Chapter 9
Effective Use of Fertilizers and Water Management for Rice–Wheat Cropping System

Abstract In this chapter of the book, effective use of fertilizers and water management for the rice–wheat cropping sequence has been detailed. It is related to the selection of the right kind of fertilizers, including the use of modified urea compounds, their timely application and balanced use, application of macro- and micronutrients and use of organic manures and bio-fertilizers. Methods and practices of fertilizer use efficiency in irrigated and rainfed areas have also been elucidated in terms of water and nutrient availability; movement of nutrients, soil moisture and root distribution; optimization of water and fertilizer use; and water use efficiency.

Keywords Effective fertilizer use • water management • rice–wheat cropping pattern

With the advent of the Green Revolution followed by the Golden and Yellow Revolutions, consumption of chemical fertilizers and pesticides increased. This was due to the introduction of high-yielding varieties of crops, responding to high rates of N, P and K use and water, especially rice and wheat. In many of the Indian states, however, indiscriminate use of fertilizers and pesticides not only rendered the 'soil ecosystem sick' but also created 'health hazards' in human beings and animals (Gupta and Singh, 2006). Moreover, the production of chemical fertilizers demands sufficient amount of energy and fossil fuels, both of which are very limited in the country. Hence, it becomes imperative to make an efficient use of fertilizers and other related inputs for increasing soil fertility and crop productivity without harming the soil and human beings/animals as well as the environment.

9.1 Efficient Use of Fertilizers

To get a successful/bumper crop, particularly of rice and wheat, it becomes essential to make effective use of fertilizers along with other important soil and water management practices. Some of these methods or ways are described below.

A. Mahajan and R.D. Gupta, *Integrated Nutrient Management (INM) in a Sustainable Rice–Wheat Cropping System*,

9.1.1 Selection of the Right Kind of Fertilizers

As efficiency of nitrogenous fertilizers is very low, especially in rice crop, seldom exceeding 40%, unnecessary soil N is lost in the atmosphere through denitrification in the form of NO, N_2O, NO_2, N_2, etc. Excess amounts of these gases cause air pollution and greenhouse gas effect.

The nitrate form of N is susceptible to losses through leaching besides denitrification. Excess NO_3 in groundwater creates the 'blue baby' disease. Hence, use of nitrogenous fertilizers having NO_3-N is less effective than those having NH_4-N, and accordingly their use should be avoided. Although application of NH_4-containing fertilizers like $(NH_4)_2SO_4$ and NH_4Cl have proved useful for rice crop production, their availability in the market is a big problem. Urea is generally considered as effective as NH_4 sources in most of the soils. This is because after application of urea its N, which is in amide form, is immediately converted into NH_4^+ and NO_3 form and becomes available to plants, depending upon the crop grown. The fate of NH_4^+ is threefold, as has been shown in Fig 9.1.

9.1.2 Application of Modified Urea Materials

As urea has now become the only principal nitrogenous fertilizer and its importance has increased manifold, concerted efforts for improving its efficiency, particularly for rice crop, have been made. As a consequence, a number of modified urea compounds have been developed. Sulphur-coated urea, lac-coated urea, neem-coated

