Technological Options for Improving Nutrient and Water Use Efficiency

Anup Das, G. C. Munda, D. P. Patel

ICAR Research Complex for NEH Region, Umiam-793 103, Meghalaya

Introduction of high yielding varieties (HYVs) coupled with expansion of irrigation facilities, and increased use of chemical fertilizers and other agro-chemicals have brought about spectacular increases in the yield of crops, particularly rice and wheat. About half of the total increase in food grain era has been attributed to the use of fertilizers and more than one-third of this increase is due to N fertilizes alone. The country has still about 65 per cent area under rainfed, and only about 35 per cent area under under irrigation. Low water use efficiency (WUE) has been the concern as the availability of water for agriculture is decreasing day by day. For saving and effective utilization of this vital resource, proper management strategies involving agro-techniques should be developed.

Inefficient inputs/fertilizer use is a key factor pushing the cost of cultivation and pulling down the profitability in farming. Total factor productivity (TFP) is used as an important measure to evaluate the performance of a production system and its declining trend is a serious issue. A fatigue in the ratio between the inputs and output is indicative of TFP deceleration with concomitant unsustainability of crop productivity. The challenge is how to increase food production in the country by around 60 per cent over next two decades without jeopardizing the soil and water resources which are already under great stress. With increased demand for cereals, pulses and cooking oil, the productivity per hectare or unit input is decreasing. Thus the risks of degradation of natural resources (soil and water) are increasing because of extractive farming practices (Conklin Jr. and Stilwel, 2007).

One of the critical constraints to higher crop productivity is the low efficiency of applied nutrients especially N and P. Nitrogen use efficiency (NUE) is often expressed in terms of agronomic efficiency (kg grain/kg N applied), physiological efficiency (kg grain/kg N taken by crop), chemical efficiency or apparent recovery (per cent of applied N taken by the crop), efficiency ratio (kg grain/kg N uptake, without considering unfertilized control), and also sometimes as partial factor productivity (kg grain/kg N applied without considering unfertilized control). The NUE is thus a function of soil to supply adequate amount of N, and ability of plant to acquire, transport in root and shoot, and to remobilize to others parts of the plant. Use efficiency of applied N as estimated by the difference in N uptake of the above-ground portions of N fertilized and unfertilized plots, and expressed as percentage of N fertilizer applied to the crop is only about 30-40 per cent. The P efficiency ranges from 20-40 per cent only. Hence, there is urgent need to increase nutrient use efficiency from the view point of costs and water quality concerns. The NUE in different countries are presented in Table 1.

Table 1. Nitrogen use efficiencies in different countries

Country	Year	NUE (kg/kg)	Change (per cent)	Rate of change (per cent per year)
USA	1980	42	-	-
	2000	57	+36	+ 1.6
UK	1981-85	36	-	-
	2001-02	44	+23	+1.1
Japan	1985	57	-	-
	2001	75	+32	+1.8
India	1970	60	-	-
	2004	20	-60	- 1.7

Source : Patil (2009).

Nutrient use efficiency

Nutrient use efficiency can be defined many ways, but the definition used most commonly by farmers and crop advisers is the crop output per unit of nutrient input. We are all interested in improving the efficiency with which we simultaneously accomplish all system level objectives: productivity, profitability, sustainability, and environmental protection.

There have also been genuine concerns over nutrient use efficiency, in general, and N use efficiency (NUE) in particular, for economic as well as environmental reasons. Worldwide, NUE for cereal production is as low as 33 per cent. The unaccounted 67 per cent represents an annual loss of N fertilizer worth up to Rs. 72,000 crores (NAAS 2005). The manufacture of nitrogenous fertilizers involves huge amounts of foreign exchange and consumes large quantities of nonrenewable energy resources such as naphtha, natural gas, coal etc. Poor utilization of fertilizer N by plants also adds to the pressure on these finite resources. Low NUE for crops implies higher costs to producers and consumers and, therefore, reduced competitiveness. Loss of N from soil plant system results from gaseous plant emission, nitrification, denitrification, surface runoff, volatilization and leaching beyond rooting 15 zones of crops. Many N recovery experiments conducted in the country on different crops have reported unaccounted losses of fertilizer N from 20 to 50 per cent depending on the local conditions. These losses of fertilizer N, or in general, the leakages of the reactive N from the agricultural systems into the environment are a cause of serious concern. Nitrogen on its own rarely increases yield much and for long; other nutrients, water, crop variety, weed and pest control must all be in proper proportion and available before fertilizer N can do its best. Harvesting high yields by applying only N is at best a short-lived phenomenon, as was shown in the early years of the green revolution. Clearly "N-driven systems" are not sustainable, as N becomes a 'shovel' to mine the soil of other nutrients, with the result that soils initially well supplied in other nutrients become deficient in them and productivity declines. Researchers have shown that the production practices that have resulted in increased N use efficiency relative to conventional or standard practices are those that will counter conditions or environments that contribute to N loss from soil-plant systems. The challenge is to make such modern farming systems accessible and affordable to the farmers, who are constantly under pressure to cut input costs (NAAS 2005).

