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MEASURES TO INCREASE FERTILIZER USE EFFICIENCY IN AGRICULTURE: A REVIEW

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ABSTRACT

Nutrient use efficiency (NUE) depends on the plant's ability to take up nutrients efficiently from the soil, but also depends on internal transport, storage and remobilization of nutrients. Nitrogen (N) is a fundamental element regulating plant growth and development. Plants have evolved inorganic and organic N-uptake systems to cope with heterogeneous N availability in the soil. However, NUE is dependent on root growth and root architecture. Endophytic bacteria have a direct influence on root growth and increase nutrient uptake. Under reciprocal exchange, trading carbon for nutrients, plant and bacteria establish a symbiotic association. In this chapter we will address how endophytic bacteria might contribute to efficient nutrient uptake, especially organic nitrogen, through bacterial cell degradation or by externally activating nitrogen transporters. Also, here we propose the use of rare earth elements as an option for improving NUE in plants and their possible use as fertilizers.

***Keywords* :** Nutrient use efficiency, Endophytic bacteria, Agriculture.

Introduction

Humans consume crop and animal products for nourishment while crops get most of their nutrient requirements from the soil. However, many soils do not provide all the nutrients in quantities needed by the crops. Soil nutrients removed by continuous cropping must be replaced through the addition of nutrient sources, such as fertilizers. Fertilizers Fertilizers are any solid, liquid or gaseous substances containing one or more plant nutrients in known amount, that is applied to the soil, directly on the plant (foliage) or added to aqueous solutions (as in fertigation) to maintain soil fertility, improve crop development, yield and/or crop quality. The purpose of fertilizer use, especially for higher yields, is identical in temperate and tropical climates:

- To supplement the natural soil nutrient supply and build up soil fertility in order to satisfy the demand of crops with a high yield potential;
- To compensate for the nutrients exported by the harvested products or lost by unavoidable leakages to the environment in order to maintain good soil conditions for cropping.

Fertilizers are applies to supplement nutrient requirement of the crop. Nutrient requirements of the crop are determined first and contribution of nutrients from different sources, particularly from soil is estimated. Rest of the crop requirement is met with inorganic sources.

Classification: Fertilizers are classified into two major forms:

(a) organic,

(b) mineral/manufactured.

Manufactured fertilizers are classified according to different criteria as follows:

A. Number of nutrients

(a) single-nutrient or **straight fertilizers** (whether for macro or micronutrients) examples: urea (46-0-0), triple superphosphate (0-46-0), muriate of potash (0-0-60), zinc/iron chelates, boric acid, etc.

(b) multi-nutrient/compound (multiple nutrients) **fertilizers**, with 2, 3 or more nutrients examples: compound fertilizers (15-15-15), diammonium phosphate (18-46-0), monopotassium phosphate (0-47-31), etc.

B. Type of combination

(a) mixed fertilizers or 'bulk-blends' are physical mixtures of two or more single-nutrient or multi-nutrient fertilizers;

(b) complex fertilizers are products in which two or more of the nutrients are chemically combined (e.g. nitrophosphates, ammonium phosphates).

C. Physical condition

a) **solid** (crystalline, powdered, prilled or granular of various size ranges;

b) **liquid** (solutions and suspensions);

c) **gaseous** (liquid under pressure, e.g. ammonia).

D. Nutrient release

(a) quick-acting (water-soluble and immediately available);

(b) slow-acting (transformation into soluble form required, e.g. direct application of phosphate rock);

(i) **controlled-release** by coating;

(ii) stabilized by inhibitors

Fertilizer use efficiency:

Nutrient use efficiency (NUE) is a critically important concept in the evaluation of crop production systems. It can be greatly impacted by fertilizer management as well as by soil- and plant-water management. The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field. NUE addresses some but not all aspects of that performance. Therefore, system optimization goals necessarily include overall productivity as well as NUE. The most appropriate expression of NUE is determined by the question being asked and often by the spatial or temporal scale of interest for which reliable data are available. In this chapter we suggest typical NUE levels for cereal crops when recommended practices are employed; however, such benchmarks are best set locally within the appropriate cropping system, soil, climate and management context. Global temporal trends in NUE vary by region. For N, P and K, partial nutrient balance (ratio of nutrients removed by crop harvest to fertilizer nutrients applied) and partial factor productivity (crop production per unit of nutrient applied) for Africa, North America, Europe, and the EU-15 are trending upwards, while in Latin America, India, and China they are trending downwards. Though these global regions can be divided into two groups based on temporal trends, great variability exists in factors behind the trends within each group. Numerous management and environmental factors, including plant water status, interact to influence NUE. In similar fashion, plant nutrient status can markedly influence water use efficiency.

