V DISCUSSION

The results of the field experiments on “System based nutrient management for maize and groundnut cropping sequences” conducted at farmer’s field, Nulugummanahalli, Gauribidnur taluk located in Eastern Dry Zone of Karnataka during the years 2010-11 and 2011-12 are discussed in this chapter by justifying the variations among treatments with scientific reasoning and in comparison with the results of research carried out by the past research workers elsewhere in the field of nutrient management for maize, groundnut and sunflower crops.

5.1 Weather and crop growth

Environment is a basic and fundamental factor determining the growth of plants. Thus, fluctuation in weather conditions directly affects on crop growth and development and expected yield. The year to year fluctuation in yield is primarily a result of variable weather conditions that prevail in an agro climatic situation apart from soil fertility status. In this context, the weather conditions prevailed during the period of experimentation would definitely have a direct bearing on the potentiality of any crop in general and particular with maize, groundnut and sunflower in the experiment.

During first year in kharif season, the rainfall received during the crop growth period from July to October was 719.9 mm of which 64.4 per cent occurred during the months of July and August. As a consequence, the relative humidity during the early stage of crop growth (July to August) was 2.5 per cent more compared to normal (Table 3.2) and depicted in Fig. 3.1. In addition, cloudy weather prevailed during July and August months led to slight infestation of downy mildew disease in maize and tikka disease in groundnut crops. Even though effective control measures of these diseases were taken up by spraying of suitable recommended agro-chemicals, the growth and yield parameters in both the crops during the
first year were slightly lower compared to the second year in *kharif* season experiments. Hence, the yield of both the crops were lower in the first year compared to the second year. During the second year *kharif* season, there was acute deficit of actual rainfall (85.4 %) compared to normal rainfall in the peak crop growth period of September month. However, crop growth and development were not affected by rainfall since the crops were grown under irrigation condition. The mean daily maximum and minimum temperature were warmer than normal during both the years of crop growth period (July to October) except in the months of August and September in the second year *kharif* season experiments.

With respect to *rabi*-summer experiments, high temperature was prevailed during 2012 especially in the months March and April (44.7 and 42.0 °C, respectively) (Table 3.4) and depicted in Fig. 3.2. Because of high temperature with lower relative humidity, the growth and development of crops were affected in the second year compared to the first year even with assured irrigation. As a consequence, the yields of maize, groundnut and sunflower crops were lower in the second year compared to the first year (Table 4.21, 4.41, 4.81 and 4.100).

### 5.2 Experiment-I: “System based nutrient management for maize groundnut and maize-sunflower sequential cropping systems”

The NPK recommendations being advocated to farmers and included in the package of practice were developed over 40 years ago and these are not matching with the present day intensive agriculture involving high yielding cultivars because of appreciable decline in the organic matter and fertility of soils all over the country. Thus it resulted in stagnation or declining potential yield of many crops in general and maize, sunflower and groundnut in particular. In order to overcome soil fertility problems, experiment on system based nutrient management for maize–groundnut and maize-sunflower sequential cropping systems were taken and the results obtained are discussed in these subheadings in light of earlier findings.
5.2.1 Growth and yield of maize as influenced by different nutrient management practices

Many factors both externally and internally influence the crop growth and productivity. Nutrient management is one such important factor which largely decides the yield of the crop produced. The economic yield of plant is an outcome of a series of integrated interactions of various biological events involving biochemical, physiological and morphological changes which take place during its development in accordance with the supply of light, water, temperature and nutrients (Donald, 1962). The grain yield depends on the synthesis and accumulation of photosynthates and their distribution among various plant parts. The synthesis, accumulation and translocation of photosynthates depend upon efficient photosynthetic structure as well as the extent of translocation into sink (grains) and also on plant growth and development during early stages of crop growth. The production and translocation of synthesized photosynthates depend upon mineral nutrition supplied either by soil or through foliar application. Most of the photosynthetic pathways are dependent on enzymes and coenzymes which are synthesized from mineral elements such as nitrogen, phosphorus and potassium. Nitrogen improves plant growth and productivity by having direct effect on the metabolism of plants. Nitrogen is usually applied through organic or inorganic sources. The time of application as well as the stage of plant growth determines the uptake and translocation of nitrogen. Phosphorus and potassium supply in early vegetative stage has greater influence on yield of crops. Hence, major nutrients play a vital role in growth and yield of crops.

In the present study, results revealed that grain yield of maize differed significantly due to different nutrient management practices. Fertilizer application based on SSNM approach for targeted yield of 100 q ha\(^{-1}\) (T\(_8\)) recorded significantly higher grain yield (93.7 q ha\(^{-1}\)) followed by STCR approach (87.3 q ha\(^{-1}\)) compared to all the other treatments. The percent increase in grain yield through SSNM over recommended dose of fertilizer was 20.8 %. Soil test based NPK recommendation (NK \pm 50 \%) and
P ± 25 %) recorded significantly lower grain yield (70.1 q ha\(^{-1}\)) (Table 4.7 and Fig. 5.3). The stover yields of maize were also significantly higher in the same treatments. Significantly higher grain yield of maize in SSNM and STCR approaches is mainly due to significantly more number of cobs plant\(^{-1}\) (1.77 and 1.63, respectively), higher cob length (25.2 and 23.1 cm, respectively), higher cob weight (321.5 and 298.8 g, respectively), number of rows cob\(^{-1}\) (19.1 and 18.0, respectively), number of seeds row\(^{-1}\) (53.2 and 49.7, respectively) and higher test weight (40.7 and 38.1 g, respectively) (Table 4.5 and 4.6 and Fig. 5.2). The results are in conformity with the findings of Sarita Jha et al. (1997), Singh et al. (2003), Verma et al. (2005), Jayaprakash et al. (2006) and Trinh et al. (2008). The enhanced values of yield attributing characters could be ascribed to the tendency of nitrogen in accelerating growth, photosynthetic activity and translocation efficiency for photosynthates in presence of increasing NPK rates.

The higher values of above mentioned yield components were due to better growth parameters particularly total dry matter production which was significantly higher at harvest stage (413.8 and 387.6 g plant\(^{-1}\), respectively) in SSNM and STCR approaches (Table 4.4 and Fig. 5.1). The results are in conformity with Ahlawat et al. (1975), Shivashankar and Sudhakara Babu (1994) and Arvind Verma et al. (2006) who observed that increase in NPK levels increased the dry matter production. Increase in dry matter production per unit area is a first step in achieving higher yield. Dry matter production during various growth stages of any crop is an important pre-requisite for higher yields as it signifies photosynthetic ability of the crop and also indicates other synthetic processes during developmental sequences. Further, harvest index indicates the percentage of dry matter partitioned and accumulated in the economic portion. Higher values of harvest index (0.47 and 0.46) were observed in SSNM and STCR approaches, respectively over lower levels of fertilizer application.

The other growth parameters responsible for higher yield and yield attributes were significantly higher leaf area (12026.3 cm\(^2\) plant\(^{-1}\) and 10580.3 cm\(^2\) plant\(^{-1}\), respectively) and higher plant height (206.1 cm and
Fig. 5.1: Total dry matter production of maize as influenced by different nutrient management practices in maize based cropping sequences.

Fig. 5.2: Yield parameters of maize as influenced by different nutrient management practices in maize based cropping sequences.

Legend:
T1: Rec. NPK as per package of practice (150:75:40 kg ha⁻¹)
T2: STCR approach for irrigated maize crop (NPK)
T3: Soil test based NPK recommendation (LMH approach) (STL method)
T4: Soil test based NPK recommendation (± 25 %)
T5: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
T6: Soil test based NPK (NK ± 50 % and P ± 25 %)
T7: Modified T3 with respect to P (Rec. NK & 75 % P if P is medium) + PSB
T8: SSNM approach for targeted yield of 100 q ha⁻¹ of maize

FYM @10 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments.
Plate 5.1: Field view of *kharif* maize crop grown with fertilizers application based on recommended NPK as per POP

Plate 5.2: Field view of *kharif* maize crop grown with fertilizers application based on site specific nutrient management
194.1 cm) in SSNM and STCR approaches (Table 4.1 and 4.3 and Plate 5.1 to 5.2). Similar observations on improved growth parameters due to application of higher levels of NPK were made by Singh et al. (2003) and Arvind Verma et al. (2006). The increased plant height might be due to increased efficiency in nutrient availability which contributed for prolonged greenness and larger leaf surface as indicated by leaf area in the present study. The higher leaf area per plant thus enabled the plant to intercept higher quantities of radiant energy.

The increased levels of N, P and K accomplished the requirement of balanced crop nutrition and caused rapid division and elongation of cells resulting in improved plant height, leaf area and dry matter production per plant. The improvement in plant growth parameters is attributed to increased nutrient concentration in plant parts. Being constituents of proteins, chlorophyll etc., they contributed for increased synthesis of carbohydrates which inturn are utilized for building of new cells. The increased mineral nutrient availability has caused higher source activity and coupled with larger leaf area, there was enhanced supply of photosynthates to growth and development of plant.

5.2.2 Nutrient uptake by maize as influenced by different nutrient management practices

Nutrient uptake was increased with the higher level of nutrients by SSNM and STCR approaches compared to other levels (Table 4.8 to 4.10 and Fig. 5.4).

5.2.2.1 Nitrogen

It is known fact that maize is one of the highly exhaustive field crops and N responsive producing higher biomass per unit of external application. Nitrogen being a structural component of proteins involved in various biological functions. The maximum nitrogen uptake (300.4 kg ha\(^{-1}\)) of maize was noticed with the application of fertilizers based on SSNM approach for targeted yield of 100 q ha\(^{-1}\) and it was on par with STCR
approach (288.7 kg ha\(^{-1}\)) (Table 4.8). Soil test based NPK recommendation (NK ± 50 % and P ± 25 %) recorded lower total nitrogen uptake (212.9 kg ha\(^{-1}\)). The higher uptake of nitrogen was due to favourable influence of nitrogen on higher degree of root proliferation, anchorage and deep penetration which in turn absorb higher amount of nutrients from the rhizosphere and supply to the crop resulting in higher dry matter production and higher nitrogen content in grain (1.93 to 2.12 %) and stover (0.88 to 0.98 %) (Appendix IV). The results corroborate with the findings of Tolessa Debele et al. (2001) and Omraj Meena et al. (2007) who stated that higher nitrogen levels enhanced the N uptake by maize. The higher nitrogen content in the seed (2.19 to 2.26 %) and stover (0.95 to 1.01 %) of hybrid maize (Super 900 M) was also reported by Basavaraju (2007).

5.2.2.2 Phosphorus (P\(_2\)O\(_5\))

Significantly higher total uptake of phosphorus (101.7 kg ha\(^{-1}\)) was recorded in SSNM approach for targeted yield of 100 q ha\(^{-1}\) compared to other treatments except STCR approach (99.7 kg ha\(^{-1}\)). Whereas, significantly lower total phosphorus uptake (67.5 kg ha\(^{-1}\)) was noticed in soil test based NPK recommendation (NK ± 50 % and P ± 25 %) (Table 4.9). The higher dose of phosphorus increased the phosphorus uptake in both the years. This was due to more availability of phosphorus with higher doses and deep penetration of roots must have facilitated in absorbing higher amount of nutrients from the rhizosphere. This is in conformity with the findings of Surendra Singh and Sarkar (2001), Tolessa Debele et al. (2001) and Mahala et al. (2006) who observed that higher application of P led to more availability of phosphorus in the soil and inturn it helped to more uptake by the maize crop.

5.2.2.3 Potassium (K\(_2\)O)

Total uptake of potassium (199.6 kg ha\(^{-1}\)) was significantly higher in SSNM approach for targeted yield of 100 q ha\(^{-1}\) compared to all other treatments. Whereas, significantly lower total potassium uptake (120.8 kg
(ha\(^{-1}\)) was recorded in soil test based NPK recommendation (NK \pm 50 \% and P \pm 25 \%) (Table 4.10). The increase in levels of K enhanced the K concentration in soil and uptake by maize. Potassium has a role in enzyme activation, photosynthesis and protein synthesis. It regulates stomatal activity, enhances the transport of sugars, water and nutrients and maintains crop quality. The continuous availability of K resulted in more uptake of potassium compared to lower levels was reported by Sutaliya and Singh (2005) and Omraj Meena et al. (2007).

