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Cropping system approach for managing soil health: Field experiences

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Abstract
Rice is the major cereal crop of India in terms of area, production and consumer preference, To maximize the production from the available resources and prevailing climatic conditions, need-based, location specific technology needs to be generated. Delineation of agro-climatic zones based on soil, water, rainfall, temperature etc. was considered as the first essential step for sustainable production. The predominant cropping systems were identified, constraints addressed, production potential estimated and matching technologies as package of practices for identified efficient alternative cropping systems prepared for ready reference of planners and farmers of different states, agro-climatic zones.

Keywords: Cropping System, Approach, Mitigation, Soil Health

1. Introduction
The rice-wheat production system has played an important role in the food security and has remained its cornerstone for rural development and natural resource conservation. But, now evidences of second generation problems have started appearing such as declining productivity, plateauing of crop productivity, declining soil organic matter. it is imperative to develop strategies that can sustain higher levels of production without an adverse effect on the environment. Rice wheat cropping system is dominant on fertile and irrigated alluvial soils of north-west India, particularly in Punjab and Haryana. To meet the food requirement of growing population without affecting environment is a great challenge. Development of new rice variety/hybrid specific to ecosystem is one of the solution to cater this problem. Beside this it is also needed to develop variety specific suitable production technologies to explore the full yield potential of the variety/hybrid. Fertility management is one of the important factor in determining the productivity of the crops and the cropping system. Diversification of cropping system is necessary to get higher yield and return, to maintain soil health, preserve environment and meet daily requirement of human and animals.
The fertilizer nutrients through fertilizers should be applied to the crop in conjunction with best management practices (BMPs) for achieving optimum nutrient efficiency. The following are some simple agronomic techniques to improve the soil health in long run.

2. Using Best Fertilizer Source
In selecting the fertilizer care should be taken to select such a type of fertilizer which will have minimum interaction with soil so as to ensure minimum immobilization of nutrients contained in the fertilizers. Ammonium and potassium ions in fertilizer may be immobilized by strong adsorption by 2:1 type clay minerals. High soil pH enhances this type of fixation. Identification of best source of fertilizer is pre-requisite for better crop production. Source of fertilizer depends on crop and variety, climatic and soil condition, availability of fertilizer, etc.

- Nitrogen: Ammonical or Nitrate
- Phosphorus: Water soluble or Citrate soluble
- Potassium: Muriate of potash
- Sulphur: Sulphate or Elemental S
- Multinutrient fertilizers: MAP, DAP, SSP, Nitrophosphates
- Multi-nutrient mixtures: Combinations of NPK
- Fortified fertilizers: Neem-coated urea, Zincated urea, Boronated SSP, NPKS mix.
- Liquid formulations.

3. Using adequate rate & diagnostic techniques for fertilizer recommendation
The fertilizer recommendation must be in adequate quantity so as to meet the demand of crop at any point of growth.

The fertilizer supply should be made by diagnosing its requirement by any of the following method to sustain soil nutrient pool.

- State recommended generalized fertilizer dose or blanket recommendation
- Soil-test based fertilizer recommendations
- Soil-test crop response based recommendation
- Plant analysis for diagnosing nutrient deficiencies
- Chlorophyll meter and Leaf colour charts, etc.

4. Balanced fertilization

Balanced fertilization includes adequate supply of all essential nutrients, proper method of application, right time of application and nutrient interrelationships. A farmer participatory survey conducted in U.P. revealed that growers generally apply >200 kg N/ha and 45 to 60 kg P2O5/ha. However, use of K, secondary nutrients, and micronutrients is altogether missing. Farmers are experiencing declining responses to N and P due to omission of other essential nutrients in their fertilizer schedules. Adoption of balanced and judicious use of all needed nutrients can help improve crop productivity (Yadav et.al., 1993). 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) [2].