The Concept and Importance of NUE

Meeting societal demand for food is a global challenge as recent estimates indicate that global crop demand will increase by 100 to 110% from 2005 to 2050. Others have estimated that the world will need 60% more cereal production between 2000 and 2050. While others predict food demand will double within 30 years equivalent to maintaining a proportional rate of increase of more than 2.4% per year. Sustainably meeting such demand is a huge challenge, especially when compared to historical cereal yield trends which have been linear for nearly half a century with slopes equal to only 1.2 to 1.3% of 2007 yields. Improving NUE and improving water use efficiency (WUE) have been listed among today's most critical and daunting research issues.

NUE is a critically important concept for evaluating crop production systems and can be greatly impacted by fertilizer management as well as soil- and plant-water relationships. NUE indicates the potential for nutrient losses to the environment from cropping systems. NUE measures are not measures of nutrient loss since nutrients can be retained in soil. Sustainable nutrient management must be both efficient and effective to deliver anticipated economic, social, and environmental benefits. As the cost of nutrients climb, profitable use puts increased emphasis on high efficiency, and the greater nutrient amounts that higher yielding crops remove means that more nutrient inputs will likely be needed and at risk of loss from the system. Providing society with a sufficient quantity and quality of food at an affordable price requires that costs of production remain relatively low while productivity increases to meet projected demand. Therefore, both productivity and NUE must increase. These factors have spurred efforts by the fertilizer industry to promote approaches to fertilizer best management practices such as 4R Nutrient Stewardship, which is focused on application of the right nutrient source, at the right rate, in the right place and at the right time.

NUE appears on the surface to be a simple term. However, a meaningful and operational definition has considerable complexity due to the number of potential nutrient sources (soil, fertilizer, manure, atmosphere (aerial deposition), etc.), and the multitude of factors influencing crop nutrient demand (crop management, genetics, weather).

The Objective of Nutrient Use and Nutrient Use Efficiency

The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other soil quality components. NUE addresses some but not all aspects of that performance The most valuable NUE improvements are those contributing most to overall cropping system performance.

Therefore, management practices that improve NUE without reducing productivity or the potential for future productivity increases are likely to be most valuable. If the pursuit of improved NUE impairs current or future productivity, the need for cropping fragile lands will likely increase. Fragile lands usually support systems with lower NUE that also use water less efficiently. The extent of the decline in productivity will be determined by source, time, and place factors, other cultural practices, as well as soil and climatic conditions.

Common Measures of NUE and their Application

The evaluation of NUE is useful to differentiate plant species, genotypes and cultivars for their ability to absorb and utilize nutrients for maximum yields. The NUE is based on (a) uptake efficiency (acquire from soil, influx rate into roots, influx kinetics, radial transport in roots are based on root parameters per weight or length and uptake is also related to the amounts of the particular nutrient applied or present in soil), (b) incorporation efficiency (transports to shoot and leaves are based on shoot parameters) and (c) utilization efficiency (based on remobilization, whole plant i.e. root and shoot parameters). Some of the commonly used efficiency definitions are given below.

An excellent review of NUE measurements and calculations was written by Table 1 is a summary of common NUE terms, as defined by Dobermann, along with their applications and limitations. The primary question addressed by each term and the most typical use of the term are also listed.

Table 1: Summary of common NUE terms, as defined by Dobermann

Term	Calculation*	Question addressed
Partial factor productivity	PFP = Y/F	How productive is this cropping system in comparison to its nutrient input?
Agronomic Efficiency	AE = $(Y-Y_0)/F$	How much productivity improvement was gained by use of nutrient input?
Partial nutrient balance	PNB = UH/F	How much nutrient is being taken out of the system in relation to how much is applied?
Recovery efficiency	RE = $(U-U_0)/F$	How much of the nutrient applied did the plant take up?
Internal utilization efficiency	IE = Y/U	What is the ability of the plant to transform nutrients acquired from all sources into economic yield (grain, etc.)?
Physiological efficiency**	PE = $(Y-Y_0)/(U-U_0)$	What is the ability of the plant to transform nutrients acquired from the source applied into economic yield?

Y = yield of harvested portion of crop with nutrient applied; Y0 = yield with not nutrient applied; F = amount of nutrient applied; UH = nutrient content of harvested portion of the crop;
U = total nutrient uptake in aboveground crop biomass with nutrient applied; U0 = nutrient uptake in aboveground crop biomass with no nutrient applied;

Partial factor productivity (PFP) is a simple production efficiency expression, calculated in units of crop yield per unit of nutrient applied. However, partial factor productivity values vary among crops in different cropping systems, because crops differ in their nutrient and water needs. If it is based on fresh matter yields, since these differ greatly depending on crop moisture contents (e.g. potato vs cereals). Therefore, geographic regions with different cropping systems are difficult to compare with this indicator.