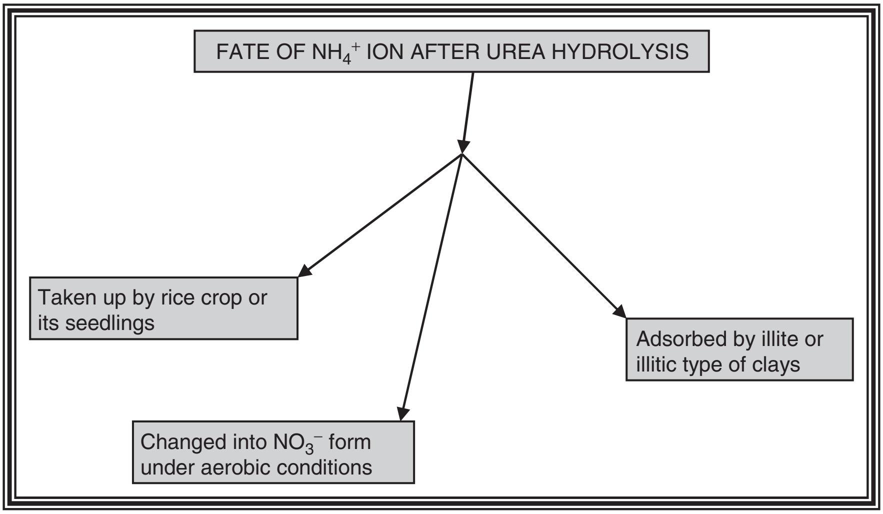

Fig. 9.1 Fate of NH_4^+ ion after urea hydrolysis

urea and urea super granule are some of the examples of modified urea compounds. The results of field experiments conducted by various scientists at the University of Agricultural Sciences and Technology, Pantnagar, and CSK Himachal Pradesh Krishi Vishvavidyalaya at Palampur have shown increase in rice yield with use of neem-coated, lac-coated and sulphur-coated urea compared to when urea prills were used.

Urea super granule should be used as a deep placement fertilizer in rice fields. When it is placed at 5–8 cm below soil surface about a week after rice transplanting, it has shown higher grain yield than split application. In light-textured soils, due to high percolation rate, its application is found to be less effective.

9.1.3 Timely Application of Fertilizers

In the case of rice crop, the whole amount of the phosphatic and potassic fertilizers and one third of nitrogenous fertilizers should be applied at the last puddling operation, but not more than 1–3 days prior to transplanting. Fertilizers should be applied well in the top 10–15 cm of puddled soil (Gupta and Kanwar, 1984). The remaining N will be applied in two equal splits, i.e. one 3 weeks after transplanting and the other 4–5 weeks later when the plants attain panicle-initiation stage. As already mentioned, application of urea or ammonium sulphate is preferred. However, if these are not available, calcium ammonium nitrate can be used for split application. But through this source of N application, considerable loss is likely to occur. As regarding phosphatic fertilizer application, superphosphate has proved more effective. The efficiency of two major K sources as potassium chloride (muriate of potash) is recommended because of its being cheaper than that of sulphate of potash.

In the case of wheat also, one third of the nitrogenous fertilizers and the whole amount of phosphatic and potassic fertilizers is applied at the time of sowing. The rest of the nitrogenous fertilizers should be added in two splits, i.e. one after first irrigation (25–30 days after sowing) and the other at the boot stage or before ear formation. While broadcasting the fertilizers, care should be taken for uniform distribution.

In light-textured soils, the number of splits should be increased from three to four. By doing so, the leaching losses due to heavy rains or irrigational water of nitrogenous fertilizers can be reduced.

9.1.4 Balanced Use of Fertilizers

Full benefit of nitrogenous fertilizers can be obtained only when the recommended doses of phosphatic and potassic fertilizers are applied (Gupta and Kanwar, 1984). In this connection, it is stressed that while adding the nitrogenous, phosphatic and potassic fertilizers their proper ratio should be maintained, i.e. 4:2:1.

9.1.5 Application of Fertilizers on the Basis of Soil Test

The best way to apply fertilizers both to rice and wheat is on the basis of soil test. Soil test is a chemical test which indicates the availability of plant nutrients in the soil vis-à-vis the texture and pH of the soils. It is worthwhile to mention that neither excess nor deficiency of nutrients in the soil is desirable for good crop yield. So it must be advocated to the farmers to make use of fertilizers based on the soil test. They must get the soil of their fields tested twice a year – once prior to transplanting the rice crop and again before sowing the wheat crop.

9.1.6 Saving Phosphatic and Potassic Fertilizers

In the fields where rice and wheat have been followed for 3 successive years with an application of recommended doses of nitrogenous and phosphatic fertilizers every year, the quantity of N should be reduced to about half for rice crop of the recommended dose for at least a year. Similarly, application of phosphatic and potassic fertilizers may be reduced or completely avoided in acidic soils if these have been applied to the preceding Rabi crops, i.e. wheat or linseed.

9.1.7 Application of Secondary and Micronutrients

There is no doubt that the rice and wheat cultivation is an optimal cropping pattern for the agriculture of Punjab, Haryana, Himachal Pradesh, Jammu region (Jammu & Kashmir) and other Indian states, but this scenario may not remain for two possible reasons. Firstly, due to continuous use of high analysis fertilizers during the Green Revolution, widespread deficiency of secondary nutrients like S, Ca and Mg and micronutrients like Zn, Fe, Cu and Mn has been seen, which limits the crop growth (Takkar and Nayar, 1986). Secondly, due to rice cultivation over a long period, there will be lowering of the water table, as this requires a large amount of water. Hence, the productivity of rice will decline. The soils of Jammu region, where rice and wheat or maize/pearl millet are grown, have also been found deficient in available Zn and S (Gupta et al., 1997a, b; Jalali et al., 2001).