a) Adequate supply of all essential nutrients

Due to more concentration and application on primary nutrients (NPK), soils developed deficiency symptoms for secondary and micro-nutrients. Hence, ignored elements must be added with the NPK (may be in minor quantity) to get higher yields of crops. Experimental results shown that micro-nutrient application in soil or two foliar sprays increases the yield of crops up to 20%. Most crops are location and season specific - depending on cultivar, management practices, climate, etc., so it is critical that realistic yield goals are established and the nutrient are applied to meet the target yield. Over- or under-application will result in poor soil health, reduced nutrient use efficiency or losses in yield and crop quality.

b) Proper method

N and K can be applied as broadcasting and band placement. Water soluble P fertilizers are preferred to apply as band placement in neutral & alkaline soils. Citrate soluble P fertilizers are applied as broadcast method in acidic soils. Sulphate forms of S fertilizers are applied as broadcasting or band placement, whereas, elemental S and pyrite are applied as broadcasting method. Micronutrients are applied in minor quantity as foliar sprays and water soluble fertilizers are applied in fertigation.

c) Right time

Rate of application and timing are also important because balancing crop demand with nutrient supply improves nutrient uptake and increases crop response. 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 (Cassman *et al*., 2002) [1]. Tissue testing, chlorophyll meters and leaf color charts have been highly successful in guiding split N applications in rice and maize production in Asia. 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-butyl-thiophosphoric triamide]) inhibit nitrification or urease activity, thereby slowing the conversion of the fertilizer to nitrate (Havlin *et al*., 2005).

d) Right place

Application method has always been critical in ensuring that fertilizer nutrients are being used efficiently. Determining the right placement is as important as determining the right application rate. Numerous placements methods are available, but most generally involve are surface or sub-surface applications before or after planting. Prior to planting, nutrients can be broadcast (i.e. applied uniformly on the soil surface and may or may not be incorporated), applied as a band on the surface, or applied as a subsurface band, usually 5 to 20 cm deep. 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.

e) Nutrient interrelationships

Antagonistic nature of fertilizers is to be considered while applying into the soil. Some of the fertilizer application in excess quantities, results in loss of yield and quality of crops. Ex. Application of excessive phosphorus @120 kg P ha-1 created an imbalance and reduced the seed and oil yields in soybean compared to 80 kg P ha-1.

Table 1: Effect of balanced fertilization on yield and N agronomic efficiency in India (Prasad, 1996).

Crop	Yield, t ha^{-1}			Agronomic efficiency, kg grain kg N^{-1}		
	Control	N alone*	+PK	N alone	+PK	Increase
Rice (wet season)	2.74	3.28	3.82	13.5	27.0	13.5
Rice (summer)	3.03	3.45	6.27	10.5	81.0	69.5
Wheat	1.45	1.88	2.25	10.8	20.0	9.2
Pearl Millet	1.05	1.24	1.65	4.7	15.0	10.3
Maize	1.67	2.45	3.23	19.5	39.0	19.5
Sorghum	1.27	1.48	1.75	5.3	12.0	6.7
Sugarcane	47.2	59.0	81.4	78.7	227.7	150.0

* 40 kg N ha^{-1}applied on cereal crops and 150 kg N ha^{-1}applied on sugarcane

5. Integrated Nutrient Management

Organic manures, crop residues, green manures, bio-fertilizers etc. are to be blended in right manner along with inorganic fertilizers to meet the crop demand. All the possible and available organic sources are to be utilized efficiently to reduce the usage of inorganic fertilizers and improve soil health.

6. Utilization of Residual Nutrients

Some of the strategies to utilize the crop residues in efficient manner are.

- Knowledge on climatic conditions & carry-over effects of residues.
- Blending rightly on cereal-legume rotations
- Mixing shallow-deep rooted crop rotation

7. Reducing Losses of Applied Nutrients

a) Leaching losses

Nitrate fertilizers are easily lost in leaching. The extent of leaching is more in sandy soil than in clayey soils. The loss is more in bare soil than cropped soil. The losses can be reduced to an extent by suitable method and timing of application. Losses in leaching also occur when Ammonical, calcium cyanamide and urea fertilizers are applied to soils. In extreme acid soils or sandy acidic soils, ammonium fertilizers are lost because ammonium ions cannot easily replace the aluminium ions in exchange sites. In alkali soils ammonium ions are subjected to volatile loss. During summer losses from the Ammonical, calcium cyanamide and urea are more because they are rapidly oxidized by nitrifying organisms. It has been proved that when urea mixed with neem seed crush is applied to paddy soil, the efficiency of urea is more. The activity of nitrifying organism is reduced and thereby the leaching loss is minimized.