NUE, Water and a Look Forward

Numerous management and environmental factors interact to influence NUE including plant water status. In similar fashion, plant nutrient status can markedly influence water use efficiency (WUE). The rest of this book will explore the interaction between these two critical crop growth factors. Water use efficiency can be improved through nutrient management. Nutrient availability affects aboveground biomass, canopy cover to reduce soil evaporation, plant residue production, nutrient dynamics in soil, and thereby improves crop growth and WUE. Adequate nutrient supply has shown to improve WUE in several crops.

Data from a lysimeter experiment conducted in Canada on spring wheat offers an excellent example of the relationship between NUE measures and WUE across a range of N levels (Figure 15). The study included both rainfed (dry) and irrigated (irr) treatments and shows the tremendous impact water status can have on yield response to N and the resulting AE and PNB. The lower graph in the figure shows that a water deficit markedly reduced both AE and PNB at all N levels, but that the efficiency reduction was considerably greater at the lower N levels. The upper graph in Figure 15 shows improvement in WUE as N levels increase for both the dryland and irrigated treatments. The lower apparent optimum N level for both yield and WUE for the irrigated treatment reflects higher NUE under irrigation shown in the bottom graph. (Fixen *et al*., 2014)

Recovery efficiency: refers to actual amount of nutrient taken up from the fertilizers

RE (%) = kg nutrient taken up by the crop/kg nutrient applied through fertilizers*100

Crop removal efficiency: removal of nutrients in harvested crop as % of nutrient applied.

Factors influencing NUE:

i. Type of soil and fertility
ii. Cropping history
iii. Season of the crop
iv. Nature of the crop and variety
v. Sowing time, plant population etc.
vi. Type, quantity, time and method of fertilizer application
vii. Method, quantity and frequency of irrigation
viii. How soil moisture is conserved
ix. Biotic factors management

Optimizing nutrient use efficiency:

Right rate: Most crops are location and season specific-depending on cultivar, management practices, climate, etc., and so it is critical that realistic yield goals are established and that nutrients are applied to meet the target yield. Over- or under-application will result in reduced nutrient use efficiency or losses in yield and crop quality. Soil testing remains one of the most powerful tools available for determining the nutrient supplying capacity of the soil, but to be useful for making appropriate fertilizer recommendations good calibration data is also necessary. Unfortunately, soil testing is not available in all regions of the world because reliable laboratories using methodology appropriate to local soils and crops are inaccessible or calibration data relevant to current cropping systems and yields are lacking. Other techniques, such as omission plots, are proving useful in determining the amount of fertilizer required for attaining a yield target (Witt and Doberman, 2002). In this method, N, P, and K are applied at sufficiently high rates to ensure that yield is not limited by an insufficient supply of the added nutrients. Target yield can be determined from plots with unlimited NPK. One nutrient is omitted from the plots to determine a nutrient-limited yield. For example, an N omission plot receives no N, but sufficient P and K fertilizer to ensure that those nutrients are not limiting yield. The difference in grain yield between a fully fertilized plot and an N omission plot is the deficit between the crop demand for N and indigenous supply of N, which must be met by fertilizers. Nutrients removed in crops are also an important consideration. Unless nutrients removed in harvested grain and crop residues are replaced, soil fertility will be depleted.

Right time: Greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N. Split applications of N during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing N use efficiency. Tissue testing is a well known method used to assess N status of growing crops, but other diagnostic tools are also available. Chlorophyll meters have proven useful in fine-tuning inseason N management and leaf color charts have been highly successful in guiding split N applications in rice and now maize production in Asia. Precision farming technologies have introduced, and now commercialized, on-the-go N sensors that can be coupled with variable rate fertilizer applicators to automatically correct crop N deficiencies on a site-specific basis. Another approach to synchronize release of N from fertilizers with crop need is the use of N stabilizers and controlled release fertilizers. Nitrogen stabilizers (e.g., nitrapyrin, DCD [dicyandiamide], NBPT [n-butylthiophosphoric triamide]) inhibit nitrification or urease activity, thereby slowing the conversion of the fertilizer to nitrate. When soil and environmental conditions are favorable for nitrate losses, treatment with a stabilizer will often increase fertilizer N efficiency. Controlled-release fertilizers can be grouped into compounds of low solubility and coated water soluble fertilizers. Most slow-release fertilizers are more expensive than water-soluble N fertilizers and have traditionally been used for high-value horticulture crops and turf grass. However, technology improvements have reduced manufacturing costs where controlled-release fertilizers are available for use in corn, wheat, and other commodity grains (Blaylock *et al.*, 2005). The most promising for widespread agricultural use are polymer-coated products, which can be designed to release nutrients in a controlled manner. Nutrient release rates are controlled by manipulating the properties of the polymer coating and are generally predictable when average temperature and moisture conditions can be estimated.