To overcome the deficiency of Zn, an application of $ZnSO_4$ at the rate of 25 kg ha^{-1} has been found to be beneficial in increasing the yields of crops like wheat, rice and maize. However, in soils where *Khaira* disease of rice due to deficiency of Zn is a serious problem, basal application of $ZnSO_4$ may not prove beneficial. In such cases Zn sprays with the following schedules have given excellent results:

- First spray of 5 kg $ZnSO_4$ + 2.5 kg lime in 750–1,0001 of water in the nursery about 10 days after sowing has proved effective in controlling the *Khaira* disease.

- Second spray as stated above should be done 20 days after sowing.
- Another spray as above is required about 15–30 days after transplanting the rice.

9.1.8 Practice of Green Manuring

Wherever it is possible, green manuring should be done. It has been found that on an average, the green manure of dhaincha (*Sesbania aculeata*), guara (*Cyamopsis* spp.) and sunn hemp (*Crotolaria juncea*) add about 82, 65 and 75 kg N ha^{-1} respectively. Green manuring in the soil is therefore a valuable means of enriching soils with N and saving nitrogenous fertilizers. Use of green manure of dhaincha prior to transplanting of rice has shown a saving of one third of the recommended dose of nitrogenous fertilizer under Ranbir Singh Pura, Jammu region (Jammu & Kashmir) soil condition (Gupta and Sharma, 2004). For proper decomposition of the green manure, it is essential to use it in a succulent condition and sufficient moisture should be present in the soils. As plants before the flowering stage contain the largest quantity of organic matter with low C/N ratio, green manuring crop should be buried into the soil prior to the flowering stage.

9.1.9 Right Conservation of Farmyard Manure

FYM generally refers to the refuse from the farm animals which contains two original components, the solid and liquid, in the ratio of 3:1. On an average, a tonne of FYM contains approximately 5–10 kg of N and 2.5–5.0 kg each of P_2O_5 and K_2O. It also possesses about 200 kg of organic matter and other plant nutrients (secondary Ca, Mg, S and micronutrients Fe, Mn, Cu, Zn, Mo, B and Cl). In addition to supplying macro- and micronutrients, FYM increases the water-holding and cation-exchange capacities of the soils, improves the structure and texture and soil porosity, and maintains the magnitude of bulk density.

Keeping in view the great importance of FYM as stated above, it must be prepared in pits to conserve the nutrient present in it and to protect it from the weather to avoid loss of nutrients.

9.1.10 Use of Azolla in Rice Fields

The use of *Azolla* as an organic fertilizer in rice cultivation was first made in North Vietnam in 1957 (Pareek and Maurya, 1984–85). Generally, one or two *Azolla* crops are taken which are then incorporated into the soil prior to transplanting paddy. For this purpose, the fields are prepared for rice cultivation, i.e. flooded with water followed by seedlings of *Azolla*. After 5–10 days, the water of the fields is drained off and the *Azolla* mat is ploughed into the soil. The process may be repeated for two crops of *Azolla*. It has been found that successive layers of *Azolla* incorporated into the soil can supply 50% of N requirement of rice.

Results have shown that generally green manuring of *Azolla* (*Azolla–Anabaena* association) has been found to fix more N=N and play an important role in increasing rice yield (Pareek and Maurya, 1984–85).

9.1.11 Use of Other Bio-Fertilizers

Use of *Azotobacter* culture in the dryland rice and wheat crops has been reported to save 25–50 kg N ha^{-1}. Bacteria like *Caulobacter* spp. and *Bacillus megatherium* living in association with blue-green algae (BGA) either double the vigour of N assimilation by *Nostoc* or stimulate N fixation. In a large number of Indian trials, BGA complemented with recommended doses of N has been found to increase the yield of rice by about 10%.

9.1.12 Timely Control of Weeds

An unwanted plant growing at an unwanted place is called a weed. Weeds rob soil fertility by competing with crops for plant nutrients, water, light, space, etc., and thus reduce the crop yields (Gupta and Kanwar, 1984). Thus, the control of weeds at a proper time in crops must be one of the important operations for the farming community. Stem F-34 (Propanil) should be sprayed at the rate of 8.5 l in 750–800 l of water with a high-volume spray pump at two- to three-leaf stage of paddy (20–25 days after transplanting) for controlling the grassy weeds which are the main problem.