5.2.3 Effect of different nutrient management practices on availability of nutrients after harvest of maize

5.2.3.1 Available nitrogen

Available N in soil differed significantly due to varied levels of nitrogen application. Plots which received fertilizers based on SSNM approach recorded significantly higher available nitrogen (275.5 kg ha\(^{-1}\)) compared to all the other treatments. Whereas, fertilizers application based on recommended NPK as per package of practice (T\(_1\)) recorded significantly lower available nitrogen (232.5 kg ha\(^{-1}\)) (Table 4.12 and Fig. 5.5). This is due to higher application of nitrogen in SSNM plots. This is in conformity with the results obtained by Banganwa et al. (1988), Dev (1998) and Harikrishna et al. (2005) who have observed that increased nitrogen level resulted in increased N availability in the soil.

5.2.3.2 Available phosphorus (P\(_2\)O\(_5\))

Significantly higher available phosphorus (67.1kg ha\(^{-1}\)) was recorded in SSNM approach for targeted yield of 100 q ha\(^{-1}\) compared to all the other treatments. T\(_7\) treatment [Modified T\(_3\) with respect to P (Rec. NK & 75 \% P if P is medium) + PSB] recorded significantly lower available phosphorus (22.5 kg ha\(^{-1}\)) (Table 4.12 and Fig. 5.5). This is attributed to higher application of phosphorus in SSNM treated plots. The initial low status of available phosphorus raised to high levels commensurating with higher phosphorus application was clearly indicated in the studies of Rekhi et al.
Fig. 5.4: Uptake of N, P₂O₅ and K₂O by maize as influenced by different nutrient management practices in maize based cropping sequences

Fig. 5.5: Available N, P₂O₅ and K₂O by maize as influenced by different nutrient management practices in maize based cropping sequences

Legend:
T₁: Rec. NPK as per package of practice (150:75:40 kg ha⁻¹)
T₂: STCR approach for irrigated maize crop (NPK)
T₃: Soil test based NPK recommendation (LMH approach) (STL method)
T₄: Soil test based NPK recommendation (+ 25 %)
T₅: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
T₆: Soil test based NPK (NK ± 50 % and P ± 25 %)
T₇: Modified T₃ with respect to P (Rec. NK & 75 % P if P is medium) + PSB
T₈: SSNM approach for targeted yield of 100 q ha⁻¹ of maize

FYM @10 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments
(2000) and Mahala et al. (2006). Whereas, the lower availability of phosphorus after harvest of maize in PSB treated plot was mainly due to more uptake of $P_2O_5$ (72.6 kg ha$^{-1}$) with lower application (75 % RDP) compared to recommended dose of phosphorus.

5.2.3.3 Available potassium ($K_2O$)

After harvest of maize, the available potassium was reduced in all the treatments except in SSNM treated plots when compared to initial status of potassium. Significantly higher available potassium (539.8 kg ha$^{-1}$) was recorded in SSNM approach for the targeted yield of 100 q ha$^{-1}$ compared to all the other treatments. Soil test based NPK recommendation (+ 25 % N, P and K if medium) recorded significantly lower available potassium (383.3 kg ha$^{-1}$) (Table 4.12 and Fig. 5.5). Higher application of potassium to SSNM treated plots contributed for higher available potassium in soils after the harvest.

5.2.3.4 Availability secondary and micronutrients

Among secondary nutrients, sulphur is known to be involved in protein synthesis, promote activity and development of enzymes and vitamins and helps in chlorophyll formation. Significantly more available sulphur (19.8 mg kg$^{-1}$) was observed in plots receiving fertilizers based on SSNM approach. Treatment T$^7$ [Modified T$^3$ with respect to P (Rec. NK & 75% P if P is Medium) + PSB] recorded significantly lower available sulphur (11.8 mg kg$^{-1}$) (Table 4.12). A similar trend was observed with respect to calcium and magnesium availability (Table 4.13). Applied single super phosphate contains sulphur and calcium in addition to phosphorus and this might be the reason for higher availability of all these secondary nutrients after harvest of maize compared to initial values.

Availability of boron was found to be significantly higher (0.49 mg kg$^{-1}$) in soil test based NPK recommendation (NK ± 50 % and P ± 25 %) and it was at par with all the other treatments except SSNM approach (0.42 mg kg$^{-1}$). Higher uptake of applied boron could be the possible reason for lower
availability in SSNM treated plots when compared to all the other treatments (Table 4.13).

5.2.4 Economics of maize as influenced by different nutrient management practices

The SSNM approach for a targeted yield of 100 q ha\(^{-1}\) incured more cost on production (₹ 32,068 ha\(^{-1}\)) followed by STCR approach (₹ 29,429 ha\(^{-1}\)). Due to higher cost towards fertilizers based on targeted yield approach, the cost of production was higher in the SSNM approach. However, lower cost on production was recorded in T\(_7\) treatment (₹ 26661 ha\(^{-1}\)).

Due to higher grain and stover yield, the gross returns and net returns were higher in SSNM approach (₹ 94262 and 62195 ha\(^{-1}\), respectively) followed by STCR approach (88029 and 58601 ha\(^{-1}\), respectively) compared to rest of the treatments. Despite increase in the cost of cultivation with SSNM and STCR approaches, the large increase in yield of maize made SSNM and STCR approaches as economical nutrient management practices. Similar results were also reported by Surendra Singh and Sarkar (2001), Anilkumar et al. (2005), Harikrishna et al. (2005), Hongting Wang et al. (2005) and Dhillon et al. (2006) (Table 4.14). However, higher B:C ratio was observed in STCR approach (2.99) followed by SSNM approach (2.94). The lower B:C ratio of maize in SSNM approach was due to higher cost of cultivation compared to STCR approach.

5.2.5 Growth and yield of groundnut as influenced by different nutrient management practices

The experimental plots of \textit{kharif} season were divided into 2 plots to raise sunflower and groundnut crops and the same treatments were imposed based on soil test results and soil fertility ratings of major nutrients after the harvest of \textit{kharif} maize crop. The fertility status after harvest of maize crop changed from MMH status to LMH status. Hence,
fertilizers were applied as per the requirement of LMH status to groundnut crop.

The economic yield of a crop is an outcome of a series of interactions of various biological and morphological changes which takes place during its development in accordance with the supply of higher moisture, temperature and nutrients. Pod yield is governed by number of factors which have a direct and indirect impact. The main factors which have direct bearing on pod yield are total number of pods per plant, pod weight per plant, shelling per cent, hundred kernel weight. The growth factor like total dry matter production has an indirect influence on pod yield.

The present study revealed that soil test based NPK recommendation (+ 25 % N, P and K if medium) recorded significantly higher pod yield (19.5 q ha$^{-1}$) compared to all the other treatments and it was on par with soil test based NPK recommendation (NK ± 50 % and P ± 25 %) (T$_6$:18.0 q ha$^{-1}$) (Table 4.21 and Fig. 5.8). The per cent increase in pod yield through soil test based NPK recommendation (+ 25 % N, P and K if medium) over recommended dose of fertilizer was 15.9 %. The differences in yield parameters observed among different fertilizer levels contributed for higher pod yield. Significant increase in yield and yield attributes were noted only by increasing nitrogen upto 25 to 50 %, phosphorus upto 25 % and decreasing K from 25 to 50 % in LMH approach. The soil of experimental field was rated low with respect to available nitrogen, medium with respect to available phosphorus and high with respect to available potassium. This probably explains the response for higher level of nitrogen, phosphorus and lower level of potassium fertilization. However, yield of groundnut tended to decrease with higher dose of nitrogen and potassium. Significantly lower pod yield (11.7 q ha$^{-1}$) was recorded in SSNM approach. The kernel yield and oil yield also followed the same trend as that of pod yield in respective treatments (Table 4.22). Similar results were reported by Reddy et al. (1992), Hameed Ansari et al. (1993), Barik and Mukherjee (1997), Tiwari and Dhakar (1997), Singh and Singh (2001) and Kandil et al. (2007).
Significantly higher pod yield of groundnut in soil test based NPK recommendation (+ 25 % N, P and K if medium) and soil test based NPK recommendation (NK ± 50 % and P ± 25 %) is mainly due to significantly more number of pods plant\(^{-1}\) (18.6 and 18.0, respectively), maximum weight of pods per plant\(^{-1}\) (16.4 and 15.7 g, respectively), higher shelling per cent (71.3 and 70.5 %, respectively) and higher test weight (31.4 and 29.1 g, respectively) (Table 4.20 and 4.21 and Fig. 5.7). The higher values of yield attributes recorded under higher levels of fertilization could be attributed to higher availability of nutrients in optimum level throughout the crop period. Adequate supply of assimilates at the reproductive stage also be the reason and this was in evidence with higher harvest index recorded in the same treatments (0.43) as compared to STCR approach (0.38) and SSNM approach (0.41).

The higher values of above mentioned yield components were due to better growth parameters like total dry matter production at harvest stage (35.0 and 32.6 g plant\(^{-1}\), respectively), more leaf area throughout the crop growth period in T\(_5\) and T\(_6\) treatments respectively (Table 4.18 and 4.19 and Fig. 5.6). However, application of N beyond 150 % of recommended dose did not improve the dry matter accumulation and yield attributes at harvest. This was in conformity with results of Chawale et al. (1993), Tiwari and Dhakar (1997) and Gogoi et al. (2000). The higher dry matter production and leaf area was mainly because of higher plant height with more number of branches noticed in the T\(_5\) and T\(_6\) treatments throughout the crop growth period (Table 4.15 and 4.17 and Plate 5.3 to 5.4). The similar results were evinced by Barik et al. (1998), Gogoi et al. (2000), Subrahmaniyan et al. (2000), Mirhat et al. (2006) and Kandil et al. (2007). The increase in the level of nutrients through fertilizers might have increased the plant height by the promotion of growth characters through rapid meristematic activity in plants. The association of nutrient elements from inorganics produced more number of leaves in the T\(_5\) and T\(_6\) treatments throughout the crop growth period (Table 4.16). The role of phosphorus associated with cell division, cell elongation and
Fig. 5.6: Total dry matter production of *rabi*-summer groundnut as influenced by different nutrient management practices in maize-groundnut cropping sequence.

Fig. 5.7: Yield parameters of *rabi*-summer groundnut as influenced by different nutrient management practices in maize-groundnut cropping sequence.

Fig. 5.8: Pod, haulm and oil yield of *rabi*-summer groundnut as influenced by different nutrient management practices in maize-groundnut cropping sequence.

Legend:
- **T1**: Rec. NPK as per package of practice (25:75:38 kg ha$^{-1}$)
- **T2**: STCR approach for irrigated groundnut crop (NPK)
- **T3**: Soil test based NPK recommendation (± 25 %)
- **T4**: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
- **T5**: Soil test based NPK (NK ± 50 % and P ± 25 %)
- **T6**: Modified T3 with respect to P (Rec. NK & 75 % P if P is medium) + PSB
- **T7**: SSNM approach for targeted yield of 25 q ha$^{-1}$ of groundnut
- **FYM @10 t ha$^{-1}$ and borax @ 10 kg ha$^{-1}$ common for all the treatments**
Plate 5.3: Field view of *rabi*-summer groundnut crop grown with fertilizers application based on recommended NPK as per POP

Plate 5.4: Field view of *rabi*-summer groundnut crop grown with fertilizers application based on soil test based NPK recommendation (+ 25 % N, P and K if medium)
photosynthesis could have in turn aided the plants to produce higher leaf area.