Nitrogen is often the most limiting nutrient in agro-ecosystems and is therefore applied in the highest quantities. According to FAO (2001), about 82 million tonns of nitrogen fertilizer were applied in 2001 globally. Of that 60 per cent was used for cereal production. Raun and Johnson (1999) estimated world-wide nitrogen efficiency (NUE) for cereals production to be 33 per cent meaning that in 2001 alone, approximately 33 million tons of N fertilizer was lost.

The cause for low NUE and declining response to N fertilizers can be grouped as follows (NAAS 2005)

1. Nutrient Supply and Soil Fertility

- Susceptibility of N fertilizers to losses by various mechanisms.
- Imbalanced use fertilizers.
- Poor management for secondary and micronutrients, especially S, Zn, Mn, Fe and B.
- Use of high analysis fertilizers like urea and diammonium phosphate (DAP) and inadequate addition of organic manures.
- Inappropriate rate, time and method of application.
- Low status of soil organic carbon and soil degradation due to high salinity, sodicity, acidity, waterlogging and having adverse effect on below-ground biodiversity, especially of agriculturally-important micro-organisms.

2. Agronomic Practices

- Delayed sowings/plantings.
- Low seed rate resulting in poor crop stands.
- Poor weed management.
- Inefficient irrigation and rainwater management.
- Large scale monoculture and non-inclusion of legumes in cropping systems.
- Lack of consideration of previous cropping in the same field.
- Lack of capturing water x nitrogen synergistic interaction.
- Inadequate plant protection.
- Non-availability of seeds of HYVs at affordable price and at the appropriate time.
- Lack of more efficient N using genotypes.

The suggested approaches to minimize N losses and increase use efficiency include the following option (Roy and Pederson 1992):

- Identification of the most suitable fertilizer material.
- Manipulation of the application techniques including split application and placement.
- Manipulation of particle size, use of coating materials and other chemicals.
- Judicious and economical application of fertilizers for synergistic interactions.
- Application of organic sources along with mineral fertilizers.
- Efficient agronomic management practices such as tillage, irrigation, mulching, weed control, plant population and use of varieties with higher NUE.

Efficient input use can be achieved by assessment of available inputs and conservation against possible losses, integrated use of inputs in a synergistic manner, optimal allocation of inputs among the competing demands to achieve maximum return, maximizing input use efficiency by developing suitable site specific technologies.

Efficient nutrient management

Nutrient plays a key role in increasing agricultural production through intensive cropping. Sustainable agriculture can be achieved by efficient utilization of this costly input. Nutrient use efficiency can be improved by checking the path ways of nutrient losses from soil-plant system, making integrated se of nutrients from all possible sources, optimal allocation of nutrients to cops and maximizing the utilization of applied and native nutrients by the crops.

Checking the pathways of nutrient losses

Nutrient present in soil and added through fertilizers and manures are lost by gaseous loss, leaching loss, runoff/erosion losses and fixation in soil. Efficient nutrient management demands understanding the pathways of nutrient losses and developing technologies to minimize these losses.

Reducing gaseous loss

Part of the applied N is lost from soil by volatilization of ammonia and part of the nitrogen is lost as N_2O and N_2 gas by denitrification. Volatilization loss of ammonia can be minimized by mixing of nitrogen fertilizers in soil rather than broadcasting on soil surface, deep placement of urea super granules (USG) in puddle rice field, using urease inhibitors like thiourea, methyl urea, caprylohydroxamic acid, phenyl phosphorodiamidate (PPD), ammonium thiosulphate etc. and adding inorganic salts of Ca, Mg or K with urea. Some coated material like sulphur coated urea (SCU), gypsum coated urea (GCU), plastic coated urea (PCU), mud ball urea and synthetic slow release urea based fertilizers viz., isobutylidene diurea (IBDU) and crotobylidene diurea (CDU) etc. may be used to retard the rate of urea hydrolysis and thereby, reducing ammonia volatilization.

Nitrous oxide (N_2O) is mainly produced by denitrification of NO_3-under anaerobic condition, as in lowland rice fields. Nitrous oxide is one of the greenhouse gases that are believed to be forcing global climate change. Dentrification loss can be minimized by avoiding the use of NO_3^{-}form of nitrogenous fertilizer (e.g. calcium ammonium nitrate, potassium nitrate etc.) in rice and use of nitrification inhibitors viz., Dicyandiamide (DCD), N-serve (2-Chloro, 6-Chloro methyl pyridine), AM (2-Amino, 4-Chloro, 6-methyl pyrimidine), coated calcium carbide (CCC), neem-coated urea, deep placement of urea sugar granules (USG) in flooded rice field and efficient and efficient water management.