9.1.13 Management of Micronutrients for Rice Soils

With the introduction of new rice varieties, the application of micronutrients for submerged rice soils has become essential due to their excess uptake by these varieties. Zn deficiency has since been observed in one or more Asian countries, both in lowland and upland soil conditions. Besides, the deficiency of Fe has also been noticed in rice-growing soils, especially in Latosols due to increased uptake of Mn (Fe–Mn antagonistic effect). Management of Zn and Fe deficiency in terms of their sources and methods of application have been detailed elsewhere (Gupta et al., 1997). They are briefly described below.

9.1.13.1 Sources of Zn and Fe

Among several inorganic compounds, zinc sulphate ($ZnSO_4$) and ferrous sulphate ($FeSO_4$) are most commonly used for combating Zn and Fe deficiencies, respectively. Though application of Zn through $ZnSO_4$ (20–25 kg ha^{-1}) has been found suitable to prevent Zn deficiency, this can also be cured by foliar spray with $ZnSO_4$ (0.5% $ZnSO_4$ + 0.25% lime) two or three times (after every 2 weeks) depending upon the persistence and severity of symptoms.

Ferrous sulphate ($FeSO_4.5H_2O$) and ferric sulphate [$Fe(SO_4)_3$] are most commonly used for combating Fe deficiency. If ferrous sulphate has to be applied, it must be broadcast followed by light harrowing. The dose may vary from 100 to 300 kg ha^{-1} or even more depending upon the extent of Fe deficiency.

Foliar spray of soluble salts is an alternative to soil application. Three per cent ferrous sulphate solution is generally found most suitable to relieve chlorosis.

9.1.14 Water and Fertilizer Interaction

Water and fertilizer are both high-cost inputs in crop production. However, they are also the highest-return input. When water is readily available to plants, nutrients may move towards roots easily for their absorption or uptake. This is the reason why under dryland conditions, the applied fertilizers have a very limited response to the growing crops. Therefore it is recommended that very little or no use of fertilizers is done in dryland agriculture due to the uncertainty of the monsoon rains. This calls for the rationalized use of fertilizers, depending upon the availability of water to crops. The fertilizer use efficiency in irrigated and rainfed areas can be enhanced through better water management and conservation practices. Some broad aspects of soil water and fertilizer interaction are described below.

9.1.14.1 Water and Nutrient Availability

The availability of soil water and mineral nutrients are related in a complex way to their effect on growth and yield of crops. Soil water, in fact, serves as a solvent for the nutrients and its amount present in the soil has both short- and long-term effects on the distribution and balance of mineral nutrients.

The short-term effect of water is on the balance of nutrient ions in the soil solution or solid phase. All nitrate in the soil remains mostly in the solution phase at any soil water potential range which supports the plant growth. P and K form the adsorbed or the solid phase but can maintain the concentration of the solution phase only in highly buffered soils. The long-term effect of water on nutrients is on the balance among the soluble, adsorbed and solid forms, and is related to the effect of water and oxygen on the chemical and microbial activity in the soil.

All nitrate, chloride, most of the sulphate and part of the boron and their associated cations move readily in the soil system and they are liable to be leached in excess of irrigation or rain water.

Mineralization of N increases with available water content of soil. The increase in soil water to an optimum level also increases P and K availability. There is a higher uptake of N, P, K Fe and Mn in rice under submerged soil conditions. Favourable soil moisture affects the response of fertilizers in two ways:

- By increasing availability or intake of nutrients contained in the fertilizers
- By utilization of adsorbed nutrients

In rainfed conditions, thus, there is a need to limit fertilizer application to rates that will not promote more growth than what available soil water can sustain until harvest.

9.1.14.2 Movement of Nutrients, Soil Moisture and Root Distribution

The movement of nutrients in the soil is primarily related to the soil moisture and secondarily by the extent of root distribution. In fact, the root distribution affects the availability of both the soil water and the nutrients from the soil profile. A deeper and extensive ramification of the root system assists in exploration of moisture and nutrients from deeper layers of soil. This together with improved top growth due to balanced fertilizers improves the water use efficiency as the effective depth of the reservoir increases according to which plants can absorb water. The available moisture capacity of the soil and its rate of use at different growth stages of the crop are important and must be understood well. The fertilizer application may stimulate early vegetative growth and exhaust the available moisture in the root zone faster. As a result, the fertilizers may have no effect on grain yield. The latter occurs more significantly when soil moisture becomes deficient to a grain crop like wheat or maize at a critical growth phase, namely flowering and grain formation. This can be, however, managed by selecting the proper crop varieties and improved water-conservation and other agro-economic practices.