5.2.6 Nutrient uptake by groundnut as influenced by different nutrient management practices

Nutrient uptake was increased with the higher level of N and P compared to recommended dose of N and P (Table 4.23 to 4.25 and Fig. 5.9).

5.2.6.1 Nitrogen

Application of higher levels of N and P significantly influenced the N, P₂O₅ and K₂O uptake by groundnut crop during both the years of study. Nitrogen being a structural component of proteins either as storage protein or proteins as such involved in various biological functions. Among the treatments, soil test based NPK recommendation (+ 25 % N, P and K if medium) recorded significantly higher total nitrogen uptake (94.6 kg ha⁻¹) compared to all other treatments. Whereas, SSNM approach recorded significantly lower total nitrogen uptake (50.8 kg ha⁻¹) (Table 4.23). The nitrogen applied at higher levels were found to be beneficial since hydrolysis of urea would have made nitrogen easily more available to the plant roots which might have contributed for higher N uptake. The similar results were observed by Deka et al. (2001) and Karunakaran et al. (2010). Even with higher level of N, the uptake of N was very low because of poor crop stand in case of SSNM approach. Yakadri and Satyanarayana (1995) reported that there is a close relationship between nutrient uptake and dry matter production in groundnut. The poor crop stand might be due to toxicity of N at initial stage of crop growth.

5.2.6.2 Phosphorus (P₂O₅)

Significantly higher total uptake of phosphorus (25.5 kg ha⁻¹) was recorded in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to other treatments. Whereas, significantly lower total
phosphorus uptake (13.7 kg ha\(^{-1}\)) was noticed in SSNM approach (Table 4.24). The higher dose of phosphorus increased the phosphorus uptake in both the years. This might be due to more availability of phosphorus and deep penetration of roots which in turn absorb higher amount of nutrients from the rhizosphere. Phosphorus being involved in cell division, cell elongation and photosynthesis, naturally the uptake was more in T\(_5\) treatment because of good growth and development of groundnut crop. This is in conformity with the findings of Chitdeshwari \textit{et al.} (2007) and Karunakaran \textit{et al.} (2010).

5.2.6.3 Potassium (K\(_2\)O)

Total uptake of potassium (53.2 kg ha\(^{-1}\)) was significantly higher in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to all the other treatments. Whereas, significantly lower total potassium uptake (31.0 kg ha\(^{-1}\)) was recorded in SSNM approach (Table 4.25). Application of optimum level of potassium along with enhanced N and P levels in LMH status of soil contributed for higher dry matter production which in turn enhances the potassium concentration in both pod and haulm of groundnut. This might be the reason for higher uptake by groundnut in T\(_5\) treatment.

5.2.7 Effect of different nutrient management practices on availability of nutrients after harvest of groundnut

5.2.7.1 Available nitrogen

After harvest of groundnut, the available nitrogen was increased in all the treatments compared to initial status. Available N in soil differed significantly due to varied levels of nitrogen application. Plots which received fertilizers based on SSNM approach recorded significantly higher available nitrogen (476.4 kg ha\(^{-1}\)) compared to all other treatments. This is attributed to both higher application of nitrogen to SSNM plots besides having higher initial N values. Whereas, fertilizers application based on recommended NPK as per package of practice (T\(_1\)) recorded lower available
Fig. 5.9: Uptake of N, P$_2$O$_5$ and K$_2$O by rabi-summer groundnut as influenced by different nutrient management practices in maize-groundnut cropping sequence

Fig. 5.10: Available N, P$_2$O$_5$ and K$_2$O by rabi-summer groundnut as influenced by different nutrient management practices in maize-groundnut cropping sequence

**Legend:**

- **T$_1$:** Rec. NPK as per package of practice (25:75:38 kg ha$^{-1}$)
- **T$_2$:** STCR approach for irrigated groundnut crop (NPK)
- **T$_3$:** Soil test based NPK recommendation (LMH approach) (STL method)
- **T$_4$:** Soil test based NPK recommendation ($\pm$ 25 %)
- **T$_5$:** Soil test based NPK recommendation (+ 25 % N, P and K if medium)
- **T$_6$:** Soil test based NPK (NK $\pm$ 50 % and P $\pm$ 25 %)
- **T$_7$:** Modified T$_3$ with respect to P (Rec. NK & 75 % P if P is medium) + PSB
- **T$_8$:** SSNM approach for targeted yield of 25 q ha$^{-1}$ of groundnut

FYM @10 t ha$^{-1}$ and borax @ 10 kg ha$^{-1}$ common for all the treatments
nitrogen (266.3 kg ha⁻¹) because of lower availability of N at initial stage (Table 4.27 and Fig. 5.10). This is in conformity with the results obtained by Bellakki and Badanur (1997) and Karunakaran et al. (2010).

5.2.7.2 Available phosphorus (P₂O₅)

Significantly more available phosphorus (92.1 kg ha⁻¹) was observed in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to all the other treatments. Higher application of phosphorus (Appendix II) resulted in higher values of available P₂O₅ in T₅ treatment. Because of lower phosphorus application, STCR approach recorded significantly lower available phosphorus (38.0 kg ha⁻¹) (Table 4.27 and Fig. 5.10).

5.2.7.3 Available potassium (K₂O)

After harvest of groundnut, the potassium availability in soil was found to decrease irrespective of the treatments except in SSNM approach over the initial values. The reduction of available potassium in soil could be attributed to the addition of large amount of potassium fertilizer which resulted in increased K fixation as there is increased solution K concentration. Thus pushing the equilibrium between soluble and fixed K in favour of fixed K pool. The same has been reflected in net loss of K from available pool.

Even with more fixation, significantly higher available potassium (549.4 kg ha⁻¹) was recorded in SSNM approach for the targeted yield of 25 q ha⁻¹ compared to all the other treatments. Application of potassium to SSNM plots was higher when compared to crop uptake thus resulting in more available K (Table 4.27 and Fig. 5.10).

5.2.7.4 Availability secondary and micronutrients

Among secondary nutrients, significantly higher available sulphur (23.0 mg kg⁻¹) was recorded in soil test based NPK recommendation (+ 25
% N, P and K if medium) compared to all the other treatments except in SSNM approach for targeted yield of 25 q ha\(^{-1}\) (22.1 kg ha\(^{-1}\)). Treatment T\(_7\) [Modified T\(_3\) with respect to P (Rec. NK & 75% P if P is medium) + PSB] recorded significantly lower available sulphur (16.1 mg kg\(^{-1}\)) (Table 4.27). The available sulphur content of soil varied significantly due to addition of sulphur through single super phosphate and the values were increased with increase in the quantity of single super phosphate added. It indicates that appreciable quantity of the added sulphur through SSP has remained in soil and has been utilized by the succeeding crop. A similar trend was observed with respect to calcium and magnesium availability (Table 4.28). Applied single super phosphate contains sulphur and calcium nutrients in addition to phosphorus and this might be the reason for higher availability of all these secondary nutrients after harvest of groundnut compared to initial values in plots which received appreciably large quantity of SSP.

Availability of zinc was found to be significantly lower (0.59 mg kg\(^{-1}\)) in soil test based NPK recommendation (+ 25 \% N, P and K if medium) compared to all the other treatments (Table 4.28). Higher uptake by the crop was a result of higher dry matter production recorded in the soil test based NPK recommendation when compared to all the other treatments.

### 5.2.8 Economics of groundnut as influenced by different nutrient management practices

The SSNM approach for a target yield of 25 q ha\(^{-1}\) incurred more cost on production (₹ 31,618 ha\(^{-1}\)). It might be due to higher cost towards fertilizers based on targeted yield approach. Because of higher pod yield, the gross returns and net returns (₹ 61,062 ha\(^{-1}\) and ₹ 30,195 ha\(^{-1}\), respectively) with B:C ratio of 1.98 was higher in soil test based NPK recommendation (+ 25 \% N, P and K if medium) compared to rest of the treatments (Table 4.29). Similar results of increased net returns and higher B:C ratio due to increased N and P levels were also reported by Tiwari and Dhakar (1997), Kavimani \textit{et al.} (2002) and Karunakaran \textit{et al.} (2010).
5.2.9 Nutrients balance studies in maize-groundnut based cropping sequence

Balance of nitrogen, phosphorus and potassium in maize-groundnut based cropping sequence as influenced by different nutrient management practices were discussed here under.

5.2.9.1 Nitrogen balance studies

During first and second year, the initial average available nitrogen in soil was 319.2 and 341 kg ha\(^{-1}\), respectively. After harvest of kharif maize and rabi-summer groundnut crops, nitrogen availability in the soil was found to decrease in all the treatments except in SSNM (474.5 and 478.2 kg ha\(^{-1}\), respectively) over the initial values. Even though groundnut crop fixes nitrogen and improves the nitrogen status after its harvest, the availability of nitrogen was lower compared to initial values of 319.2 and 341 kg ha\(^{-1}\), respectively. This was mainly due to exhaustive nature of maize crop as more nitrogen was taken up by maize crop compared to amount of nitrogen added in all the treatments (Table 4.30 and 4.31). This is in conformity with the earlier findings of Tolessa et al. (2001) and Omraj Meena et al. (2007) who also observed that higher uptake of N by maize crop compared to added amount of nitrogen.

5.2.9.2 Phosphorus (P\(_2\)O\(_5\)) balance studies

The initial available of phosphorus in soil during first and second year of experiment was 34.9 kg ha\(^{-1}\) and 32.6 kg ha\(^{-1}\), respectively (Table 4.32 and 4.33). After harvest of kharif maize and rabi-summer groundnut crops, the phosphorus availability in the soil was found to be higher in all the treatments compared to the initial value. The addition of more phosphorus through organic and inorganic sources compared to uptake by the crops and fixation of phosphorus after its application in the soil resulted in more availability. Because of varied levels of phosphorus application and uptake by the crop, the actual balance after harvest of groundnut crop (91.2 kg ha\(^{-1}\) and 93.0 kg ha\(^{-1}\), respectively) were found
The increased level of phosphorus in maize and groundnut based cropping systems was also evinced by Mahala et al. (2006) and Karunakaran et al. (2010). The lower net loss of phosphorus was found to be observed in PSB treated plots (T7) during both the years (Table 4.32 and 4.33). This might be due to solubilisation of fixed phosphorus by bacterial inoculant.

5.2.9.3 Potassium (K2O) balance studies

During the first year, the initial status of potassium before start of the experiment was 604.8 kg ha⁻¹. After harvest of kharif maize and rabi-summer groundnut crops, the potassium availability in the soil was found to decrease in all the treatments except in SSNM approach (640.5 kg ha⁻¹) compared to its initial value. This was mainly due to higher uptake of potassium by both the crops compared to added fertilizer (Table 4.34). The higher uptake of potassium by maize and groundnut crops was also reported by Tolessa et al. (2001), Mandal et al. (2002), Sutaliya and Singh (2005) and Karunakaran et al. (2010). The same trend of potassium balance was observed in second year also (Table 4.35).

5.2.10 Growth and yield of sunflower as influenced by different nutrient management practices

The experimental plots of kharif season were divided into 2 plots to raise sunflower and groundnut crops and the same treatments were imposed based on soil test results and soil fertility ratings of major nutrients after the harvest of kharif maize crop. The fertility status after harvest of maize crop changed from MMH status to LMH status. Hence, fertilizers were applied as per the requirement of LMH status to sunflower crop. However, high status of phosphorus was noticed in SSNM plots after harvest of maize crop. Hence, the requirement of phosphorus was reduced in SSNM approach compared to all the other treatments. In intensive cropping systems, the inherent soil fertility would be depleted, leading to deficiency of important plant nutrients which finally causes poor
productivity. Since sunflower is exhaustive crop, augmenting adequate nutrition plays an important role in boosting the production. Hence, the present investigation was undertaken to supply nutrients for sunflower crop based on different nutrient management practices in maize-sunflower cropping system.