Reducing leaching loss

Mobile nutrients (e.g. NO_3^{--}) are lost from the soil-plant system with the percolating water. Besides reducing the nutrient may pollute the groundwater. The groundwater having more than 10 mg NO_3^{--}, N per litre is unfit for drinking purpose (WHO). Leaching loss of NO_3^{-}can be minimized by balanced fertilization, split application of urea synchronizing with crop demand, manipulation of water application and rooting depth, appropriate crop rotations and use of slow release fertilizers and nitrification inhibitors like N-serve, DCD, AM, CCC and neem-coated urea.

Despite the success of synthetic nitrification and unrease inhibitors in research farms they have poor acceptability among farmers because of high cost. However, the use of products plants like neem for coating urea can be popularized among the farmers to affect N economy and minimize long-term environmental consequences of denitrification and nitrate leaching.

Reducing runoff and erosion losses

Many water-soluble nutrients are lost through runoff. This loss can be minimized by proper crops land management and selection of proper crops and cropping systems, tillage and mulching. Nutrients sorbed on the surface of soil particles-clays and silts and soil organic matter are lost when the top soil is eroded by water or wind. Proper soil conservation measures should be adopted to minimize this loss.

Reducing fixation of nutrients in soil

In acid soils phosphorus is fixed as Fe^{++} and Al^{++} phosphates and in neutral and calcareous soils it gets fixed as Ca^{++} phosphate. The availability of these fixed phosphates is very low. Phosphate-fixation in acid soil can be reduced by combined application of rock phosphate and single super phosphate and liming of acid soils. In both acid and calcareous soils phosphorus-fixation can be minimized by band placement of phosphatic fertilizers along with crop rows. Use of rock phosphate along with acid forming materials like pyrites or phosphate-solubilizing microorganisms help in solubilizing of sparingly soluble rocks. Vesicular-arbuscular mycorrhizal (VAM) fungi are helpful in mobilizing both applied and native P reserves.

K^{++} and NH_4^{++} ions are also fixed in the interlayer of 2:1 clay minerals like illite, vermiculite etc. nutrients fixed on soil-plant system but are not available to the crop in a short-term period. However, these are released at later stages of crop growth.

Integrated plant nutrient management system

The high cost of fertilizers coupled with relatively greater losses of fertilizer N leading to environmental pollution and yield decline over the year's calls for a cheaper and more sustainable measure to improve productivity by substituting part of the inorganic fertilizers by organic sources of nutrients. Organic sources of nutrients alone cannot sustain the crop yield at higher level to meet the demand of growing population. There is need to combine the use of inorganic fertilizers and organic sources of nutrients viz., manures, green manures, crop residues, biofertilizers etc. in a synergistic manner, which is referred as Integrated Plant Nutrient Supply (IPNS) System.

Integrated nutrient supply system sustains and improves the physical, chemical and biological health of soil and enhances the availability of both applied and native soil nutrients during growing season of the crops. This helps in retarding soil degradation and deterioration of water and environmental quality by promoting carbon sequestration and checking the losses of nutrients to water bodies and atmosphere. Besides, organic sources of nutrient acts as slow release fertilizer as it synchronizes the nutrient demand set by plants, both in time and space, with supply of the nutrients from the labile soil and applied nutrient pools.

Application of N, half as urea and half as farmyard manure, resulted in higher fertilizer N recovery by Pusa Basmati-1 rice, higher retention of fertilizer in soil and lower unaccounted for fertilizer N than sole urea application in a sandy loam soil.

Green manuring crops grown in-situ (e.g. clover, vetch, cowpea, sesbania etc.) or brought from outside (e.g. Gliricidia) can be incorporated in soil to improve the crop productivity. For example 50-60 days old *Sesbania aculeate*, on an average, accumulates 4 to 5 t/ha dry matter or 100 to 130 kg/ha/N. The major constraint in green manuring is fitting it to crop rotation and managing the extra inputs i.e. fertilizer and water for it by the resource poor farmers. When the crops are harvested mechanically a sizable quantity of crop residues are left in field that can be recycled for nutrient supply. Out of the nutrient taken up by cereals, on an average, 25per cent of each N and P, 50per cent of S and 75per cent K are retained in crop residues making them available sources of nutrients. The low decomposition rate because of high C:N ration and immobilization of nutrients by cereal residues are some of the constraints in using them as source of nutrients. The major problem in using crop residues lies with the demand of these materials for other competing purposes e.g. animal feed and thatching of root etc. The NUE is considered altered when N fertilizers are applied in combination with organic manures, green manures, crop residues and biofertilizers (Sharma and Mitra 1990).

Biofertilizer help in improving soil fertility through biological nitrogen-fixation, solubilizing P from native soil and applied sources and mobilizing the micronutrients like Zn++ and Cu++ for plant-uptake. Rhizobium strains play a major role in symbiotic N-fixation in legumes. Similarly blue-green algae, Azotobacter sp. and Azospirillum sp. Help in N-fixation in cereals. The vesicular-arbuscular mycorhizal (VAM) fungi have an extensive mucellial network that increase the transport and uptake of P and micronutrients like Zn++ and Cu+_+. Bphosphate solubilizing microbes e.g. Pseudomonas striata, Bacillus polymyxa and Aspergillus awamori help in solubilizing of native soil P and rock phosphates.