Table 2: Chemical compounds when applied with nitrogen fertilizers inhabit the nitrifying organisms and reduces the leaching loss.

Name	Rate of application
N- Serve (2 – chloro – 6 – trichloromethyl pyridine)	0.15 – 0.5 Kg/ha
AM (2 – Amino-4-chlore-6- methyl pyridine)	0.3 – 0.4% (of applied fertilizer)
Thiourea	1.5 – 2.5% (of applied fertilizer)

Applied potassic fertilizers are easily lost in drainage water in sandy soils and acid soils. However in clayey soils there is no appreciable loss. The loss can be minimized by adjusting the time of application to synchronize with maximum plant uptake period and also applying the fertilizer in 2 or more split doses. There are some slow release potassic fertilizers which are not subjected to leaching losses easily. E.g. potash frits, potassium meta phosphate and fused potassium phosphate.

b) Gaseous losses

The nitrogen compounds present in the fertilizer are lost as gases under certain soil condition. The following kinds of gaseous losses are noted.

1. Loss as ammonia under high pH conditions i.e. under alkaline conditions.
2. Loss as N_2, N_2O, NO due to denitrification.
3. Loss as N_2, N_2O, or NO under nitrification of ammonium fertilizers.

The above losses are determined by soil pH, fresh organic matter, moisture, temperature and type of micro- organisms present in soil. Losses in the form of ammonia under high pH conditions can be controlled by proper placement of urea. As far as possible ammonium fertilizer should be avoided. If there is no alternative to ammonium fertilizers, the fertilizer should be placed at least 4-6 inches below the surface. Wherever loss of N by denitrification processes is observed, urea should be used instead of ammonium and nitrate fertilizer.

c) Immobilization of fertilizer nutrients

Nutrient elements may be immobilized or fixed or converted into unavailable forms by one or more of the following three means.

1. Chemical immobilization
2. Physicochemical immobilization
3. Microbiological immobilization

While selecting the fertilizer care should be taken to select those fertilizers which will have minimum interaction with soil and the time and mode of application should be such as to ensure minimum immobilization of nutrients contained in the fertilizers. Ammonium and potassium ions in fertilizer may be immobilized by strong adsorption by 2:1 type clay minerals. High soil pH enhances this type of fixation. In acid soils, the efficiency of water soluble phosphorus is very low. The water soluble phosphorus is immediately converted into insoluble phosphorus compounds. In such soils insoluble phosphatic fertilizer like rock phosphates should be utilized. Further a thorough mixing of the phosphorus with soil increases the efficiency of the fertilizers. In calcareous soils applied phosphatic fertilizers invariably converted into tricalcium phosphate – a compound from which phosphorus is not easily available. Under such conditions water soluble phosphorus are relatively more efficient than water insoluble P like rock phosphate. Microbiological fixation of fertilizer N may be a serious problem when un-decomposed organic materials of high C/N ratio are present in the soil. This type of immobilization is of short duration only. It can be overcome by application of larger quantities of water soluble N fertilizers or by allowing enough time for complete decomposition of unrecompensed organic matter.

d) Interaction between different fertilizers

It is a common practice to mix fertilizers containing different nutrient carriers, just prior to application. The efficiency of the following fertilizers will be lowered if mixed with the fertilizer or amendment noted against them. Ammonium sulphate - Basic slag Ammonium sulphate - Calcium carbonate, Super phosphate - Basic slag Ammonium phosphate - Basic slag, Ammonium phosphate - Calcium carbonate Super phosphate - Calcium carbonate, Urea can be mixed with all fertilizers.