The present study revealed that significantly higher seed yield (29.2 q ha\(^{-1}\)) with higher B:C ratio (2.50) (Fig. 5.13) was registered by application of higher levels of N and K and reduced P level through SSNM approach. The per cent increase in seed yield through SSNM over recommended dose of fertilizer was 42.1 %. Significantly higher seed yield of sunflower in SSNM approach was mainly due to significantly higher head diameter (28.3 cm), more number of seeds head\(^{-1}\) (1203), lower chaffiness per cent (6.8 %), higher test weight (48.6 g) and more seed weight plant\(^{-1}\) (54.6 g) (Table 4.40 and 4.41 and Fig. 5.12). The oil yield followed the same trend of seed yield (Table 4.42). The response of sunflower to nutrient application may be attributed to the fact that addition of fertilizers improved the uptake of nutrients, which might have favored the plants growth and yield contributing characters under SSNM approach. Improvement in seed yield and yield contributing parameters with increasing fertility levels were confirmed by findings of Ujjinaiah et al. (1995), Reddy and Kumar (1996), Singh and Singh (1997), Devidayal and Agarwal (1999), Lal et al. (1998) and Yadav et al. (2009). The enhanced values of yield attributing characters were witnessed due to the tendency of major nutrients in accelerating growth, photosynthetic activity and translocation efficiency of photosynthates towards the reproductive sink.

The higher values of above mentioned yield components were due to better growth parameters like significantly higher leaf area at various growth stages and total dry matter production at harvest stage (183.9 g plant\(^{-1}\)) in SSNM approach (Table 4.38 and 4.39 and Fig. 5.11 and Plate 5.5 to 5.6). The results are in conformity with Reddy and Kumar (1996), Nagavani et al. (1997) and Tomar et al. (1997). The higher leaf area and dry matter production were mainly due to robust growth of sunflower plants
Fig. 5.11: Total dry matter production of *rabi*-summer sunflower as influenced by different nutrient management practices in maize-sunflower cropping sequence

Fig. 5.12: Yield parameters of *rabi*-summer sunflower as influenced by different nutrient management practices in maize-sunflower cropping sequence

Legend:
- \( T_1 \): Rec. NPK as per package of practice (62.5:75:62.5 kg ha\(^{-1}\))
- \( T_2 \): STCR approach for irrigated sunflower crop (NPK)
- \( T_3 \): Soil test based NPK recommendation (LMH approach) (STL method)
- \( T_4 \): Soil test based NPK recommendation (± 25 %)
- \( T_5 \): Soil test based NPK recommendation (+ 25 % N, P and K if medium)
- \( T_6 \): Soil test based NPK (NK ± 50 % and P ± 25 %)
- \( T_7 \): Modified \( T_3 \) with respect to P (Rec. NK & 75 % P if P is medium) + PSB
- \( T_8 \): SSNM approach for targeted yield of 37.5 q ha\(^{-1}\) of sunflower

FYM @ 7.5 t ha\(^{-1}\) and borax @ 10 kg ha\(^{-1}\) common for all the treatments

Fig. 5.13: Seed, stalk and oil yield of *rabi*-summer sunflower as influenced by different nutrient management practices in maize-sunflower cropping sequence
Plate 5.5: Field view of *rabi*-summer sunflower crop grown with fertilizers application based on recommended NPK as per POP

Plate 5.6: Field view of *rabi*-summer sunflower crop grown with fertilizers application based on site specific nutrient management
with maximum plant height of 208.1 cm at harvest stage. The increased plant height might be attributed to increased efficiency in nutrient availability resulting in prolonged greenness and larger leaf surface as indicated by larger leaf area at all the growth stages. Further, harvest index indicates the percentage of dry matter partitioned and accumulated in the economic portion. Higher values of harvest index (0.45) observed in SSNM over lower levels of fertilizer application.

The increased levels of N and K through SSNM approach accomplished the requirement of balanced crop nutrition and caused rapid division and elongation of cells that resulted in improved plant height, leaf area and dry matter production per plant. The improvement in plant growth parameters could also be attributed to increased nutrient concentration especially nitrogen which is an essential constituent of proteins and chlorophyll and it has great physiological importance in plant metabolism.

5.2.11 Nutrient uptake by sunflower as influenced by different nutrient management practices

Since sunflower is highly exhaustive in nature, the nutrients particularly N and K are required in large quantities for exhibiting their potential yield. The present study revealed that nutrient uptake was increased with higher levels of nutrients applied through SSNM approach compared to all the other treatments (Table 4.43 to 4.45 and Fig 5.14).

The total uptake of N, P_2O_5 and K_2O (125.3, 41.8 and 99.2 kg ha\(^{-1}\), respectively) were found to be maximum under SSNM approach for targeted yield of 37.5 q ha\(^{-1}\) (Table 4.43 to 4.45). Whereas, recommended NPK as per package of practice recorded lower N, P_2O_5 and K_2O uptake (64.9, 22.9 and 61.1 kg ha\(^{-1}\), respectively). The increased nutrient application through SSNM approach resulted in greater absorption of nutrients from soil and these in turn led to higher NPK content in seed and
Fig. 5.14: Uptake of N, P₂O₅ and K₂O by rabi-summer sunflower as influenced by different nutrient management practices in maize-sunflower cropping sequence

Fig. 5.15: Available N, P₂O₅ and K₂O by rabi-summer sunflower as influenced by different nutrient management practices in maize-sunflower cropping sequence

Legend:
T₁: Rec. NPK as per package of practice (62.5:75:62.5 kg ha⁻¹)
T₂: STCR approach for irrigated sunflower crop (NPK)
T₃: Soil test based NPK recommendation (LMH approach) (STL method)
T₄: Soil test based NPK recommendation (+ 25 %)
T₅: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
T₆: Soil test based NPK (NK ± 50 % and P ± 25 %)
T₇: Modified T₃ with respect to P (Rec. NK & 75 % P if P is medium) + PSB
T₈: SSNM approach for targeted yield of 37.5 q ha⁻¹ of sunflower
FYM @ 7.5 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments

Fig. 5.16: Maize equivalent yield under different maize based cropping sequences as influenced by different nutrient management practices
stalk. The results are in line with the findings of Mishra et al. (1995), Singh and Singh (1997), Thavaprakash (2000).

5.2.12 Effect of different nutrient management practices on availability of nutrients after harvest of sunflower

5.2.12.1 Available nitrogen

Available N in soil after harvest of sunflower crop differed significantly due to varied levels of nitrogen application in maize-sunflower cropping sequence. During first and second year, the initial status of nitrogen was increased from 273.6 to 467.7 kg ha\(^{-1}\) and 277.3 to 490.6 kg ha\(^{-1}\), respectively after harvest of sunflower through SSNM approach. (Table 4.47 and Fig. 5.15). This might be due to higher application of nitrogen (308.5 kg ha\(^{-1}\)) to sunflower crop than its uptake.

5.2.12.2 Available phosphorus (P\(_2\)O\(_5\))

Application of phosphorus to sunflower crop through STCR approach at the rate of 100 kg ha\(^{-1}\) increased the soil available phosphorus from 42.0 to 77.6 kg ha\(^{-1}\) and 41.0 to 78.2 kg ha\(^{-1}\), respectively during first and second year (Table 4.47 and Fig. 5.15). Higher application of phosphorus to STCR plots left more phosphorus in soil after the harvest. The initial medium status of available phosphorus raised to high levels commensurating with higher phosphorus application. This was evinced by Nalatwadmath et al. (2003) in their studies.

5.2.12.3 Available potassium (K\(_2\)O)

Available potassium in soil after harvest of sunflower crop differed significantly due to varied levels of potassium application in maize-sunflower cropping sequence. During first and second year, the initial status of potassium was increased from 631.5 to 659.6 kg ha\(^{-1}\) and 448.0 to 506.9 kg ha\(^{-1}\), respectively after harvest of sunflower through SSNM
approach (Table 4.47 and Fig. 5.15). This might be due to higher application of potassium (147.5 kg ha\(^{-1}\)) during both the years.

### 5.2.12.4 Availability secondary and micronutrients

Among secondary nutrients, significantly higher available sulphur (24.5 mg kg\(^{-1}\)) was recorded in plots which received the fertilizers based on STCR approach. Whereas, treatment T\(_7\) [Modified T\(_3\) with respect to P (Rec. NK & 75% P if P is Medium) + PSB] recorded significantly lower available sulphur (15.2 mg kg\(^{-1}\)) (Table 4.47). Similarly, availability of calcium and magnesium was also found to be higher in plots which received the fertilizers based on STCR approach (Table 4.48). Applied single super phosphate (100 kg ha\(^{-1}\)) contained sulphur and calcium nutrients in addition to phosphorus and contributed for higher availability of all these secondary nutrients.

Availability of boron was found to be higher (0.73 mg kg\(^{-1}\)) in recommended NPK as per package of practice it was at par with all the other treatments except in SSNM and STCR approaches (0.62 and 0.66 mg kg\(^{-1}\), respectively). Higher uptake of applied boron might be the reason for lower availability in SSNM and STCR plots compared to all the other treatments (Table 4.48).

### 5.2.13 Economics of sunflower as influenced by different nutrient management practices

The SSNM approach for a targeted yield of 37.5 q ha\(^{-1}\) incurred maximum cost on production (₹ 34,397 ha\(^{-1}\)) was due to higher cost towards fertilizers. But due to higher seed yield, the gross returns and net returns were higher in SSNM approach (₹ 86,021 and 51,624 ha\(^{-1}\), respectively) compared to rest of the treatments. Despite increase in the cost of cultivation with SSNM approach, the large increase in seed yield of sunflower made SSNM approach as economical nutrient management practice with higher B:C ratio of 2.50 (Table 4.49). The similar results of higher net returns and B:C ratio with higher levels of nutrients are evinced
5.2.14 Nutrients balance studies in maize-sunflower based cropping sequence

Balance of nitrogen, phosphorus and potassium in maize-sunflower based cropping sequence as influenced by different nutrient management practices are discussed here under.

5.2.14.1 Nitrogen balance studies

During first and second year, the initial average available nitrogen in soil was 319.2 and 341 kg ha$^{-1}$, respectively. After harvest of kharif maize and rabi-summer sunflower crops, the nitrogen availability in the soil was found to decrease irrespective of the treatments except SSNM (467.7 and 490.6 kg ha$^{-1}$, respectively) over the initial values. This was mainly due to exhaustive nature of both maize and sunflower crops which are going to exhaust more of nitrogen compared to added amount in all the treatments (Table 4.50 and 4.51).

5.2.14.2 Phosphorus ($P_{2}O_{5}$) balance studies

The initial average available phosphorus in soil during first and second year of experiment was 34.9 kg ha$^{-1}$ and 32.6 kg ha$^{-1}$, respectively (Table 4.52 and 4.53). After harvest of kharif maize and rabi-summer sunflower crops, the phosphorus availability in the soil was found to be higher irrespective of the treatments compared to initial values. This might be due to addition of more phosphorus through organic and inorganic sources compared to uptake by the crops. Because of varied levels of phosphorus application and uptake by the crop, the actual balance after harvest of sunflower crop (77.6 kg ha$^{-1}$ and 78.2 kg ha$^{-1}$, respectively) were found higher in STCR approach. This was mainly due to higher level of phosphorus application through STCR approach (100 kg ha$^{-1}$). The increased level of phosphorus in maize and sunflower based cropping
systems was also evinced by Nalatwadmath et al. (2003) and Mahala et al. (2006). The lower net loss of phosphorus was found to be observed in PSB treated plots (T7) during both the years (Table 4.52 and 4.53). This might be due to solubilisation of fixed phosphorus by bacterial inoculant.

5.2.14.3 Potassium (K₂O) balance studies

During first year, the initial status of potassium before start of the experiment was 604.8 kg ha⁻¹. After harvest of kharif maize and rabi-summer sunflower crops, the potassium availability in the soil was found to be decreased in all the treatments except SSNM approach (659.6 kg ha⁻¹) compared to initial value. This was mainly due to higher uptake of potassium by both the crops compared to added fertilizer (Table 4.45). The higher uptake of potassium by maize and sunflower crops was also reported by Thavaprakash (2000), Tolessa et al. (2001) and Sutaliya and Singh (2005). The same trend of potassium balance was observed in second year also (Table 4.55).