Right place: Determining the right placement is as important as determining the right application rate. The objective of placement of fertilizer is to make the nutrient available easily to the crop. It should be near to the roots. Application may be surface broadcast (i.e. applied uniformly on the soil surface and may or may not be incorporated) or applied as a subsurface band, at furrow bottom, place deep (usually 5 to 20 cm deep) or slightly below the root zone, top dressed, side dressed or to foliage. This depends on type of crop, rooting pattern, feeding area and ease of application. Prior to planting, nutrients can be broadcast

Applied at planting, nutrients can be banded with the seed, below the seed, or below and to the side of the seed. After planting, application is usually restricted to N and placement can be as a top dress or a subsurface side-dress. In general, nutrient recovery efficiency tends to be higher with banded applications because less contact with the soil lessens the opportunity for nutrient loss due to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to influence nutrient uptake and availability. Plant nutrients rarely work in isolation. Interactions among nutrients are important because a deficiency of one restricts the uptake and use of another. Numerous studies have demonstrated that interactions between N and other nutrients, primarily P and K, impact crop yields and N efficiency. For example, data from a large number of multi-location on-farm field experiments conducted in India show the importance of balanced fertilization in increasing crop yield and improving N efficiency (Table 3). Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of N fertilizer and is equally effective in both developing and developed countries. In a recent review based on 241 site-years of experiments in China, India, and North America, balanced fertilization with N, P, and K increased first-year recoveries an average of 54% compared to recoveries of only 21% where N was applied alone (Fixen *et al.*, 2005).

Right fertilizer: fertilizers vary in respect to solubility besides their grade. Choice of fertilizer is location specific and needs to be found out by field experimentation. The choice is more with respect to nitrogen and phosphatic fertilizers than for potassic. Studies on crop response is also more for than for P and K fertilizers because leaching loss is more for nitrogenous fertilizers and its residual effect is negligible or nil. In case of P, its indirect, residual an cumulative effects are more important nitrogen in nitrate form is more prone to leaching. Leaching losses are more in *kharif* than in summers and in sandy soils than clayey soils.

Other considerations:

i. Controlled irrigation: irrigated crops respond better to fertilizer than non irrigated crop
ii. Responsive and best suited varieties for the locality
iii. Use of HYV
iv. Optimum time of sowing
v. Proper spacing
vi. Use of organic residues
vii. Crop rotation with legumes
viii. Proper drainage
ix. Balanced fertilization
x. Split application
xi. Depth of the placement
xii. Top dressing
xiii. Nitrification inhibitors
xiv. Application of zinc sulphate in deficient areas
xv. Use of rock phosphate
xvi. Use of amendments
xvii. Weed control
xviii. Control of pests and diseases

Table 2 : Nutrient uptake (kg/ha) and Agronomic and physiological N-use efficiency of Bt. cotton as influenced by split and foliar application of nitrogen (mean data of 2 years)

Treatments	**N uptake (kg/ha)**	**AE (N) (kg/kg applied)**	**PE (N) (kg/kg uptake)**
T_1 (N:3- S, 30 and 60 DAS)	152.3	9.8	16.9
T_2 [N:3- S(20%), 30 (40%) and 60 DAS(40%)]	**146.2**	**8.3**	**16.3**
T_3 (N:4- S, 30, 45 and 60 DAS)	175.1	12.5	16.4
T_4 (N:5- S, 30, 45, 60 and 75 DAS)	**191.1**	**13.9**	**15.6**
T_5 [N:6- S (20%), 30, 45, 60, 75 and 90 DAS]	**221.6**	**15.9**	**14.3**
T_6 – T_1 + foliar 20 g urea/l H_2O (60, 75 and 90 DAS)	168.3	12.1	**17.2**
T_7 – T_1 + foliar 20 g KNO_3/l H_2O (60, 75 and 90 DAS)	178.5	12.4	16.0
T_8 – T_2 + foliar 20 g urea/l H_2O (60, 75 and 90 DAS)	151.0	9.4	16.7
T_9 – T_2 + foliar 20 g KNO_3/l H_2O (60, 75 and 90 DAS)	173.5	12.2	16.1
T_{10} – Control	79.5	-	-
CD (P=0.05)	21.2	1.9	NS

Giri *et al.* (2014) observed that 6 splits had the higher N uptake and WUE because of better water availability. Lowest was observed in 3 split application.