Despite all the positive aspects of biofertilizers their use efficiency is highly soil, crop, location and management specific. It requires reliable system of storage, transportation and management in field to increase its acceptability among farmers.

Legumes are known to increase soil fertility through their capacity to fix atmospheres N and hence the soil fertility can be improved by inclusion of a legume in the cropping system. Yields of cereals following legumes are reported to be 0.3 to 3 mg/ha; or 30-35per cent higher than those following a cereal in cropping sequence. Besides N-fixation, legumes also help in solubilizing of occluded P, soil conservation, increase in soil microbial activity, organic matter restoration and improvement of physical health of soil.

Optimal allocation of nutrients

The available nutrients should be optimally allocated among the competing crops to get the maximum returns by following optimizing of nutrient production functions which relate crop responses to applied nutrients under given soil, climate and management factors. Fertilizer allocation to crops based on soil test crop correlation approach for targeted yield can help in improving the nutrient use efficient by crops.

Enhancing recovery of added nutrients by crops

The nutrient management practices that help in enhancing nutrient recovery by crops, maximizing yield and minimizing losses of nutrient lead to enhanced nutrient use efficiency. Some of these practices include selection of crops and cropping systems, balanced nutrition application and selection of proper, rate, time and method of nutrient application, optimum interaction with other inputs and amelioration of problem soils.

Selection of crops and cropping systems

Proper genotype of a crop should be selected which can mine the nutrients from soil and applied sources and converts them into desired output. Crops and cropping systems should be selected such that the residual nutrient left by one crop is efficiently utilized by the following crops. From a 10 years study in an Ustochrept in Punjab, it was seen that the apparent recovery of P declined rice-wheat>rice-berseem>cotton-wheat>corn-wheat>groundnut-wheat>pearl millet-berseem.

Balanced fertilization

Major factor responsible for the low and declining crop response to fertilizers is the continuous mining of soil without adequate replenishment to a desired extent (NAAS, 35). The continuous use of N fertilizers alone or with inadequate P and K application has led to mining of native soil P and K. it is estimated that about 28 million tones of NPK are removed annually by crops in India, while only 18 million tonnes or even less are added as fertilizer, leaving a net negative balance of 10 million tones. Further, soil are getting continuously depleted of S and micronutrients like Zn, B, Fe and Mn due to continued adoption of intensive cropping systems and use of high analysis fertilizers without adequate addition of organics.

Balanced fertilizer use at the macro level in India is generally equated with a nutrient consumption ration of 4:2:1 (N: P_2O5:K_2O). The N: P_2O5:K_2O ratio is as wide as 30.8:8.8:1 in Punjab, 48.2,14.9:1 in Haryana and 53.0:19.3:1 in Rajasthan compared with all India average of 6.9:2.6:1 (FAI.2004-05).

Blanced fertilizer i.e., use of fertilizer nutrients in right proportion and in adequate amount are considers as promising agrotechniques to sustain yield, increase fertilizer use efficiency and to restore soil health (Yadav *et al*. 1998). Continuous heavy application of only one nutrient disturbs the nutrient balance and leads to depletion of other nutrients as well as to under-utilization of fertilizer N. the response of a crop to N not only depends on the status of N but also on the deficiency or sufficiency of other associated plant nutrients (Yadav *et. al.,* 1998). Thus, balanced use of all nutrients is essential because no agronomic manipulation can produce high efficiency out of an unbalanced nutrient use.

Organic manure

Organic manures are important to enhance use efficiency of fertilizer inputs and also serve as alternative source of nutrients to chemical fertilizers. Combined use of organic manure and N fertilizer maintains a continuous N supply, checks losses and thus helps in more efficient utilization of applied fertilizers. Incorporation and decomposition of organic manures has a solubilising effect on native soil N and other nutrients including micronutrients. Further, such integrated plant nutrient supply (IPNS) systems also help in mitigating the adverse effects of acidity due to chellation of excess Al^{++} and/or Fe^{++} by the organic molecules liberated from FYM in the course of mineralization. The effect of FYM was found to be similar to like amendment in these acid soils, which seems mainly due to the formation of Al-organo chellates or complexes, resulting in the reduction of Al^{++} ion concentration in soil solution to levels beneficial to plant growth. In another study, apparent N recovery was increased when N fertilizer was applied along with organic manures such as biological study, FYM and *Eupatorium adenophorum* (Mahajan *et. al.* 2002).

Green Manuring

Inclusion of legumes in cropping systems for green manuring, fodder or grain purposes is an assured agro-technology to improve nutrient-use efficiency, especially that of N. The advantages of green manuring are indicated by increased N availability in soil, higher recovery of green manure N and its greater contribution towards grain production of crop.

Selection of source, rate, and time and method of nutrient application

The nature of fertilizer used and the rate, time and method of its application influences the recovery of the added nutrient by crop plants and it varies with the crop and root type.