9.1.15 Management of Soil Water and Fertilizer Use

A general belief of the farmers that more fertilizer application requires more irrigation is not true although more consumption of fertilizers has been reported in irrigated areas. Fertilizers and irrigation act independently as well as jointly, and application of economic doses of fertilizers is justified over a wide range of combinations. In irrigated conditions, the response to application of 120 kg N + 60 kg P_2O_5 has been reported in the case of wheat in many states. There is also response of K_2O application up to a certain extent (Tomar and Singh, 1984–85). It was attributed to a higher content of K in most of the soils due to the presence of

K-bearing minerals. But now, in many Indian soils very good response of added potassic fertilizers has been noticed in the rice–wheat cropping sequences. It is due to exhaustion of K reserves in the soils.

The effect of each unit of application of nitrogen fertilizer has enabled the production of more grain of wheat, and response was found to increase with the number of irrigations. The fertilizer use efficiency seems to be the highest with an application of 120 kg N ha^{-1}.

9.1.16 Optimizing Water and Fertilizer Use

For optimizing soil moisture and fertilizer use, application of fertilizers should be made according to the amount of available soil moisture. As nitrogenous fertilizer stimulates early vegetative growth and may exhaust the soil water supply before the critical crop growth stage like the reproductive stage. Therefore, in the areas where the entire water requirement of the crop has to be met from the stored soil water, the N doses should be just enough to stimulate the deeper and extensive root growth. Once the plants are well established, water can be extracted from deeper soil depth. This is observed more in high water-table areas. Application of P is known to improve the yields under low rainfall conditions by improving early growth plus root vigour development and maturity of crops. As discussed earlier, when fertilizers were applied at the rate of N (120 kg ha^{-1}), N + P_2O_5 (120 + 60 kg ha^{-1}) and N + P_2O_5 + K_2O (120 + 60 + 60 kg ha^{-1}), the wheat grain yield increased by 57%, 38% and 13%, respectively, over the control. Total increase in wheat yield was 108% over the control, when N, P_2O_5 and K_2O were applied in proper amounts.

Thus, the balanced use of fertilizers is beneficial to increase the yield of the crops both in limited and irrigated conditions.

9.2 Water Use Efficiency

Water use efficiency refers to the yield of marketable crop produced per unit of water used for consumption. Among others, the primary soil management practices affect water use efficiency in the use of fertilizers. If fertilizer use results in high yield, this may also increase the water use efficiency. Under irrigated conditions it becomes imperative to make use of applied water more efficiently. This can be done by making the irrigation schedule according to the need of the rice and wheat crops. The level of nutrient supply should be maintained to ensure the efficient use of soil water supply. In rainfed conditions, however, every effort should be made to increase the amount of water available to the crop for production. Loss of water that occurs due to evaporation and transpiration must be reduced.