5.2.15 Maize equivalent yield under different maize based cropping sequences

In maize-sunflower cropping sequence, SSNM approach recorded higher maize equivalent yield of sunflower (84.0 q ha⁻¹) and total maize equivalent yield (177.8 q ha⁻¹) compared to all the other treatments. The higher equivalent yields by SSNM approach was mainly due to higher productivity of both the crops (Table 4.56 and Fig. 5.16).

In maize-groundnut cropping sequence, soil test based NPK recommendation (+ 25 % N, P and K if medium) recorded higher maize equivalent yield of groundnut (59.6 q ha⁻¹) and total maize equivalent yield (140.8 q ha⁻¹) compared to all the other treatments. The higher equivalent yields by soil test based NPK recommendation (+ 25 % N, P and K if medium) was mainly due to higher yield of groundnut (Table 4.56 and Fig. 5.16).
5.2.16 Economics (₹ ha⁻¹) of maize-groundnut and maize-sunflower cropping sequences

In maize-groundnut based cropping sequence, higher gross returns, net returns and B:C ratio (₹ 1,43,084, 84,099 ha⁻¹ and 2.43, respectively) were observed with soil test based NPK recommendation (+ 25 % N, P and K if medium). This might be due to higher productivity of both the crops in general and groundnut crop in particular.

In maize-sunflower cropping sequence, gross returns and net returns (₹ 1,80,283 and 1,13,819 ha⁻¹, respectively) were observed in SSNM approach with higher B:C ratio of 2.71. The higher economical values were mainly due to higher productivity of both the crops coupled with better market price inspite of higher cost of cultivation incurred in this treatment (₹ 66,465 ha⁻¹) (Table 4.57).

5.2.17 Population of soil microorganisms after groundnut-maize and groundnut-sunflower cropping sequences

In maize-groundnut cropping sequence, bacterial population at harvest of groundnut crop was found to be increased in all the treatments compared to initial values during both the years. Significantly higher bacterial population was observed in PSB treated plot (T₇) (52.2 x 10⁵ cfu g⁻¹) and it was on par with treatment T₅ (50.8 x 10⁵ cfu g⁻¹). The higher bacterial population in PSB treated plot compared to uninoculated plots was may be due to build up of inoculated phosphate solubilizing bacteria (PSB) population which inturn helps to higher bacterial population. The results corroborate with the findings of Chesti and Tahir Ali (2012) who have observed that soils treated with PSB registered significantly higher bacterial population over the untreated plots. However, significantly higher population of fungi (32.7 x 10³ cfu g⁻¹) and actinomycetes (21.3 x 10³ cfu g⁻¹) were recorded in plots which received the fertilizers as per soil test based NPK recommendation (+ 25 % N, P and K if medium) and they are on par with treatment T₄ (29.3 x 10³ and 18.5 x 10³ cfu g⁻¹,
respectively) compared to all the other treatments (Table 4.58). The higher population of fungi and actinomycetes in T₅ and T₄ treatments may be due to higher nutrient availability in the rhizosphere as indicated by good growth of groundnut crop. These results are in conformity with the findings of Tilak et al. (1995) and Lalfakzuala et al. (2008) who have stated that higher availability of nutrients in the rhizosphere increased the microbial population.

In maize-sunflower cropping sequence, significantly higher bacterial population was observed in PSB treated plot (T₇) \( (50.7 \times 10^5 \text{ cfu g}^{-1}) \) compared to all the other treatments. The higher bacterial population in PSB treated plot compared to uninoculated plots may be due to build up of introduced beneficial microorganisms (PSB) population which in turn helped higher bacterial population. Gupta (2004) and Chesti and Tahir Ali (2012) have also the same opinion on improvement in bacterial population due to use of PSB. However, significantly higher population of fungi \( (30.0 \times 10^3 \text{ cfu g}^{-1}) \) and actinomycetes \( (19.2 \times 10^3 \text{ cfu g}^{-1}) \) were found in plots applied with fertilizers based on SSNM approach compared to all the other treatments (Table 4.59). The higher population of fungi and actinomycetes was attributed to improvements in soil fertility, higher availability of nutrients and the associated enhanced plant growth and higher rhizodeposition.

5.3 Experiment-II: “System based nutrient management for groundnut–maize and groundnut-sunflower sequential cropping systems”

Field experiment-II was carried out during 20010-11 and 2011-12 to study the system based nutrient management for groundnut–maize and groundnut-sunflower sequential cropping systems. Based on soil fertility ratings and soil test values, the NPK levels were decided as in case of the first experiment.
5.3.1 Growth and yield of groundnut as influenced by different nutrient management practices

Pod yield in groundnut crop depends on the synthesis and accumulation of photosynthates and their distribution among various plant parts during pod filling stage. The production and translocation of synthesized photosynthates in turn depend upon mineral nutrition supplied either by soil or through foliar application. Most of the photosynthetic pathways are dependent on enzymes and coenzymes which are synthesized from mineral elements such as nitrogen, phosphorus and potassium. Since nitrogen is an essential constituent of proteins and chlorophyll and is present in many other compounds of great physiological importance in plant metabolism, it improves plant growth and productivity by having direct effect on the metabolism of plants. Similarly, the supply of phosphorus early in plant life is important in laying down the primordia for the reproductive parts of the plants in addition to root development. Potassium imparts increased vigour and disease resistance to plants and helps in formation of proteins and chlorophyll in groundnut crop. Hence, major nutrients play a vital role in growth and yield of a crop.

The economic yield of a crop is an outcome of a series of interaction of various biological and morphological changes which take place during its development in accordance with the supply of optimum water, temperature and nutrients. Pod yield is governed by a number of factors which have a direct and indirect impact. The main factors which have direct bearing on pod yield are total number of pods per plant, pods weight per plant, shelling per cent, hundred kernels weight. The growth factor like total dry matter production has an indirect influence on pod yield.

The present study revealed that soil test based NPK recommendation (+ 25 % N, P and K if medium) recorded significantly higher pod yield (24.1 q ha⁻¹) compared to all the other treatments (Table 4.66 and Fig. 5.19). The per cent increase in pod yield through soil test based NPK recommendation...
(+ 25 % N, P and K if medium) over recommended dose of fertilizer was 12.9 %. This might be due to differences in yield parameters achieved among different fertilizer levels. The soil of experimental field was rated medium in available nitrogen and phosphorus and high in available potassium. Hence, significant increase in yield and yield attributes were noted only up to increasing N and P by 25 % and decreasing K by 25 % in MMH approach. Whereas, higher levels of nitrogen and potassium through SSNM approach reduced the groundnut yield (16.4 q ha⁻¹). The kernel yield and oil yield also followed the same trend of pod yield in respective treatments (Table 4.67 and Fig. 5.19). Similar results were reported by Reddy et al. (1992), Hameed Ansari et al. (1993), Barik and Mukherjee (1997), Tiwari and Dhakar (1997), Singh and Singh (2001) and Kandil et al. (2007) who also reported that application of NPK at optimum dose improve the pod yield and as N rate increases beyond certain level, there was decrease in pod yield.

Significantly higher pod yield of groundnut in soil test based NPK recommendation (+ 25 % N, P and K if medium) is mainly due to significantly more number of pods plant⁻¹ (25.2), maximum weight of pods per plant⁻¹ (22.9 g), higher shelling per cent (72.8 %) and higher test weight (33.1 g) (Table 4.65 and 4.66 and Fig. 5.18). The higher values of yield attributes recorded under higher levels of fertilization could be attributed to higher availability of nutrients in optimum level throughout the crop period. Adequate supply of assimilates at the reproductive stage could also be the reason and this was amply proved by recording higher harvest index in the same treatment (0.44).

The higher values of above mentioned yield components were due to better growth parameters like total dry matter production at harvest stage (51.9 g plant⁻¹), more leaf area throughout the crop growth period in treatment T₅ (Table 4.63 and 4.64 and Fig. 5.17). However, application of N beyond 125 % of recommended dose did not improve the dry matter accumulation and yield attributes at harvest. This is in conformity with results of Chawale et al. (1993), Tiwari and Dhakar (1997) and Gogoi et al.
Fig. 5.17: Total dry matter production of groundnut as influenced by different nutrient management practices in groundnut based cropping sequences

Fig. 5.18: Yield parameters of groundnut as influenced by different nutrient management practices in groundnut based cropping sequences

Fig. 5.19: Pod, haulm and oil yield of groundnut as influenced by different nutrient management practices in groundnut based cropping sequences

Legend:

T<sub>1</sub>: Rec. NPK as per package of practice (25:75:38 kg ha<sup>-1</sup>)
T<sub>2</sub>: STCR approach for irrigated groundnut crop (NPK)
T<sub>3</sub>: Soil test based NPK recommendation (LMH approach) (STL method)
T<sub>4</sub>: Soil test based NPK recommendation (+25%)
T<sub>5</sub>: Soil test based NPK recommendation (+25% N, P and K if medium)
T<sub>6</sub>: Soil test based NPK (NK±50% and P±25%) (NL method)
T<sub>7</sub>: Modified T<sub>3</sub> with respect to P (Rec. NK & 75% P if P is medium) + PSB
T<sub>8</sub>: SSNM approach for targeted yield of 25 q ha<sup>-1</sup> of groundnut

FYM @10 t ha<sup>-1</sup> and borax @ 10 kg ha<sup>-1</sup> common for all the treatments
The higher dry matter production and leaf area was mainly because of higher plant height with more number of branches noticed in the T₅ treatment throughout the crop growth period (Table 4.60 and 4.62). Similar results were evinced by Barik et al. (1998), Gogoi et al. (2000), Subrahmanian et al. (2000), Mirhat et al. (2006) and Kandil et al. (2007). Increase in the levels of N and P up to 125 % through fertilizers might have increased the plant height by promoting growth characters through rapid meristematic activity in plants. The association of higher quantities of nutrient elements from inorganics produced more number of leaves in the treatment particularly T₅ throughout the crop growth period (Table 4.61). Association of phosphorus nutrient with cell division, cell elongation and photosynthesis helped the plants to produce higher leaf area.

5.3.2 Nutrient uptake by groundnut as influenced by different nutrient management practices

Nutrient uptake was increased with the higher level of N and P compared to recommended dose of N and P (Tables 4.68 to 4.70 and Fig. 5.20).

5.3.2.1 Nitrogen

Application of higher levels of N and P had significantly influenced the N, P and K uptake by groundnut crop during both the years of study. Nitrogen being a structural component of proteins either as storage protein or proteins as such involved in various biological functions. Among the treatments, soil test based NPK recommendation (+ 25 % N, P and K if medium) recorded significantly higher total nitrogen uptake (110.9 kg ha⁻¹) compared to all the other treatments. (Table 4.68). The nitrogen applied at higher level was found to be beneficial since hydrolysis of urea would have made nitrogen easily available to the plant roots which might have contributed for higher N uptake. Similar results were observed by Deka et al. (2001) and Karunakaran et al. (2010). Even with higher level of N, the uptake of N was very low because of poor crop stand in case of SSNM
approach. Yakadri and Satyanarayana (1995) reported that there is a close relationship between nutrient uptake and dry matter production in groundnut. The poor crop stand might be due to toxicity created by higher quantity of N at initial stage of crop growth.

5.3.2.2 Phosphorus (P₂O₅)

Significantly higher total uptake of phosphorus (32.5 kg ha⁻¹) was recorded in soil test based NPK recommendation (+25 % N, P and K if medium) compared to all the other treatments (Table 4.69). Higher dose of phosphorus increased the phosphorus uptake in both the years. This might be due to more availability of phosphorus and deep penetration of roots which in turn absorb higher amount of nutrients from the rhizosphere. Phosphorus being involved in cell division, cell elongation and photosynthesis, naturally caused more uptake in treatment T₅ by promoting good growth and development. This is in conformity with the findings of Chitdeshwari et al. (2007) and Karunakaran et al. (2010). They observed that increased phosphorus level improve the phosphorus uptake that led to significantly higher growth and yield of groundnut crop.

