभी की कुल उपज, मृदा परीक्षण मानों, प्रयोग मे लाये गए उर्वरक, मृदा एवं उर्वरकों की अनुक्रिया एवं एफ॰ वाई॰ एम॰ के मध्य प्रतिगमन गुणांक (R^2) अत्यंत सार्थक (0.831) पाया गया। उच्चतम फसल अनुक्रिया 100 किग्रा॰ नाइट्रोजन, 50 किग्रा॰ फास्फोरस एवं 100 किग्रा॰ पोटेशियम मे प्राप्त हुई। फूल उपज भी फूलगोभी के वृद्धि मानक के साथ सार्थक रूप से सहसम्बंधित पायी गयी। फूलगोभी के गुणवत्ता वाले मानक जैसे कि प्रोटीन मान, एस्कार्बिक अम्ल, संपूर्ण फेनोल एवं फ्लेवेनोइड विभिन्न उपचारों में सार्थक रूप से कंट्रोल से बेहतर पाये गए। फसल की कटाई के बाद उपलब्ध नाइट्रोजन, फास्फोरस एवं पोटेशियम के लिए आंकलन अनुमान समीकरण विकसित किए गए। सत्यापन तथा अनुसरण प्रयोगों के परिणाम से लक्ष्य उपज प्रणाली, सामान्य उर्वरक संस्तुति की अपेक्षा श्रेष्ठ स्थापित हुई। अतः प्रस्तुत परिणामों के आधार पर फूलगोभी के लिए विकसित किए गए उर्वरक निर्धारण समीकरण, समान मृदा व जलवायवीय परिस्थितियों के लिए सत्यापन प्रयोग के पश्चात प्रयोग किए जा सकते है।

(सोबरन सिंह)
सलाहकार

(अलका आर्या)
लेखिका