Ammonium nitrate is considered to be a better source of nitrogenous fertilizer for upland crops whereas ammonical and amide form of N are superior to the nitrate containing sources for lowland rice crop. However, urea is the most economic source of nitrogeneous fertilizer. Fertilizer rates greater than the optimum level lead to lower utilization efficiency. Timing of fertilizer application should match with the crop demand. Split application of N is superior to basal application. P is usually applied as basal and in some light textured soils split application of K is advisable.

Method of applying fertilizers greatly affects their agronomic efficiency by influencing nutrient losses and their availability to plant roots. Superiority f fertilizer application before pre-sowing irrigation over application of the same at the time of seeding for enhancing fertilizer use efficiency was reported by many workers. Similarly in rice, basal application os urea with no standing water is superior to broadcast application of urea into standing floodwater at 10 days after transplanting in reducing the volatilization losses of ammonia.

The efficiency of water-soluble phosphatic fertilizers can be improved by band placement with, below or to the side of the seed row. This can improve the physical fertility of soil as the plants roots can easily take up nutrients from these sources.

Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Total P is often 100 times higher than the fraction of soil P available to crop plants. Most cereal growing areas in the developed world will overcome the problem of low P availability through management practices such as the application of phosphorus-based fertilizer/manure (Ortiz-Monasterio *et. al*., 2002). P availability is strongly influenced by soil pH. Availability of P is maximized when soil pH is between 5.5 and 7.5. Acid soil conditions (pH < 5.5) cause dissolution of aluminum and iron minerals which precipitates with solution P effectively "tying" it up. Basic soil conditions (pH > 7.5) cause excessive calcium to be present in soil solution which can precipitate with P decreasing P availability.

Land configuration and soil tillage have tremendous potential for its further exploitation and improving TFP. Yield enhancement is also possible by sowing crops in more innovative spatial patterns, such as in clumps rather than in rows (Bandaru *e.t al.,* 2006).

Crop rotation involving legumes

There is need to develop crop rotations involving legumes to tap the benefits of biological nitrogen fixation (BNF). Nitrogen use efficiency for cereals following legumes is greater than that for cereals following cereals or fallow. The role of legumes in N economy is well researched but the problem is how to increase N input and the options are increased system efficiency or increase in the area under the system. N derived from BNF in legumes varies from 40-80 per cent and residual effect on succeeding crops is variable and depends on several factors. The more intensive systems (growing more crops in a given period of time) require greater fertilizer N inputs but are economically advantageous to farming community. More intensive dry land cropping systems

involving legumes in rotation lead to increased water use efficiency and also better maintain soil quality. The research has shown a positive impact of BNF on nitrogen economy of cropping systems but the vast potential of BNF has remained unrealized at the farmers' level due to many reasons and needs to be looked into from the holistic approach on nitrogen use in agricultural production systems. Some aspects which need immediate attention are: increasing public investment in microbiology for teaching, research and training, encouraging private investment in manufacture of biofertilizers, constitution of nodal agency for registration of manufacturers, establishment of quality control laboratories and
act as a watch dog and promoting products through DAVP and media. The private sector needs to play a crucial role and set an example by employing qualified microbiologists for production, assuring quality through creation of brand equity, ensuring *niche* marketing through entrepreneurship ventures and providing dealers' involvement as advisor and friend on product and proper application.

There is an urgent need to improve the inputs of organics and BNF and to increase the production of quality inoculants and popularize their use in Indian agriculture rapidly. Development of effective and competitive strains tolerant to high temperature, drought, acidity and other abiotic stresses are of high priority. Newer formulations of mixed biofertilizers, improvement of inoculant quality and devising effective delivery systems are crucial for making further progress in taking the BNF technology to farmers' fields.

Breeding input efficient crop varieties

Breeding and selecting crop cultivars that make more efficient use of water and fertilizer N (including higher N fixation and N partition) while maintaining productivity and crop quality has been a long-term goal of production agriculture. Development of nitrogen-efficient cultivars could help decrease fertilizer N inputs and resulting reactive N losses to air and ground water. These nitrogen-efficient cultivars could also be useful in regions where limited-resource farmers are unable to afford synthetic N fertilizers. Selection of N efficient genotypes that is the varieties which can extract more N from soil at lower availability will enhance the production in these regions. Molecular and biotechnological approaches for searching for regulatory targets for manipulation of N use efficiency be strengthened. Unraveling the details of N signal transduction to provide additional clues to improve N uptake and assimilation efficiency.

Collaboration and accurate measurement

Improving N-use efficiency in major food crops will require collaboration among ecologists, agronomists, soil scientists, agricultural economists, and politicians. Great needs exist for accurate measurements of actual fertilizer N-use efficiency, N losses, and loss pathways in major cropping systems. Only in this way we can: a) identify opportunities for increased N-use efficiency by improved crop and soil management; b) quantify N-loss pathways in major food crops; and c) improve human understanding of local, regional, and global N balances and N losses from major cropping systems. The starting point for any improvement has to be a clear understanding of the fluxes and balances of nitrogen at the farm level. Direct on-farm measurements are necessary because estimates from small plots on research stations overestimate field-scale fertilizer N-use efficiency (NAAS 2005).