e) Compaction and fertilizers efficiency

Soil compaction brings about the soil particles closer resulting in the decreased bulk density or apparent density. The combined effect of the changes in different physical properties of soils due to compaction is the poor response for nitrogen and phosphorus fertilizers. Under mechanized farming, soil compaction is most common observation.

f) Soil temperature – Fertilizer response

Soil temperature is one of the important environmental factors affecting plant growth and fertilizers response of crops. To an extent the soil temperature is manageable by common management practices like tillage, mulching and irrigation. Soil temperature affects the fertilizers efficiency by changing solubility of fertilizers, concentration of solubilized fertilizer cation exchange and also the ability of the plants to absorb and use nutrients. Variation in temperature causes differential response to crop uptake, of $NH4^{+}$ and $NO3^{-}$ - N fertilizers. Below 13°c the uptake of N from NH4 or NO3 fertilizers is almost nil. Maximum uptake of N by plants from NO 3 and NH4 fertilizers is observed in the range of 19° - 24°c. The efficiency of phosphatic fertilizers increases significantly with the increase in soil temperature from 10-35°C.

g) Soil moisture

One of the most important aspects in agriculture is the lack and sufficient moisture in the soil. Efficient water management is complementary to efficient fertilizer management. Maximum efficiency of fertilizers can be obtained only in the presence of adequate soil moisture and vice versa. Excessive moisture leads to leaching loss of added fertilizers whereas lack of moisture results in poor availability of the added fertilizer and high osmotic pressure of soil solution due to concentration of fertilizers soils.

h) Plant characteristics

Different crops remove varied amount of plant nutrients from soils. There is also appreciable variation within varieties of same plants, between dicots and monocots etc. Since the roots are the principal organs through which plants take up nutrients, the rooting pattern and habit have an important bearing on the nutrient removal. Plants which develop a vigorous deep-root system during their early stages of growth require a large quantity of fertilizer as Basal dressing. The fertilizer needs of deep rooted crops are generally lower than shallow rooted crops.

i) Fertilizer characteristics

The mobility of the fertilizer nutrients in the fertilizer, the type of fertilizer and the time and mode of application decide the efficiency of a fertilizer. The nitrogenous fertilizers are highly mobile and subjected both downward and sideward mobility. Phosphorus is highly immobile. Potassium is also mobile but compared to nitrogen its mobility is lower. To get maximum efficiency N and K fertilizer should be applied in frequent split doses and phosphorus as basal dressing or near the root zone.

8. Use of Liquid Formulations

In order to, utilize the land to its optimum potential and maximize crop production and conserving soil. Liquid Fertilizers has the answer. These products can improve crops' nutrient use efficiency and reduce the amount of applied fertilizer needed. As a result, it is possible to get top crop performance while still employing sustainable agricultural practices. Here are four sustainable farming practices that can help you increase nutrient use efficiency and boost crop yields by using liquid formulations.

a) Improve nutrient utilization

Rising fertilizer prices, environmental concerns and stagnant crop prices have forced the growers to look for ways to increase the nutrient use efficiency of their crops. For example, eNhance™ is a nitrogen additive that works within the plant, nutritionally fortifying it so that it can use nitrogen more effectively. This formulation helps reduce the needed rate of urea ammonium nitrate (UAN) solutions, often with a yield response comparable to full rate UAN applications. LiberateCa™ aids with nutrient mobilization throughout the plant and improves nutrient availability in conservation tillage environments. It also helps with availability of nutrients in the root zone.

b) Maximize crop response to nutrient applications

Liquid formulations have high levels of absorption and effectiveness within the plant, which maximizes crop response to them. For example NResponse™, a premium nitrogen product that quickly assimilates into the crop for fast-acting results. Rate of application and timing are also important because balancing crop demand with nutrient supply improves nutrient uptake and increases crop response.

c) Utilize fertilizers with a low salt index

Fertilizers with a high salt index can damage plant tissues, making nutrient absorption more difficult. Liquid Fertilizers' products have low salt indexes, which makes it safer to use them for foliar applications and apply them near the active root zone.

d) Reduce amount of applied fertilizer

Volume is rarely the determining factor when it comes to eliciting a positive plant response; rather what matters is the type of product used and the plant's ability to utilize it. Over application of nutrients is wasteful and unnecessary when smaller amounts of product can produce the same or better results. Balanced formulations that include micronutrients make liquid products highly usable and efficient. There is less risk to the environment when more of the applied nutrients end up in food and fiber and not in our streams and lakes.