Table 3 : Effect of source and method of Zn application on Zn use efficiencies in corn

Treatment (all values are quantities of Zn ha^{-1})	**Harvest index (%)**	**Agronomic efficiency**	**Recovery efficiency (%)**	**Total N uptake by corn (kg/ha)**	**ZniNRE**
control (no added Zn)	36.9	-	-	93	-
5 kg to soil	**38.7**	**140**	2.02	118	19.2
1 kg foliar	34.6	**420**	15.27	107	10.76
5 kg to soil + 1 kg foliar	35.6	183	4.48	130	28.46
2.83 kg through Zn-coated urea (to soil)	35.4	283	6.58	120.3	21
LSD (for p=0.05)	2.1	9	0.08	6.4	-

Prasad and Shivay. (2014) revealed that the highest harvest index was recorded for the single soil application Zn sulphate, significantly higher than all other Zn treatments, but not the control. All treatments were significantly different from one another with respect to agronomic efficiency, and as expected, this was much the highest with the foliar treatment and lowest with the soil treatment (as Zn sulphate). The recovery index varied from substantially due to different Zn treatments. All Zn treatments for agronomic efficiency and recovery efficiency were in the following order: 1 kg Zn ha^{-1} (foliar) > 2.83 kg Zn ha^{-1} through Zn-coated urea (soil) > 5 kg Zn ha^{-1} (soil) + 1 kg Zn ha^{-1} (foliar) > 5 kg Zn ha^{-1} (soil).

Table 4 : Effect of Agrotain on nitrogen rate, N-use efficiency and rice yield

	Product	**N (kg/ha)**	**Efficiency (kg rice/kg N)**	**Yield (t/ha)**
Summer	Urea	80	11.4	2.77
	Urea + Agrotain	60	16.7	2.89
	Net efficiency	-25%	+46.5%	+4.3%
Winter	Urea	75	20.1	6.18
	Urea + Agrotain	75	24.1	6.48
	Net efficiency	-	+19.9%	+4.9%

Trenkel (2010) studied the effect of urease inhibitor on rice crop and found an increase of 46.5% in summer and 19.9% in winter crop. Yield increased to an extent of 4.3% in summer and 4.9% in winter crop

Table 5 : Fertilizer N saving and use efficiencies in rice and wheat crops in FFP and SSNM averaged for 2 years

	Rice		Wheat	
N applied (kg/ha)	**FP**	**SSNM**	**FP**	**SSNM**
AEN (kg grain/kg N)	8	**15.3** (83)	8	**13.0** (63)
REN (kg grain/kg N)	20	**30** (50)	15.34	**25.44** (59)
PEN (kg grain/kg N)	34.5	**45.5** (27)	29	**36.7** (26)

Khurana *et al.* 2008 reported higher AE, REN and PEN under SSNM with an increase of 83%, 50% and 27% in rice and 63%, 59% and 26% in wheat.

Table 6: Nitrogen uptake, N harvest index (NHI), N use efficiency (NUE), and N recovery efficiency (NRE) as affected by

	N uptake			
	Plant uptake (kg/ha)	**NHI (kg/kg)**	**NUE (kg/kg)**	**NRE (kg/kg)**
Continuous corn	171c	0.67	16c	0.30c
Soybean-corn	**201a**	0.69	**27a**	0.47a
Ist year corn	197ab	0.68	24a	0.43ab
IInd year corn	185b	0.68	20b	0.38b
CV (%)	10.8	6.1	33	37.4

Attia *et al.* (2015) observed higher plant uptake, NUE and NRE in soybean-corn sequence than continuous corn because of better nitrogen status of soil after soybean crop.

Table 7: Mean seed yield, agronomic efficiency of N and PFP in pearl millet, castor and cluster bean on Aridisol at SK. Nagar (Gujarat) during 1988-2006

Treatment	**Pearlmillet**			**Castor**			**Cluster bean**		
	Yield	**AE**	**PFP**	**Yield**	**AE**	**PFP**	**Yield**	**AE**	**PFP**
Control	413	-	-	438	-	-	280	-	-
Recommended N (urea)	**777**	4.6	9.8	796	6.0	13.3	445	8.3	22.3
50 % of rec. N (urea)	617	3.0	15.4	674	4.0	22.5	417	6.9	41.7
50 % of rec. N – FYM	557	3.6	13.9	630	**3.2**	21.0	475	9.8	47.5
50 % of N urea + 50 % of N (FYM)	**821**	**5.1**	10.2	827	**6.5**	13.8	572	**14.5**	26.0
Farmer's practice	575	-	-	565	-	-	418	-	-
CD (5%)	98.5			197.0			-		

Recommended N (urea) @80 kg/ha in pearlmillet, @60 kg/ha in castor and @20kg/ha in cluster bean.

Srinivasarao *et al.* (2011) observed highest mean yield was recorded with INM 50 % of N urea + 50 % of N (FYM) followed by Recommended N (urea). NUE (AE) varied from 3.0-5.1 and was higher with INM. PFP also increased in INM. Similar trend was observed in case of castor and cluster bean. In general, AE and PFP decreased with increasing N levels.