5.3.2.3 Potassium (K₂O)

Total uptake of potassium (69.6 kg ha⁻¹) was significantly higher in soil test based NPK recommendation (+25 % N, P and K if medium) compared to all the other treatments (Table 4.70). Application of optimum level of potassium along with enhanced N and P levels in MMH status of soil contributed for higher dry matter production which inturn enhanced the K concentration in both pod and haulm yield of groundnut. This might be the reason for higher uptake by groundnut in treatment T₅.
5.3.3 Effect of different nutrient management practices on availability of nutrients after harvest of groundnut

5.3.3.1 Available nitrogen

Available N in soil differed significantly due to varied levels of nitrogen application. After harvest of groundnut, higher uptake of nitrogen results in lower availability of nitrogen in treatment T₅ (318.0 kg ha⁻¹) compared to all the other treatments. This is in conformity with the results obtained by Deka et al. (2001) and Chitdeshwari et al. (2007). Whereas, plots which received fertilizers based on SSNM approach recorded significantly higher available nitrogen (451.0 kg ha⁻¹) compared to all the other treatments. This might be due to higher application of nitrogen to SSNM treated plots (Table 4.72 and Fig. 5.21).

5.3.3.2 Available phosphorus (P₂O₅)

Significantly more available phosphorus (69.2 kg ha⁻¹) was observed in soil test based NPK recommendation (+25 % N, P and K if medium) compared to all the other treatments. Higher application of phosphorus (Appendix I) has resulted in more availability of phosphorus in treatment T₅. Because of lower phosphorus application, STCR approach recorded significantly lower available phosphorus (19.0 kg ha⁻¹) (Table 4.27 and Fig. 5.21).

5.3.3.3 Available potassium (K₂O)

After harvest of groundnut, the potassium availability in soil was found to decrease in all the treatments over the initial values. The reduction of available potassium in soil is due to increased potassium uptake besides more fixation in the soil. Even with more fixation, significantly more available potassium (496.5 kg ha⁻¹) was observed in SSNM approach for targeted yield of 25 q ha⁻¹ compared to all the other treatments. This is mainly due to higher application of potassium (Table 4.72 and Fig. 5.21).
Fig. 5.20: Uptake of N, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O by groundnut as influenced by different nutrient management practices in groundnut based cropping sequences.

Fig. 5.21: Available N, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O by groundnut as influenced by different nutrient management practices in groundnut based cropping sequences.

**Legend:**

- \(T_1\): Rec. NPK as per package of practice (25:75:38 kg ha\textsuperscript{-1})
- \(T_2\): STCR approach for irrigated groundnut crop (NPK)
- \(T_3\): Soil test based NPK recommendation (LMH approach) (STL method)
- \(T_4\): Soil test based NPK recommendation (± 25 %)
- \(T_5\): Soil test based NPK recommendation (+ 25 % N, P and K if medium)
- \(T_6\): Soil test based NPK (NK ± 50 % and P ± 25 %)
- \(T_7\): Modified \(T_3\) with respect to P (Rec. NK & 75 % P if P is medium) + PSB
- \(T_8\): SSNM approach for targeted yield of 25 q ha\textsuperscript{-1} of groundnut

FYM @10 t ha\textsuperscript{-1} and borax @ 10 kg ha\textsuperscript{-1} common for all the treatments
5.3.3.4 Available secondary and micronutrients

Among secondary nutrients, higher availability of sulphur (16.5 mg kg\(^{-1}\)) was found in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to all other treatments (Table 4.72). The available sulphur content of soil varied significantly due to addition of sulphur through single super phosphate and the values increased with increase in the quantity of single super phosphate added. It indicated that appreciable quantity of added sulphur through SSP was remained in the soil which could have been utilized by the succeeding crop. A similar trend was observed with respect to calcium and magnesium availability (Table 4.73). Applied single super phosphate contained sulphur and calcium in addition to phosphorus and this could be the possible reason for higher availability of secondary nutrients after harvest of groundnut when compared to their initial values.

Availability of boron was found to be lower (0.59 mg kg\(^{-1}\)) in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to all the other treatments (Table 4.73). Higher uptake by the crop as a result of higher dry matter production is responsible for lower availability of boron in these treatments.

5.3.4 Economics of groundnut as influenced by different nutrient management practices

The SSNM approach for a targeted yield of 25 q ha\(^{-1}\) incurred more cost on production (₹ 30,265 ha\(^{-1}\)). It is due to higher cost towards fertilizers based on targeted yield approach. Because of higher pod yield, the gross returns and net returns (₹ 73,451 ha\(^{-1}\) and ₹ 43,743 ha\(^{-1}\), respectively) with B:C ratio of 2.47 was found to be higher in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to rest of the treatments (Table 4.74). Similar results of increased net returns and higher B:C ratio due to increased N and P levels were reported by
Tiwari and Dhakar (1997), Kavimani et al. (2002) and Karunakaran et al. (2010).

5.3.5 Growth and yield of maize as influenced by different nutrient management practices

The experimental plots of kharif season were divided into 2 plots to raise maize and sunflower crops and the same treatments were imposed based on soil test results and soil fertility ratings of major nutrients after the harvest of kharif groundnut crop. The fertility status after harvest of groundnut crop remains as MMH. Hence, fertilizers were applied as per the requirement of MMH status to maize crop.

In the present study, pooled results revealed that grain yield of maize differed significantly due to different nutrient management practices. Fertilizer application based on SSNM approach for targeted yield of 100 q ha$^{-1}$ ($T_8$) recorded significantly higher grain yield (81.4 q ha$^{-1}$) compared to all the other treatments and the next best yield was observed in STCR approach (75.8 q ha$^{-1}$) (Table 4.81 and Fig. 5.24). The per cent increase in grain yield through SSNM over recommended dose of fertilizer was 20.9 %. The stover yield of maize was also significantly higher with the same treatments. Higher grain yield of maize in SSNM and STCR approaches is mainly due to more number of cobs plant$^{-1}$ (1.53 and 1.41, respectively), higher cob length (20.6 and 18.8 cm, respectively), higher cob weight (257.1 and 239.0 g, respectively), number of rows cob$^{-1}$ (16.8 and 15.9, respectively), number of seeds row$^{-1}$ (43.3 and 40.4, respectively) and higher test weight (38.6 and 36.2 g, respectively) (Table 4.79 and 4.80 and Fig. 5.23). The results are in conformity with the findings of Sarita Jha et al. (1997), Singh et al. (2003), Verma et al. (2005), Jayaprakash et al. (2006) and Trinh et al. (2008). The enhanced values of yield attributing characters witnessed the tendency of nitrogen in accelerating growth, photosynthetic activity and translocation efficiency for photosynthates with increasing NPK rates.
Fig. 5.22: Total dry matter production of \textit{rabi}-summer maize as influenced by different nutrient management practices in groundnut-maize cropping sequence.

Fig. 5.23: Yield parameters of \textit{rabi}-summer maize as influenced by different nutrient management practices in groundnut-maize cropping sequence.

Legend:

T₁: Rec. NPK as per package of practice (150:75:40 kg ha⁻¹)
T₂: STCR approach for irrigated maize crop (NPK)
T₃: Soil test based NPK recommendation (LMH approach) (STL method)
T₄: Soil test based NPK recommendation (±25%)
T₅: Soil test based NPK recommendation (+25% N, P and K if medium)
T₆: Soil test based NPK (NK ±50% and P ±25%)
T₇: Modified T₃ with respect to P (Rec. NK &75% P if P is medium) + PSB
T₈: SSNM approach for targeted yield of 100 q ha⁻¹ of maize

FYM @10 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments.

Fig. 5.24: Grain and stover yield of \textit{rabi}-summer maize as influenced by different nutrient management practices in groundnut-maize cropping sequence.
The higher values of above mentioned yield components were due to better growth parameters particularly total dry matter production. The SSNM approach recorded significantly higher total dry matter production at harvest stage (320.2 g plant^-1) (Table 4.78 and Fig. 5.22). The results are in conformity with Ahlawat et al. (1975), Shivashankar and Sudhakara Babu (1994) and Arvind Verma et al. (2006). Dry matter production during various growth stages of any crop is an important pre-requisite for higher yields as it signifies photosynthetic ability of the crop and also indicates other synthetic processes during developmental sequences. Further, harvest index indicates the percentage of dry matter partitioned and accumulated in the economic portion. Higher values of harvest index (0.46 and 0.45) observed in SSNM and STCR approaches, respectively over lower levels of fertilizer application.

The other growth parameters responsible for higher yield and yield attributes were significantly higher leaf area observed in all the stages and at 60 DAS in particular (9107.4 cm^2 plant^-1) and higher plant height at harvest stage (156.4 cm) in SSNM approach (Table 4.75 and 4.77). The STCR approach was the next best approach in attaining all the growth and yield parameters. Similar observations on improved growth parameters due to application of higher levels of NPK were made by Singh et al. (2003) and Arvind Verma et al. (2006). The increased plant height might be due to increased nutrient availability which might have resulted in prolonged greenness and larger leaf surface as indicated by larger leaf area. The higher leaf area per plant which enabled the plants to intercept higher quantities of radiant energy.

The increased levels of N, P and K accomplished the requirement of balanced crop nutrition and caused rapid division and elongation of cells that resulted in improved plant height, leaf area and dry matter production per plant. The improvement in plant growth parameters could also be attributed to increased nutrient concentration in plant parts which are constituents of proteins, chlorophyll etc., which in turn resulted in increased synthesis of carbohydrates that are being utilized
for build up of new cells. The increased mineral nutrient availability has caused for higher source activity coupled with larger leaf area might have enhanced supply of photosynthates to growth and development of plant.

**5.3.6 Nutrient uptake by maize as influenced by different nutrient management practices**

Nutrient uptake by maize was increased with the higher level of nutrients by SSNM approach compared to other treatments (Tables 4.82 to 4.84 and Fig. 5.25).

It is a known fact that maize is one of the highly exhaustive and nutrients responsive field crop for producing higher biomass per unit of external application of nutrients. The maximum total nitrogen uptake (268.0 kg ha\(^{-1}\)) of maize was noticed with application of fertilizers based on SSNM approach for targeted yield of 100 q ha\(^{-1}\) (Table 4.82). The higher uptake of nitrogen might be due to favourable influence of nitrogen on higher degree of root proliferation, anchorage and deep penetration which in turn absorb higher amount of nutrients from the rhizosphere and supply to the crop resulting in higher dry matter production and higher nitrogen content in grain and stover (Appendix XVI). The results corroborate with the findings of Tolessa Debele *et al.* (2001) and Omraj Meena *et al.* (2007). The higher nitrogen content in the seed (2.19 to 2.26 %) and stover (0.95 to 1.01 %) of hybrid maize (Super 900 M) was also reported by Basavaraju (2007).

Similar trend of nitrogen uptake was observed in phosphorus and potassium uptake, where in significant maximum uptake of phosphorus (95.8 kg ha\(^{-1}\)) and potassium (164.9 kg ha\(^{-1}\)) was noticed in SSNM approach (Table 4.83 and 4.84). The higher dose of phosphorus increased the phosphorus uptake in both the years. This is due to more availability of phosphorus and deep penetration of roots which in turn absorb higher amount of nutrients from the rhizosphere. The results are in conformity with the findings of Surendra Singh and Sarkar (2001), Tolessa *et al.*
(2001) and Mahala et al. (2006). The increase in levels of K enhances the K concentration in the soil and uptake by maize. The continuous availability of K resulted in more uptake of potassium compared to lower levels as reported by Sutaliya and Singh (2005) and (Omraj Meena et al., 2007).