9. Inter Cultivation

Cultivation practices taken up after sowing of crop is called inter-cultivation. It is otherwise called as after operation. There are three important after cultivation processes viz., Thinning and gap filling, weeding and hoeing and earthing up.

i) Thinning and Gap filling

The objective of thinning and gap filling process is to maintain optimum plant population. Thinning is the removal of excess plants leaving healthy seedlings. Gap filling is done to fill the gaps by sowing of seeds or transplanting of seedlings in gap where early sown seed had not germinated. It is a simultaneous process. Normally, these are practiced a week after sowing to a maximum of 15 days. In dryland agriculture, gap filling is done first. Seeds are dibbled after 7 days of sowing. Thinning is done after gap filling; in order to avoid drought. It is a management strategy to remove a portion of plant population to mitigate stress is referred to as mid season correction.

ii) Weeding and Hoeing

Weeding is removal of unwanted plants. Weeding and hoeing is a simultaneous operation. Hoeing is disturbing the top soil by small hand tools and helps in aerating the soil. This reduces the competition and more uptake of nutrients by the crop and hence improves nutrient use efficiency.

iii) Earthing up

It is a dislocation of soil from one side of a ridge and to be placed nearer the cropped side. It is carried out in wide spaced and deep rooted crops. It is done around 6-8 weeks after sowing / planting in sugarcane, tapioca, banana, etc.

iv) Other inter cultivation practices

Topping

Removal of terminal buds. It is done to stimulate auxiliary growth. Practiced in cotton and tobacco crops to encourage auxiliary growth and prevent apical dominance.

Propping

Provision of support to the crop is called propping. Practiced in sugarcane commonly. It is done to prevent lodging of the crop. Cane stalks from adjacent rows are brought together and tied with their own trash and old leaves.

De-trashing: Removing of older leaves from the sugarcane crop.

De-suckering: Removal of auxiliary buds and branches which are considered non essential for crop production and which removes plant nutrients considerably are called suckers. Ex. Tobacco.

Intercropping for better soil health: Intercropping is essential for minimizing risk in rainfed agriculture and to improve economic returns. At the same time if proper combinations of crop are selected following the basic principles for intercropping soil health can be maintained or improved in long run. Some of the intercropping systems are.

Sugarcane + Potato	Maize + Groundnut	Bajra +Cowpea	Castor +Cowpea
Sugarcane+ Rajmash	Maize +Soybean	Bajra + Pigeonpea	Castor +Soybean
Sugarcane+ Mustard	Maize + Pigeonpea	Bajra +Soybean	Castor +Clusterbean
Sugarcane + Wheat	Maize +Cowpea		

Diversified use of legume in cropping system: Potentiality tested in various cropping system through, Intercropping, cover crop, relay crop, alley crops, Border crops, Cash crops, green manure, crop rotation, hedge rows by farming (inter use of nutrient cycling nitrogen fixation, disease & pest break). Carryover nitrogen addition of legumes for succeeding crops.

Crop	Scientific name	Nitrogen (kgha^{-1})
Berseem	Trifolium alexandrinum L.	60-120
Indian clover	Melilotus parviflora	75
Cluster bean	Cyamopsis tetragonoloba L.	75
Fodder cowpea	Vigna unguiculata L.	35-60
Chickpea	Cicer aeritinum L.	68
Blackgram	Vigna mungo L.	55
Greengram	Vigna radiata L.	55
Groundnut	Arachis hypogeae L.	54-58
Soybean	Glycine max L.	50-51
Lathyrus	Lathyrus aphaca L.	50
Pigeon pea	Cajanus cajan L.	36-42

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