Table 8: N use efficiency in sorghum and sunflower at different NP levels as influenced by horse gram biomass incorporation during 10 years experiment on alfisols, Hyderabad

Treatment	**Sorghum**				**Sunflower**			
	Without incorporation		**With incorporation**		**Without incorporation**		**With incorporation**	
	Yield (kg/ha)	**AE (kg grain /kg N)**	**Yield (kg/ha)**	**AE (kg grain /kg N)**	**Yield (kg/ha)**	**AE (kg grain /kg N)**	**Yield (kg/ha)**	**AE (kg grain /kg N)**
$\mathbf{N_0P_0}$	307	-	397	-	258	-	343	7.3
$\mathbf{N_{25}P_0}$	570	13.1	758	18.1	436	7.2	525	15.0
$\mathbf{N_{25}P_{30}}$	816	20.4	1040	25.7	637	15.2	718	9.9
$\mathbf{N_{50}P_{30}}$	990	13.4	1216	24.3	715	9.2	840	
LSD (0.05)								
Main (incorporation)		100				56		
Sub (fertilizers)		92				76		

Srinivasarao *et al.* 2011. N use efficiency showed increase with the application P as well as cover crop incorporation. Low levels of sorghum yields were due to poor rainfall received during rainy season. Higher yields were associated with higher N use efficiency. AE and PFP were highly associated with amount of rainfall during 10 years.

Table 9 : Yield and N recovery for wheat grown in rice-wheat rotation with different rates of N applied

	N- applied (kg/ha)	**2007-08**	**2008-09**
Yield (kg/ha)	**150**	**4.86**	**4.80**
	150(GS)	4.73	4.81
	210	**5.06**	**5.00**
	CD (5%)	NS	NS
AR (%)	150	59.50	60.12
	150(GS)	**69.23**	**75.20**
	210	50.80	50.41

Coventry *et al.* (2011) studies that higher efficiency was achieved when N was applied at the rate of 150 kgN/ha. The third fertilizer dose was given with the help of green seeker.

Table 10: Nitrogen (N) uptake, N recovery and NUE by tomato plants as influenced by N application rate and fertigation frequency

N rate kg/ha	Fertigation frequency	Tomato yield (t/ha)	Fruit yield (kg/plant)	N uptake	N recovery %	NUE
200	Daily	52.54	1.75	159	68	240
	3 days	50.76	1.63	150	64	231
	Weekly	49.18	1.63	138	58	223
	Biweekly	42.37	1.39	119	48	189
300	Daily	67.75	2.27	**215**	64	211
	3 days	65.13	2.13	197	58	202
	Weekly	63.29	2.02	183	53	196
	Biweekly	54.35	1.76	146	41	166
CD (P=0.05)		4.76	0.15	24	-	14

Badr and Yazeid (2007) observed that marketable yield and per plant yield is significantly higher with daily fertigation in comparison to other frequencies. N uptake in the fruits was significantly higher with daily than with biweekly fertigation. Other differences were not significantly different. In the high N treatment, N uptake was as high as 215 kg N/ha in daily fertigation. Apparent N use efficiency was significantly affected by both N rate and fertigation frequency. NUE was significantly higher at the low N compared with the high N rate. With both N rate treatments, NUE was significantly higher with daily compared with biweekly fertigation.

Table 11: Efficacy of different methods of P-K application on agronomic efficiency

Methods	AE (kg cotton/kg PK)
Control	-
Broadcasting manually	7.94c
Broadcasting with spreader	8.77b
Band placement	**9.06a**
CD (5%)	0.22

Din *et al*. (2015) observed significantly higher AE in band placement of PK.

Table 12: Effect of PU, USG and NPK briquette on nitrogen use efficiency of BR22 rice

Treatment	NUE (kg grain/kg N applied)
T_1 - Control	-
T_2 (52 kg N/ha – USG)	33.87
T_3 (104 kg N/ha – USG)	28
T_4 (78 kg N/ha – PU)	10.77
T_5 (120 kg N/ha – PU)	11.30
T_6 (51 kg N/ha – NPK briquettes)	35.09
T_7 (78 kg N/ha – USG)	21.13
T_8 (78 kg N/ha – NPK briquettes)	22.08
CD (5%)	1.2

Naznin *et al* (2013) studied that significantly higher NUE was observed in use of NPK briquettes @51kg/ha followed by 52 kg N/ha – USG.