Holistic crop management for improving nutrient use efficiency

Some suggestions for holistic management of crops include:

- Adopt proven methods of individual nutrient use, with knowledge-intensive nutrient management.
- Harness the positive nutrient interactions and control negative nutrient interactions
- Maintain natural resource base, the soil quality and prevent environmental degradation.

- Use biotechnological tools for reducing the nutrient use, viz. selective ion uptake or exclusion, herbicide tolerance, Bt crops, efficient strains of bio-inoculant and bio-control agents and tolerance to abiotic stresses (drought, salinity, low photo- and thermo-sensitivity).

Multi-nutrient deficiencies are emerging and hidden hunger status for secondary and micronutrients is evident. Nutrient-use efficiency depends on several agronomic factors including tillage, time of sowing, appropriate crop variety, proper planting or seeding, adequate irrigation, weed control, pest or disease management and balanced and proper nutrient corrects nutrient use. Balanced use of plant nutrients corrects nutrient deficiency, improves soil fertility, increase-nutrient and water-use efficiency, improves crop yield and farmers' income, and better the crop and environmental quality. These factors largely influence the use efficiency, either individually or collectively. The entire crop, management practices that promote better crop growth will invariably increase the nutrient-use efficiency. Adoption of best crop management practices on system basis is essential to get higher input-use efficiency and profitability. To reap the benefits of balanced use of plant nutrients, it is important to have good-quality seed, adequate moisture and better agronomic practices with greater emphasis on timeliness and precision in farm operations.

Efficient Water Management

Water is the most crucial input for agricultural production. Vagaries of monsoon and declining water-table due to its overuse resulted in shortage of fresh water supplies for agricultural use, which calls for an efficient use of this resource. Strategies for efficient management of water for agricultural use involves conservation of water, integrated water use, optimal allocation of water and enhancing water use efficiency by crops.

Conservation of water

In-*situ* conservation of water can be achieved by reduction of runoff loss and enhancement of infiltrated water and reduction of water losses through deep seepage and direct evaporation from soil. Runoff is reduced either by increasing the opportunity time or by infiltrability of soil or both. Opportunity time can be manipulated by land shaping, tillage, mechanical structures and vegetative barriers of water flow and infiltrability can be increased through suitable crop rotations, application of amendments, tillage, mulching etc. Water loss by deep seepage can be reduced by increasing soil-water storage capacity through enlarging the root zone of crops and increasing soil-water retentively. Direct evaporation from soil can be controlled with shallow tillage and mulching.

Ex-*situ* conservation of water can be achieved by harvesting of excess water in storage ponds for its reuse for irrigation purpose.

Integrated water use

Efficient utilization of water resources and minimization of detrimental effect of water management on soil and water resources can be achieved by the integrated use of water from different sources viz., by irrigation to supplement profile stored rainwater, conjunctive use of surface-water and groundwater, poor and good quality water and recycled (waste) water for irrigation. Supplemental irrigation for growing crops is an integrated use of rainwater stored in the profile and the irrigation water regardless of its source.

Small (30-50 mm) early post-emergence irrigation stimulates root extension into deeper layers thus causing greater use of profile-stored water. So the water extraction obtained from the supplemental irrigation at crucial crop growth period is more than the proportionate increase in the level of supplemental irrigation, which is referred as priming effect of the supplemental irrigation. The priming effect varies with soil type, fertility level and amount of irrigation. It generally increases with the increase in the N rate, soil water retentively and decreases with the increase in the amount of irrigation after a certain threshold value.

Optimal allocation of water

Optimal allocation of available water among the competing crops and optimum timing of application is to be decided under adequate and limited water supply situation so as to maximize economic returns from available water. Under adequate water supply situation optimal allocation involves timing of irrigations so that crop yields are maintained at their achievable potential, as per climatic conditions of the location. Under limited water supply situation irrigation water must be allocated so that periods of possible water deficits coincide with the least sensitive growth periods. Thus irrigation scheduling should be decided based on the water availability. The procedure for optimal allocation of water under limited water supply condition includes quantifying water use (ET or T) *vs* crop biomass relations and employment optimizing models with operational constraints. Crop simulation models can be used to schedule irrigation under different water availability conditions.

Enhancing water-use efficiency crops

Water-use efficiency by crops can be improved by selection of crops and cropping systems based on available water supplied and increasing seasonal evapotranspiration (ET). The later can be achieved by selection of irrigation method, irrigation scheduling, tillage, mulching and fertilization.