5.3.7 Effect of different nutrient management practices on availability of nutrients after harvest of maize

5.3.7.1 Available nitrogen

Available N in soil differed significantly due to varied levels of nitrogen application. Plots which received fertilizers based on SSNM approach recorded significantly higher available nitrogen (446.5 kg ha\(^{-1}\)) compared to all the other treatments (Table 4.86 and Fig. 5.26). Higher application of nitrogen in SSNM treated plots contributed for higher availability. This observation is in conformity with the results obtained by Banganwa et al. (1988), Dev (1998) and Harikrishna et al. (2005).

5.3.7.2 Available phosphorus (P\(_2\)O\(_5\))

Application of phosphorus to maize crop through soil test based NPK recommendation (+ 25 % N, P and K if medium) increased the soil available phosphorus from 72.0 to 80.0 kg ha\(^{-1}\) and 66.4 to 84.3 kg ha\(^{-1}\), respectively during first and second year (Table 4.86 and Fig. 5.26). This might be due to higher application of added phosphorus in conjunction with residual phosphorus. The initial low status of available phosphorus raised to high levels commensurating with phosphorus application as evinced by Rekhi et al. (2000) and Mahala et al. (2006).

5.3.7.3 Available potassium (K\(_2\)O)

After harvest of maize, the available potassium was reduced in all the treatments except in SSNM treated plots compared to initial status of potassium. During first and second year, the initial status of potassium was increased from 598.5 to 663.9 kg ha\(^{-1}\) and 394.5 to 460.5 kg ha\(^{-1}\),
Fig. 5.25: Uptake of N, P₂O₅ and K₂O by rabi-summer maize as influenced by different nutrient management practices in groundnut-maize cropping sequence.

Legend:
T₁: Rec. NPK as per package of practice (150:75:40 kg ha⁻¹)
T₂: STCR approach for irrigated maize crop (NPK)
T₃: Soil test based NPK recommendation (LMH approach) (STL method)
T₄: Soil test based NPK recommendation (± 25 %)
T₅: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
T₆: Soil test based NPK (NK ± 50 % and P ± 25 %)
T₇: Modified T₃ with respect to P (Rec. NK & 75 % P if P is medium) + PSB
T₈: SSNM approach for targeted yield of 100 q ha⁻¹ of maize
FYM @10 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments.

Fig. 5.26: Available N, P₂O₅ and K₂O by rabi-summer maize as influenced by different nutrient management practices in groundnut-maize cropping sequence.
respectively after harvest of maize through SSNM approach (Table 4.86 and Fig. 5.26). This is mainly due to higher application of potassium (229.0 kg ha\(^{-1}\)) during both the years.

### 5.3.7.4 Available secondary and micronutrients

Among secondary nutrients, significantly more available sulphur (22.9 mg kg\(^{-1}\)) was observed in plots which received fertilizers based on SSNM approach and it was on par with T\(_5\) treatment. Treatment T\(_7\) [Modified T\(_3\) with respect to P (Rec. NK & 75% P if P is medium) + PSB] recorded significantly lower available sulphur (15.9 mg kg\(^{-1}\)) (Table 4.86). A similar trend was observed with respect to calcium and magnesium availability (Table 4.87). Applied single super phosphate contained sulphur and calcium nutrients in addition to phosphorus and it is responsible for higher availability of these secondary nutrients after harvest of maize compared to initial values.

Availability of boron was found to be significantly higher (0.77 mg kg\(^{-1}\)) in soil test based NPK recommendation (NK ± 50 % and P ± 25 %) and it was at par with all the other treatments except SSNM approach (0.71 mg kg\(^{-1}\)) and recommended NPK as per package of practice (0.70 mg kg\(^{-1}\)). This could be attributed to production of higher biomass with higher uptake of boron in groundnut-maize sequence through SSNM approach and T\(_1\) treatment (Table 4.87).

### 5.3.8 Economics of maize as influenced by different nutrient management practices

The SSNM approach for a targeted yield of 100 q ha\(^{-1}\) incurred more cost towards production (₹ 32,160 ha\(^{-1}\)) followed by STCR approach (₹ 29,521 ha\(^{-1}\)). It is due to higher cost towards fertilizers based on targeted yield approach. However, lower cost on production was recorded in T\(_7\) treatment (₹ 26,753 ha\(^{-1}\)).
Due to higher grain and stover yield, the gross returns and net returns were higher in SSNM approach (₹ 91,043 and 58,883 ha\(^{-1}\), respectively) followed by STCR approach (₹ 85,051 and 55,530 ha\(^{-1}\), respectively) compared to rest of the treatments (Table 4.88). Despite increase in the cost of cultivation with SSNM and STCR approaches, a greater increase in yield of maize made SSNM and STCR approaches as economical nutrient management practices. Similar results were also reported by Surendra Singh and Sarkar (2001), Anilkumar et al. (2005), Harikrishna et al. (2005), Hongting Wang et al. (2005) and Dhillon et al. (2006). However, higher B:C ratio was observed in STCR approach (2.88) followed by SSNM approach (2.83). The lower B:C ratio of maize in SSNM approach was due to higher cost of cultivation compared to STCR approach.

5.3.9 Nutrients balance studies in groundnut-maize based cropping sequence

Balance of nitrogen, phosphorus and potassium in groundnut-maize based cropping sequence as influenced by different nutrient management practices were discussed here under.

5.3.9.1 Nitrogen balance studies

During first and second year, the initial average available nitrogen in soil was 319.2 and 341.0 kg ha\(^{-1}\), respectively. After harvest of kharif groundnut and rabi-summer maize crops, the nitrogen availability in the soil was found to decrease in all the treatments except in SSNM approach (432.5 and 460.4 kg ha\(^{-1}\), respectively) and in second year, STCR approach (347.0 kg ha\(^{-1}\)) over the initial values. This was mainly due to exhaustive nature of maize crop as it exhausts more nitrogen compared to added amount in all the treatments (Table 4.89 and 4.90). This was in conformity with the earlier findings of Tolessa Debele et al. (2001) and Omraj Meena et al. (2007).
5.3.9.2 Phosphorus (P$_2$O$_5$) balance studies

The initial average available phosphorus in soil during first and second year of experiment was 34.9 kg ha$^{-1}$ and 32.6 kg ha$^{-1}$, respectively (Table 4.91 and 4.92). After harvest of *kharif* groundnut and *rabi-summer* maize crops, phosphorus availability in the soil was found to be higher in all the treatments compared to initial values. This might be due to addition of more phosphorus through organic and inorganic sources and fixation of phosphorus after its application in the soil compared to uptake by the crops. Because of varied levels of phosphorus application and uptake by the crop, the actual balance after harvest of maize crop (80.0 kg ha$^{-1}$ and 84.3 kg ha$^{-1}$, respectively) was found higher in treatment T$_5$. The increased level of phosphorus in groundnut-maize based cropping sequence was also evinced by Mahala *et al.* (2006) and Karunakaran *et al.* (2010). The lower net loss of phosphorus was found to be observed in PSB treated plots (T$_7$) during both the years (Table 4.91 and 4.92). This might be due to solubilisation of fixed phosphorus by bacterial inoculant.

5.3.9.3 Potassium (K$_2$O) balance studies

During first year, the initial status of potassium before the start of experiment was 604.8 kg ha$^{-1}$. After the harvest of *kharif* groundnut and *rabi*-summer maize crops, potassium availability in soil was found to decrease in all the treatments except in SSNM approach (663.9 kg ha$^{-1}$) as compared to initial value. This was attributed to higher uptake of potassium by both the crops when compared to added fertilizer (Table 4.93). Higher uptake of potassium by groundnut and maize crops was also reported by Tolessa Debele *et al.* (2001), Mandal *et al.* (2002), Sutaliya and Singh (2005) and Karunakaran *et al.* (2010). The same trend of potassium balance was observed in the second year (Table 4.94).
5.3.10 Growth and yield of sunflower as influenced by different nutrient management practices

The experimental plots of kharif season were divided into 2 plots to raise maize and sunflower crops and the same treatments were imposed based on soil test results and soil fertility ratings of major nutrients after the harvest of kharif groundnut crop. The fertility status after harvest of groundnut crop was found to be MMH. Hence, fertilizers were applied as per the requirement of MMH status to sunflower crop.

The present study revealed that significantly higher seed yield (31.8 q ha\(^{-1}\)) with higher B:C ratio (2.75) was registered by application of higher levels of nitrogen and potassium through SSNM approach (Appendix III). The per cent increase in seed yield through SSNM over recommended dose of fertilizer was 23.9 %. Significantly higher seed yield of sunflower in SSNM approach was mainly due to significantly higher head diameter (30.8 cm), more number of seeds head\(^{-1}\) (1307.2), lower chaffiness per cent (6.6 %), higher test weight (49.8 g) and more seed weight plant\(^{-1}\) (58.8 g) (Table 4.99 and 4.100 and Fig. 5.28). The oil yield followed the same trend as that of seed yield (Table 4.101 and Fig. 5.29). The response of sunflower to nutrient application could be attributed to the fact that addition of fertilizers improved the uptake of nutrients, which might have favoured the plants growth and yield contributing characters under SSNM approach. Improvement in seed yield and yield contributing parameters with increasing fertility levels as confirmed by findings of Ujjinaiah et al. (1995), Reddy and Kumar (1996), Singh and Singh (1997), Devidayal and Agarwal (1999), Lal et al. (1998) and Yadav et al. (2009).

The higher values of above mentioned yield components were due to better growth parameters and significantly higher leaf area at various growth stages and total dry matter production at harvest stage (201.3 g plant\(^{-1}\)) in SSNM approach (Table 4.97 and 4.98 and Fig. 5.27). The results are in conformity with Reddy and Kumar (1996), Nagavani et al. (1997) and Tomar et al. (1997). The higher leaf area and dry matter
Fig. 5.27: Total dry matter production of *rabi*-summer sunflower as influenced by different nutrient management practices in groundnut-sunflower based cropping sequence

Legend:
- **T**_1_: Rec. NPK as per package of practice (62.5:75:62.5 kg ha⁻¹)
- **T**_2_: STCR approach for irrigated sunflower crop (NPK)
- **T**_3_: Soil test based NPK recommendation (LMH approach) (STL method)
- **T**_4_: Soil test based NPK recommendation (+ 25 %)
- **T**_5_: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
- **T**_6_: Soil test based NPK (NK ± 50 % and P ± 25 %)
- **T**_7_: Modified **T**_3_ with respect to P (Rec. NK & 75 % P if P is medium) + PSB
- **T**_8_: SSNM approach for targeted yield of 37.5 q ha⁻¹ of sunflower

FYM @ 7.5 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments

Fig. 5.28: Yield parameters of *rabi*-summer sunflower as influenced by different nutrient management practices in groundnut-sunflower cropping sequence

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Fig. 5.29: Seed, stalk and oil yield of *rabi* summer sunflower as influenced by different nutrient management practices in groundnut-sunflower cropping sequence
production were mainly due to robust growth of sunflower plants recording maximum plant height of 222.4 cm at harvest stage. The increased plant height was due to increased nutrient availability. Further, harvest index indicates the percentage of dry matter partitioned and accumulated in the economic portion. Higher values of harvest index (0.45) were observed in SSNM approach over lower levels of fertilizer application.

The increased levels of nitrogen and potassium through SSNM approach accomplished the requirement of balanced crop nutrition and caused rapid division and elongation of cells that resulted in improved plant height, leaf area and dry matter production per plant.

5.3.11 Nutrient uptake by sunflower as influenced by different nutrient management practices

Since sunflower is highly exhaustive in nature, the uptake of nutrients particularly nitrogen and potassium are more for exhibiting their potential yield. The present data revealed that nutrient uptake was increased with the higher levels of nutrients by SSNM approach compared to all the other levels (Table 4.102 to 4.104 and Fig. 5.30).