9.3 Suggestions and Priorities for the Future

- Where water is scarce, high-value but low-water-requiring crops should be grown.
- All pulses and oilseeds are important income-earning and soil-enriching crops, so they should be included in rice-farming systems wherever they can be grown.
- Hidden hunger of soils due to the deficiency of S, Zn and B leads to hidden hunger in human diet.
- As crop management systems totally based on the use of chemical fertilizers have already lost, and will further lose, their production potential in the long term, farmers must take steps to restore soil organic matter and control measures of secondary nutrients and micronutrient deficiencies.
- The farming families should be provided with Soil Health Cards, which will help them to maintain soil productivity at a high level without resorting to soil mining. Factor productivity with reference to nutrients will go up only if integrated attention is given to the physics, chemistry and microbiology of the soils.
- There is an urgent need to develop and disseminate eco-technologies for rainfed and semi-arid, hill and island areas, which have so far been bypassed by modern yield-enhancement technologies.
- For defending the gains already obtained, in the rice–wheat cropping sequence, an important requirement is the development and adoption of technologies that will lead to economic gain without ecological loss.
- As intensive cropping involving rice and wheat removes N, P_2O_5 and K_2O from the soil to the extent of 500–700 kg ha^{-1} per year, this amount of nutrients is required to be added.
- Many of the farmers are, however, not able to apply such amounts of nutrients as the fertilizers are very costly. Hence, an alternative is to apply nutrients through other sources (FYM, compost, green manure).
- So far, infrastructure, technology and skill have been built on such lines so as to carry on the rice–wheat enterprises successfully. It took decades to build the system. Similarly, it should be restructured slowly and steadily.
- Since these days sustainability is the major concern, alternatives have to be found by stressing on research activities. For example, maize can be an alternative food grain for rice during *Kharif* season.
- Increase the area under irrigation. This is the most practical and technically feasible solution. By increasing the area under irrigation, the productivity of crops, especially of rice and wheat, can definitely be increased.
- In soils where faulty irrigation has caused salinity and alkalinity, suitable measures should be taken. This can be done by introducing modern irrigation systems such as drip or sprinkle irrigation.
- A variant drip irrigation system, with features such as drip emitters, drip laterals, filters and fertigation equipment to better suit India’s small-sized farms, should be used.

Impact Points to Remember

- Excess of NO_3 in groundwater may lead to 'blue baby' disease.
- Urea super granule should be used as a deep placement fertilizer in rice fields.
- The use of *Azolla* as an organic fertilizer in rice cultivation was first made in North Vietnam in the year 1957.
- Weeds rob soil fertility by competing with the crops for plant nutrients, water, light, space, etc., and thus reduce the crop yields.
- The fertilizer use efficiency in irrigated and rainfed areas can be enhanced through better water management and conservation practices.
- There is higher uptake of N, P, K, Fe and Mn in rice under submerged soil conditions.
- Application of P is known to improve the yields under low rainfall conditions by improving early growth plus root vigour development and maturity of crops.
- Water use efficiency refers to the yield of marketable crop produced per unit of water used for consumption.

Study Questions

1. Define the following:
   (a) Leaching loss of NO_3^-
   (b) Soil testing
   (c) Balanced use of fertilizers
   (d) Modified urea compounds
2. Write down the fate of NH_4^+ ion after hydrolysis of urea.
3. What is meant by selection of right kind of fertilizers?
4. Differentiate between effective use of fertilizers and water management for rice and wheat cropping pattern.
5. What are the various modified forms of urea? How do they help in checking the nitrate losses in rice soils?

References

Gupta, J.P., Sumbria, N.M. and Gupta, R.D. (1997a). Sulphur deficiency in soils of Jammu region. *The Daily Excelsior, The Sunday Magazine*. October 26, pp. 3.

Gupta, J.P., Sumbria, N.M. and Gupta, R.D. (1997b). Zinc deficiency in crops. *The Daily Excelsior, The Sunday Magazine*. March 16, pp. 3.

Gupta, R.D. and Kanwar, B.S. (1984). Efficient use of fertilizers for crops. *Farmers and Parliament* **8 (11–12)**: 30.

Gupta, R.D. and Sharma, A.K. (2004). Revive green manuring practice for higher production in agriculture. *The Kashmir Times* **61 (290)**: 7.

Gupta, R.D. and Singh, H. (2006). Indiscriminate use of fertilizer poses health hazards. *Farmer's Forum*. **6 (9)**: 20–24.

Gupta, R.D., Sharma, A.K. and Bhagat, G.R. (1997). Micronutrients management for submerged (lowland) and upland rice soils. *Popular Science* **5 (1)**: 26–29.

Jalali, V.K., Gupta, J.P. and Gupta, R.D. (2001). Zinc status of the soils of Jammu region of Jammu and Kashmir State. Department of Soil Science, SKUAST, R.S. Pura, Jammu, J&K India.

Pareek, R.P. and Maurya, B.R. (1984–85). *Azolla* as a biofertilizer. *Indian Farmers Digest* **17–18 (12 & 1)**: 25–26.

Takkar, P.N. and Nayyar, V.K. (1986). Integrated approach to combat micronutrient deficiency. *Proceedings Growth and Modernisation of Fertilizer Industry*. FAI Seminar, New Delhi, India, PS III/2 – 1 III/2.

Tomar, V.S. and Singh, M.P. (1984–85). Water and fertilizer interaction for higher yield. *Indian Farmers Digest* **17–18 (12 & 1)**: 3–6.