Water use efficiency

The water utilized by crop is evaluated in terms of Water Use Efficiency. This water use efficiency can be classified into

1. **Crop Water Use Efficiency (CWUE)**

   It is the ratio of crop yield (Y) to the amount of water used by the crop for evapotranspiration (ET)

$$CWUE = \frac{Y}{ET}$$

2. **Field Water Use Efficiency (FWUE)**

   It is the ratio of crop yield (Y) to the total amount of water used in the field (WR)

$$FWUE = \frac{Y}{WR}$$

3. **Physiological Water Use Efficiency (PWUE)**

   The physiological WUE is calculated in terms of the amount of C_2O fixed per unit of water transpired

$$PWUE = \frac{\text{Rate of Photosynthesis}}{\text{Rate of Transpiration}}$$

Strategies to increase water use efficiency

Water-use efficiency (WUE) of crops can be improved by selection of crops and cropping systems based on available water supplies and increasing seasonal evapotranspiration (ET). The later can be achieved by selection of irrigation method, irrigation scheduling, tillage, mulching and fertilization.

Selection of crops and cropping system

Selection of crops and cropping systems for high water-use efficiency should be done on the basis of availability of water under rainfed crops, limited irrigated crops and fully irrigated crops. The average WUE of different crops varies from 3.7 to 13.4 kg/ha/mm of water.(Tables 2 and 3)

Table 1. WUE of some important field crops in India

Crops	WUE (kg-ha/mm)
Rice	3.7
Finger millet	13.4
Wheat	12.6
Sorghum	9.0
Maize	8
Groundnut	9.2

Table 2. WUE of some important field crops in India

High	Medium	Low
Maize	Wheat	Green
Sorghum	Barley	Gram
Pearl millet	Oats	Pigeonpea
Finger millet		Soybean
Sugarcane		Peas

Rainfed crops

The amount of rainfall converted into plant-available soil water is determined by the amount and intensity of rainfall, topography, infiltrability and water retentivity of soil, depth of root zone and soil depth. Depth of soil due to its effect on the available water storage capacity decides the type of cropping locality. On medium soil depth monocropping or intercropping can be practiced whereas in deep soil with 200 mm available soil moisture status double cropping can be practiced.

Limited irrigated crops

Selection of crops and cropping sequences under limited irrigation situation should be done as there should be minimum water stress during the growing season although some water-stress to the crops and associated yield reduction is inevitable. Therefore, along with selection of crops special care should be taken for irrigation scheduling of these crops.

Fully irrigated crops

Under fully irrigated condition selection of crops is not constrained by water availability but by adoptability of the crops to prevailing climatic and soil condition. In general, water use efficiency of C_4 plants is higher than C_3 plants, particularly under semi-arid environment.

Increasing seasonal evapotranspiration

Seasonal evapotranspiration (ET) is a measure of consumptive water use by the crops. Increasing the transpiration (T) component of ET, results in higher utilization of water by the crops to increase the productivity. The T can be increased by following improved irrigation methods, irrigation scheduling, tillage, mulching and fertigation.

Irrigation method

Efficient micro-irrigation methods like sprinkler and drip irrigation for utilization of available water in case of scarce in lean season developed mainly for high value horticultural and plantation crops could save up to 50per cent of water and also increase the crop yield and quality substantially.

Irrigation scheduling

Under adequate water availability the main emphasis is on securing potential yield of the crops without wasting water. Whereas, under limited water supply, the objective is to achieve maximum WUE. There are different methods for irrigation scheduling viz., critical crop growth stages, feel and appearance method, soil moisture depletion approach, irrigation water at different cumulative pan evaporation method.

Tillage

Tillage practices mainly influence the physical properties of soil viz., soil moisture content, soil aeration, soil temperature, mechanical impedance, porosity and bulk density of soil and also the biological and chemical properties of soil which in turn influence the edaphic needs of plants viz., seedling emergence and establishment, root development and weed control. Tillage also influences the movement of water and nutrients in soil and hence their uptake by crop plants and their losses from soil-plant system.

Tillage affects the WUE by modifying the hydrological properties of the soil and influencing root growth and canopy development of crops. Tillage methods influence wettability, water extraction pattern and transport of water and solutes through its effect on soil structure, aggregation, total porosity and pore size distribution. Tillage system suitable for a soil depends upon soil type, climate and cropping system practiced. Shallow inter-row tillage into growing crops reduces short-term direct evaporation loss from soil even under weed-free condition by breaking the continuity of capillary pores and closing the cracks.

Deep tillage to a depth of 30-45 cm at 60-120 cm intervals helps in breaking subsoil hard pans in alfisols facilitating growth and extension of roots and improving grain yield of crops as well as increasing residual soil moisture. However, the benefit is absent in suboptimal rainfall years and restricted to only deep-rooted crops in high rainfall years.

Conservation tillage practice normally stores more plant available moisture than the conventional inversion tillage practices when other factors remain same. The high soil moisture content under conservation tillage is due to both improved soil structure and decrease in the evaporation loss under continuous crop residue mulch cover. Increase in the available water content under conservation tillage, particularly in the surface horizon, increases the consumptive use of water by crops and hence improves the water use efficiency.

Off season tillage or summer ploughing opens the soil and improves infiltration and soil moisture regimes.