The total uptake of N, P₂O₅ and K₂O (141.6, 53.0 and 112.0 kg ha⁻¹, respectively) were found maximum under SSNM approach for targeted yield of 37.5 q ha⁻¹ (Table 4.102 to 4.104). The total biological yield was increased with increasing nutrient application, thus absorption of nutrients from soil was more. The nutrient content in seed and stalk was also higher which in turn led to higher uptake of NPK in SSNM plots. The results conform to the findings of Mishra et al. (1995), Singh and Singh (1997), Thavaprakash (2000).
5.3.12 Effect of different nutrient management practices on availability of nutrients after harvest of sunflower

5.3.12.1 Available nitrogen

Available N in soil after harvest of sunflower crop differed significantly due to varied levels of nitrogen application in groundnut-sunflower cropping sequence. During first and second year, the initial status of nitrogen was increased from 444.3 to 546.8 kg ha\(^{-1}\) and 457.7 to 566.2 kg ha\(^{-1}\), respectively after harvest of sunflower through SSNM approach. (Table 4.106 and Fig. 5.31). This was due to higher application of nitrogen (237.4 kg ha\(^{-1}\)) to sunflower crop than its uptake.

5.3.12.2 Available phosphorus (P\(_2\)O\(_5\))

Application of phosphorus to sunflower crop through soil test based NPK recommendation (+ 25 % N, P and K if medium) increased the soil available phosphorus from 72.0 to 102.3 kg ha\(^{-1}\) and 66.4 to 102.0 kg ha\(^{-1}\), respectively during first and second year (Table 4.106 and Fig. 5.31). Higher application of phosphorus (93.7 kg ha\(^{-1}\)) besides higher initial values of phosphorus during both the years contributed for higher availability. The initial medium status of available phosphorus raised to high levels commensurating with higher phosphorus application as evinced by Nalatwadmath et al. (2003).

5.3.12.3 Available potassium (K\(_2\)O)

Available potassium in soil after harvest of sunflower crop differed significantly due to varied levels of potassium application in groundnut-sunflower cropping sequence. During first and second year, the initial status of potassium was increased from 598.5 to 624.8 kg ha\(^{-1}\) and 394.5 to 443.4 kg ha\(^{-1}\), respectively after harvest of sunflower through SSNM approach. (Table 4.106 and Fig. 5.31). This was due to higher application of potassium (147.5 kg ha\(^{-1}\)) during both the years.
Fig. 5.30: Uptake of N, P2O5 and K2O by rabi-summer sunflower as influenced by different nutrient management practices in groundnut-sunflower cropping sequence

Fig. 5.31: Available N, P2O5 and K2O by rabi-summer sunflower as influenced by different nutrient management practices in groundnut-sunflower cropping sequence

Legend:
- T1: Rec. NPK as per package of practice (62.5:75:62.5 kg ha⁻¹)
- T2: STCR approach for irrigated sunflower crop (NPK)
- T3: Soil test based NPK recommendation (LMH approach) (STL method)
- T4: Soil test based NPK recommendation (± 25 %)
- T5: Soil test based NPK recommendation (+ 25 % N, P and K if medium)
- T6: Soil test based NPK (NK ± 50 % and P ± 25 %)
- T7: Modified T3 with respect to P (Rec. NK & 75 % P if P is medium) + PSB
- T8: SSNM approach for targeted yield of 37.5 q ha⁻¹ of sunflower

FYM @ 7.5 t ha⁻¹ and borax @ 10 kg ha⁻¹ common for all the treatments

Fig. 5.32: Groundnut equivalent yield under different groundnut based cropping sequences as influenced by nutrient management practices
5.3.12.4 Availability secondary and micronutrients

Among secondary nutrients, significantly higher available sulphur (22.9 mg kg⁻¹) was recorded in soil test based NPK recommendation (+ 25 % N, P and K if medium) and it was on par with STCR approach (21.3 mg kg⁻¹)(Table 4.106). Similarly, availability of calcium and magnesium also found to be higher in T₅ treatment (Table 4.107). Applied single super phosphate (93.7 kg ha⁻¹) contains sulphur and calcium nutrients in addition to phosphorus and this might be the possible reason for higher availability of secondary nutrients.

Availability of boron was found to be higher (0.71 mg kg⁻¹) in STCR approach and it was at par with T₆ treatment (0.67 mg kg⁻¹). Lower uptake of applied boron contributed for higher availability in STCR and treatment T₆ as compared to all the other treatments (Table 4.107).

5.3.13 Economics of sunflower as influenced by different nutrient management practices

The SSNM approach for a targeted yield of 37.5 q ha⁻¹ incurred maximum cost on production (₹ 34128 ha⁻¹) and it was mainly to higher cost towards fertilizers. Due to higher seed yield, the gross returns and net returns were higher in SSNM approach (₹ 93597 and 59469 ha⁻¹, respectively) compared to rest of the treatments. Despite increase in the cost of cultivation with SSNM treatment, the large increase in seed yield of sunflower made SSNM approach as economical nutrient management practice with higher B:C ratio of 2.75 (Table 4.108). Similar results of higher net returns and B:C ratio with higher levels of nutrients have been reported by Reddy and Sudhakara Babu (1997), Thavaprakash and Malligawad (2002) and Reddy et al. (2002).
5.3.14 Nutrients balance studies in groundnut-sunflower based cropping sequence

Balance of nitrogen, phosphorus and potassium in maize-sunflower based cropping sequence as influenced by different nutrient management practices has been discussed here under.

5.3.14.1 Nitrogen balance studies

During first and second year, the initial average available nitrogen in soil was 319.2 and 341.0 kg ha\(^{-1}\), respectively. After harvest of *kharif* groundnut and *rabi*-summer sunflower crops, the nitrogen availability in the soil was found to decrease in all the treatments except SSNM approach (546.8 and 566.2 kg ha\(^{-1}\), respectively) over the initial values. The lower availability of nitrogen after harvest of sunflower was mainly due to exhaustive nature of sunflower crop which is going to exhaust more of nitrogen compared to added amount in all the treatments (Table 4.109 and 4.110).

5.3.14.2 Phosphorus (\(P_2O_5\)) balance studies

The initial average available phosphorus in soil during first and second year of experiment was 34.9 kg ha\(^{-1}\) and 32.6 kg ha\(^{-1}\), respectively (Table 4.111 and 4.112). After harvest of *kharif* groundnut and *rabi*-summer sunflower crops, the phosphorus availability in the soil was found to be higher in all the treatments compared to initial values. This was due to addition of more phosphorus through organic and inorganic sources compared to uptake by the crops. Because of varied levels of phosphorus application and uptake by the crop, the actual balance after harvest of sunflower crop (102.3 kg ha\(^{-1}\) and 102.0 kg ha\(^{-1}\), respectively) was found higher in treatment T\(_5\) and was due to application of higher level of inorganic phosphorus (93.7 kg ha\(^{-1}\)). The increased level of phosphorus in groundnut and sunflower based cropping systems was also evinced by Nalatwadmath *et al.* (2003) and Karunakaran *et al.* (2010). The lower net loss of phosphorus was found to be observed in PSB treated plots (T\(_7\))
during both the years (Table 4.111 and 4.112). This might be due to solubilisation of fixed phosphorus by bacterial inoculant.

5.3.14.3 Potassium (K₂O) balance studies

During first year, the initial status of potassium before start of the experiment was 604.8 kg ha⁻¹. After harvest of *kharif* groundnut and *rabi*-summer sunflower crops, the potassium availability in the soil was found to decrease in all the treatments except in SSNM approach (624.8 kg ha⁻¹) compared to initial value. This was mainly due to higher uptake of potassium by both the crops compared to added fertilizer. The higher uptake with higher application of potassium by groundnut and sunflower crops was also reported by Thavaprakash (2000) and Chideshwari *et al.* (2007). The same trend of potassium balance during first year was observed in second year (Table 4.114).

5.3.15 Groundnut equivalent yield under different groundnut based cropping sequences

In groundnut-sunflower cropping sequence, the total groundnut equivalent yield (49.5 q ha⁻¹) was higher in soil test based NPK recommendation (+ 25 % N, P and K if medium) inspite of more groundnut equivalent yield of sunflower (30.0 q ha⁻¹) in SSNM approach. The higher total groundnut equivalent yield by soil test based NPK recommendation (+ 25 % N, P and K if medium) was mainly due to higher productivity of groundnut (24.1 q ha⁻¹) (Table 4.115 and Fig. 5.32).

In groundnut-maize cropping sequence, the total groundnut equivalent yield (47.2 q ha⁻¹) was higher in soil test based NPK recommendation (+ 25 % N, P and K if medium) compared to all the other treatments. This was mainly due to higher productivity of groundnut crop (24.1 q ha⁻¹) (Table 4.115 and Fig. 5.32).
5.3.16 Economics (₹ ha⁻¹) of groundnut-maize and groundnut-sunflower cropping sequences

In groundnut-maize cropping sequence, higher gross returns, net returns and B:C ratio (₹ 1,52,701, 94,783 ha⁻¹ and 2.64, respectively) were observed in soil test based NPK recommendation (+ 25 % N, P and K if medium). This might be due to higher productivity of both the crops in general and groundnut crop in particular.

In groundnut-sunflower cropping sequence, gross returns and net returns (₹ 1,52,646 and 91,368 ha⁻¹, respectively) were observed in soil test based NPK recommendation (+ 25 % N, P and K if medium) with higher B:C ratio of 2.49. The higher economical values were mainly due to higher productivity of both the crops (Table 4.116).

5.3.17 Population of soil microorganisms after groundnut-maize and groundnut-sunflower cropping sequences

In groundnut-maize cropping sequence, significantly higher bacterial population was observed in PSB treated plot (T₇) (54.0 x 10⁵ cfu g⁻¹) and it was on par with treatment T₈ (50.3 x 10⁵ cfu g⁻¹) compared to all the other treatments. However, significantly higher population of fungi (36.2 x 10³ cfu g⁻¹) and actinomycetes (23.3 x 10³ cfu g⁻¹) were found in SSNM approach compared to all the other treatments T₇ (Table 4.117).

In groundnut-sunflower cropping sequence, significantly higher bacterial population was observed in PSB treated plot (T₇) (52.5 x 10⁵ cfu g⁻¹) compared to all the other treatments. However, significantly higher population of fungi (33.3 x 10³ cfu g⁻¹) and actinomycetes (19.8 x 10³ cfu g⁻¹) were found in SSNM approach compared to all the other treatments (Table 4.118). The higher bacterial population in PSB treated plot compared to uninoculated plots was due to the reason of buildup of introduced beneficial microorganisms (PSB) population which inturn helped to higher bacterial population. Gupta (2004) and Chesti and Tahir Ali (2012) have also the same opinion on improvement in bacterial population.
due to use of PSB. The higher population of fungi and actinomycetes was attributed to improvements in soil fertility and the associated enhanced plant growth and higher rhizodeposition in plots applied fertilizers based on SSNM approach in both groundnut-maize and groundnut-sunflower based cropping sequences.

5.4 Results of practical significance

Based on the results of experiment, it can be concluded that:

- In maize-sunflower cropping sequence, SSNM approach was an effective nutrient management practice to achieve higher maize and sunflower equivalent yield with higher B:C ratio.
- In maize-groundnut cropping sequence, soil test based NPK recommendation (+ 25 % N, P and K if medium) was an effective nutrient management practice to achieve higher maize and groundnut equivalent yields with higher B:C ratio.
- In groundnut-sunflower and groundnut-maize cropping sequences, soil test based NPK recommendation (+ 25 % N, P and K if medium) was an effective nutrient management practice to achieve higher groundnut and sunflower or maize equivalent yields with higher B:C ratio.

5.5 Future line of work

- Since it is difficult to practise soil testing after each crop, a reliable base has to be developed from model experiments to predict the changes in soil test values reasonably well so that yield targeting could be successfully planned.
- Needs to modify the equations of STCR approach for irrigated groundnut crop by conducting multi-location trials.
- Long term experiments on varied levels of phosphorus along with P solubilizers in different cropping systems need to be studied.