Table 13: Effect of cropping system, phosphorus sources and levels on phosphorus use efficiency indices (Sepat and Ahlawat 2012)

Treatment	Groundnut								Groundnut + cotton							
	AE		PRE		PFP		PEI		AE		PRE		PFP		PEI	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
17.5 kg P/ha through SSP	6.24	2.08	10.25	8.21	**22.37**	**19.44**	**0.88**	**0.87**	**7.27**	**16.64**	12.52	13.27	**61.28**	**62.16**	**1.26**	**1.88**
35.0 kg P/ha through SSP	**6.04**	**3.07**	**10.07**	**8.99**	14.11	11.75	0.80	0.73	7.58	8.98	12.99	9.74	34.59	31.73	1.03	1.61
17.5 kg P/ha through RP+PSB+AM	**5.31**	**1.73**	**7.59**	**4.06**	**21.44**	**19.09**	**0.94**	**1.05**	1.45	7.94	4.92	6.45	**55.46**	**53.46**	**1.38**	**2.03**
35.0 kg P/ha through RP+PSB+AM	3.77	1.44	4.91	5.43	11.83	10.12	0.94	0.81	**3.77**	**7.48**	**8.63**	**6.61**	33.88	30.24	1.25	1.83

Sole groundnut had highest AE with application of 35 kg P/ha through SSP but in case of intercropped groundnut 17.5 kg P/ha through SSP was superior. 17.5 kg P/ha through RP+PSB+AM performed better in sole groundnut and 35 kg P/ha in intercropped. This might be because RP with biofertilisers at low doses does not meet out the P demand in intercropping system. PRE followed the same trend. PFP was highest with lower doses of P in both systems. PEI was highest in control plots followed by 17.5kg P/ha and 35 kg P/ha through RP+AM+PSB.

Improving water use efficiency

Water is an elixir of life. The gift of nature is the saviour of life. However, water is becoming increasingly scarce worldwide. Demand for water from various sectors is ever rising but the water availability in the country is decreasing. Though India has the largest irrigated area in the world, the coverage of irrigation is only about 40 percent. WUE is low because of the predominant use of flood (conventional) method of irrigation. Recognizing this, a number of management strategies and programmes have been introduced. The first step in conserving water is to check for and eliminating any leaks. In agriculture, water and nutrients are two most critical inputs. Fertigation is an appropriate method of fertilizer application. If managed properly, it not only gives higher productivity but maintains environment quality. 80-84% of water consumed for agriculture. Lower productivity of most of the major crops. Real problem: wastage of water & lack of Demand management, not shortage. Wasteful utilisation of water resources diminish crop productivity, resulting in lower efficiency.

Enhancing WUE is an important goal in our water policy. Efficiency is a measure of output, obtained from a given unit of input. Efficient water utilisation reflects. how efficiently water is stored, distributed and used for crop production. Principle factors influencing WUE:

a) Design of the irrigation system
b) Degree of land preparation and
c) Skill & care from the irrigator

Key Challenge: Limited technical & managerial capabilities

- Low levels of water efficiency and productivity
- Low levels of technical awareness and adoptions
- Limited storage capacity
- High quantum of leakages from poor service delivery network
- Lack of governance & autonomy

Best Practices in Agriculture

a) Drip irrigation
b) Green House Technology
c) Hydroponics -- A soilless plant growing technology
d) Mulching

- ➢ Covers open ground surface around plant root with dry grass/hay/leaves for conservation of underneath moisture.
- ➢ Reduces evaporation significantly and increases water use efficiency.
- ➢ Waste Water Treatment & Recycling
    - Use of Semi-treated sewage water as source of irrigation and plant nutrients
    - Recycling of drainage from farms containing water with unused fertilisers

WUE=Y/ET

WUE=kg/ha-mm

Water use efficiency relies on:

- the soil's ability to capture and store water
- the crop's ability to access water stored in the soil and rainfall during the season
- the crop's ability to convert water into biomass
- the crop's ability to convert biomass into grain (harvest index)

Table 14: Green pods yield, average number and weight on pods for french bean under different methods of irrigation (Tomar *et al.,* 1999)

Methods of irrigation	Water use (cm)	Average number of pods	Average weight per pod (g)	Average weight of seeds(g)
Drip	18.42 (32.45)	**71.07**	5.52	24.45 (48.99)
Sprinkler	30.50 (18.71)	63.70	**6.17**	**24.77** (50.94)
Surface	44.51	53.66	4.45	16.41

Tomar *et al.* studied that sprinkler irrigation had higher average number of pods, weight per pod and seed weight than surface irrigation method.