Mulching

Mulching influences WUE of crops by affecting the hydrothermal regime of soil, which may enhance root and shoot growth, besides it helps in reducing the evaporation (E) component of the evapotranspiration. Under moisture stress conditions, when moisture can be carried over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yield.

Fertilization

There is strong interaction between fertilizer rates and irrigation levels for crop yield and WUE. Application of nutrients facilitates root growth, which can extract soil moisture from deeper layers. Furthermore, application of fertilizers facilitates early development of canopy that covers the soil and intercepts more solar radiation and thereby reducing the evaporation.

Weed control

Weed management is the most efficient and practical means of reducing transpiration. Weeds compete with crops for soil moisture, nutrients and light. Weeds transpire more amount of water compared to associated crops plants.

Cultural manipulations

A timely –sown crop result in good stand and vigour and thereby higher efficiency of the basally-applied N fertilizer. On the other hand a crop sown late requires additional inputs like seed, fertilizer, irrigation etc. to compensate for the loss in crop stand and yield. In adequate crop stand is the major cause of low crop productivity under stresses environment like rainfed, drought and flood-prone conditions. Weed competes with crop plants for water, nutrients, sunlight and thereby reduce crop yields and consequently NUE.

Varieties

Breeding and selecting crop cultivars that make more efficient use of soil and fertilizer N (including higher N fixation and N portioning) while maintaining productivity and crop quality has been a long-term goal of production agriculture. Development of nutrient efficient cultivars could help decrease fertilizer inputs and resulting nutrient losses to air and groundwater..

Incidence of insects and diseases

Plant health is government by diseases, insects and weeds that compete for water and nutrient resources and low NUE. Incidence of insects and diseases generally increases at higher levels of N application. Stem-borer infestation in rice was 42per cent more than application of 40 kg N/ha than without N under lowland conditions (Sharma, 2002). At higher levels of N, the rice crop lodged and showed greater susceptibility to bacterial leaf blight and bacterial lead, streak, resulting in low grain yield.

Precision farming techniques

Application of N on the basis of soil test valued is essential to economize on the cost of fertilizer application. Land leveling and root zone wetting through micro-irrigation systems also lead to efficient use of water and N fertilizer inputs. Employment of drip irrigation and fertigation techniques have grained popularity in recent years, particularly in the widely-spread high-value crops. Precisely in controlled quantity and at appropriate time directly to the root zone as per crop needs at different growth stages. This nor only enhances WUE but also enables efficient use of nutrients, particularly N for higher productivity. Using N in accordance with chlorophyll meter has been found to be more efficient than fixed schedule N fertilizer splits as key growth stages. Precision land leveling has tremendous impact on agronomic efficiency of N, P and K (Jat *et al.*

2004). Under irrigated agriculture, precision water management has large bearing on the water productivity, higher yield and income. Higher water productivity and NUE was reported under precision drill seeding compared to broadcasting and traditional drill (Pal *et al.* 2004).

Interaction with other inputs

The utilization of nutrients can be improved by optimum and synergistic interaction with other inputs viz., water, tillage and mulches. These inputs modify the physical, chemical and biological environment of soil, which influence the nutrient recovery by crop plants.

Significant and positive interaction between applied N and water supply was observed on wheat yield and water and nutrient use efficiency by wheat (Bhale et al., 2009). With 80 kg N/ha, N use efficiency increased up to 300 mm water supply in sandy loam soil. Interestingly, with 120 kg/ha, it did not increase when water supply was increased from 50 mm to 125 mm, but increased markedly when water supply was further increased to 300 mm (**Table No** 3). This implied that the balance between these two inputs influenced input use efficiency.

Table 3. Nitrogen and irrigation effects on water use efficiency (kg/grain/mm) and nitrogen use efficiency (kg grain/kg fertilizer N) in sandy loam soil

Irrigation (mm)	WUE				NUE		
	N rate (kg/ha)				N rate (kg/ha)		
	0	40	80	120	40	80	120
0	5.3	7.6	8.1	6.0	8.5	5.5	1.5
50	6.3	9.5	11.3	13.3	20.2	18.4	17.8
125	5.7	10.3	11.9	11.8	33.2	25.5	17.0
300	4.6	7.4	9.5	10.2	30.2	30.3	23.7

Source: Bhale *et al.* (2009)

Application irrigation and nutrient in conjunction through pressure irrigation system result in efficient utilization of both resources. This will save water as well a reduces nutrient leaching losses and thereby increased WUE as well as NUE. This will increase the yield and quality f crops. There is saving of water and nutrient to the extent of 35 and 22 per cent, respectively. fertigation is most commonly used for plantation crops like banana, sugarcane and orchards of Maharashtra.

Amelioration of problem soils

Soil related constraints affecting crop production influence the nutrient use efficiency crops. For example liming of acid soils with calcite, dolomite or paper mill sludge improves the phosphorus use efficiency. Similarly amelioration of alkali and saline-alkali soils with gypsum helps in improving nutrient use efficiency. Any other physical constraint like sub-soil compaction should be ameliorated using appropriate tillage practices to improve the nutrient use efficiency.

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