Table 15: Yield increase and water savings in laser leveled and traditionally leveled for rice crop in PAU, Ludhiana

Site	Yield increase (%) in leveling over unleveled	Water savings (%)
1	13.60	26.15
2	10.30	-
3	8.57	25
Mean	**10.82**	**25.57**

Directorate of soil and water conservation studied higher WUE in laser land leveling in comparison to traditional leveling

Table 16: Effects of drip fertigation on dry pod yield, water saving, WUE, water productivity and B:C in chillies (Muralikrishanasammy *et al.*, 2013)

Treatments	Dry pod yield (kgha^{-1})	Water saving (%)	WUE (kg/ha/mm)	H_2O productivity	B:C
Surface irrigation at 0.90 IW/CPE + entire NPK	**1327**	**-**	**2.3**	**2.0**	**1.77**
Drip irrigation at 100% PE + 75% N, K through fertigation	1989	-	3.1	2.5	1.67
Drip irrigation at 100% PE + 100% N, K through fertigation	**2217**	-	3.4	3.2	1.86
Drip irrigation at 100% PE + 125% N, K through fertigation	2117	-	3.3	2.9	1.78
Drip irrigation at 75% PE + 75% N, K through fertigation	1993	15.9	4.1	3.3	1.67
Drip irrigation at 75% PE + 100% N, K through fertigation	**2222**	15.9	4.6	4.2	**1.87**
Drip irrigation at 75% PE + 125% N, K through fertigation	2123	15.9	4.4	3.8	1.78
Drip irrigation at 50% PE + 75% N, K through fertigation	2015	36.9	6.0	4.9	1.69
Drip irrigation at 50% PE + 100% N, K through fertigation	2200	36.9	**6.5**	**6.0**	1.85
Drip irrigation at 50% PE + 125% N, K through fertigation	2075	36.9	6.1	5.2	1.74
CD (p=0.05)	186	-	-	-	-

Muralikrishanasamy *et al.* (2013) studied that drip irrigation at 75% PE + 100% N, K through fertigation was a better treatment as it gave more returns and higher yield. Although water use efficiency was moderate.

Table 17: Effect of drip fertigation levels on growth, yield and WUE in hybrid sunflower

Treatments	Seed yield (kgha^{-1})	Total water use (mm)	WUE (kgha^{-1}mm^{-1})	Dry matter accumulation After 90 DAS
T_1N_1	2225.00	228.30	9.74	5875
T_2N_2	2468.00	228.30	10.81	**6240**
T_3N_3	**2843.00**	228.30	**12.45**	6750
T_4N_4	1787.00	228.30	7.82	5356
T_5N_5	1437.00	389.60	3.68	4250
CD(P=0.05)	-	-	-	949.6

Vijay and Yassin (2007) observed higher yield and WUE in the 125%RDF + DI treatment.

Table 18: Water use efficiency of the rice cultivars with different nitrogen treatments

Year	N rate (kg/ha)	WUE (kg/m^3)
2013	100	0.71c
	200	0.85a
	300	0.80b
2014	100	0.71c
	200	0.92a
	300	0.79b

Wang *et al.* (2016) observed higher WUE in medium nitrogen levels in comparison to low or high rate of N applied.

Table 19: Comparative efficacy of sprinkler and surface methods of irrigation in cumin

Treatments	Seed yield (qha^{-1})	Water saving (%)	WUE (kg seed/m^3 water used)	NMR (Rs/ha)
F4H3	2.71	53	0.212	7457
F5H3	4.11	**41**	0.260	16558
F6H3	3.76	35	0.204	13778
F4H4	3.09	37	0.245	9683
F5H4	**4.32**	21	**0.286**	**17463**
F6H4	4.12	13	0.228	15786
SM5	3.76		0.218	11858
CD (P=0.05)	0.55	-	-	2363

Jangir *et al* (2007) studied that higher WUE was observed in F5H4 treatment ie. **0.286 kg seed/m^3 water used** where water saving was 21% in comparison to surface irrigation method.

Table 20: Effects of surface and drip irrigation with fertigation on onion seed yield parameters, B:C ratio, water saved, water use efficiency and fertilizer use efficiency

Treatments	Onion see yield (t/ha)	B:C ratio	Water saved	WUE (kg/ha-mm)	FUE (NPK) (kg seed/kg nutrient yield)
100 % RDF CFA + SI	0.66	2.78	-	0.90	2.62
100 % RDF CFA + DI	0.76	2.84	39.88	1.75	3.05
100 % RDF + N through DI	0.81	3.01	39.88	1.86	3.24
125 % RDF + DI	1.03	3.27	39.88	**2.37**	3.31
100 % RDF +DI	1.00	3.30	39.88	2.30	4.01
75 % RDF + DI	0.91	3.14	39.88	2.09	4.87
50 % RDF + DI	0.80	2.85	39.88	1.83	**6.38**
SEm±	0.01		-	-	-
CD at 5 %	0.03		-	-	-

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Highest FUE was observed in 50 % RDF through drip irrigation and lowest FUE in surface application of fertilizers. Water saving of 40 % was reported due to fertigation over conventional fertilizers and surface irrigation. They also recorded WUE of 2.37 kg/ha-mm with 125% RDF applied through drip irrigation compared to 0.90 kg/ha-mm with 100% RDF through conventional fertilizer

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