Sugarcane nutrition for food and environmental security

Nutrição da cana-de-açúcar para segurança alimentar e ambiental

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ABSTRACT

Sugarcane is an important cash crop cultivated globally from temperate to tropical regions. Improving cane yield and recovery sustainably is an important research area for improving livelihoods of the cane farmers. Among different approaches sill judicious and integrated use of nutrients as per plant needs holds the special place. Further, applying need based N management through optical gadgets viz. Leaf color chart (LCC), SPAD, Green seeker, integrated nutrient management, fertigation, special focus on for improving the efficiency of different fertilizers through different state of art technologies. For having higher fertilizer use efficiency in sugarcane, some aspects of fertilization especially *How much? What type of? When to add? Is it worth? Number of splits? Mode of action?* must be considered both for seed or ratoon. Further, soil textural class and climatic conditions on one side while on changing climatic conditions also affected it a lot. Further, inherent fertility status of the soils is also an important factor which affects the fate of applied fertilizers. There is a need to create awareness in between the farmers for not to applying huge quantity of different fertilizers as per their neighboring farmers, rather farmer should be smart enough to adopt different technologies in a smart way for having better benefits and thus livelihoods as the purpose is to fed the canes but not the soil. In the present review an attempt being made to compare the comparative performance of sugarcane with respect to fertilization for finally guiding the sugarcane cultivars. Idea is to enlighten them regarding need based sustainable fertilization with an aim to improve the fertilizer use efficiencies for having improved yield and quality parameters instead of loading the soil with much of fertilizers which further have environmental concerns.

Keywords: Sugarcane, Fertilization, Quality, Input use efficiency, Yields.

RESUMO
A cana-de-açúcar é uma importante cultura comercial cultivada globalmente das regiões temperadas às tropicais. Melhorar o rendimento e a recuperação da cana de forma sustentável é uma importante área de pesquisa para melhorar a subsistência dos agricultores de cana. Entre as diferentes abordagens, o uso criterioso e integrado de nutrientes conforme as necessidades da planta ocupa um lugar especial. Além disso, a aplicação de gerenciamento N baseado nas necessidades através de aparelhos óticos, tais como: carta de cores das folhas (LCC), SPAD, Green seekker, gerenciamento integrado de nutrientes, fertirrigação, foco especial para melhorar a eficiência de diferentes fertilizantes através de diferentes tecnologias de última geração. Por ter maior eficiência no uso de fertilizantes na cana-de-açúcar, alguns aspectos da fertilização, especialmente Quanto? Que tipo de fertilização? Quando adicionar? Vale a pena? Número de rachaduras? Modo de ação? deve ser considerado tanto para a semente quanto para a soqueira. Além disso, a classe textural do solo e as condições climáticas de um lado, ao mesmo tempo em que as condições climáticas mudam, também a afetam muito. Além disso, o estado de fertilidade inerente dos solos também é um fator importante que afeta o destino dos fertilizantes aplicados. Há uma necessidade de conscientização entre os agricultores para não aplicar uma quantidade enorme de diferentes fertilizantes como por seus agricultores vizinhos, ao invés disso, o agricultor deve ser inteligente o suficiente para adotar diferentes tecnologias de forma inteligente para ter melhores benefícios e, portanto, meios de subsistência, pois o objetivo é alimentar as bengalas, mas não o solo. Na presente revisão está sendo feita uma tentativa de comparar o desempenho comparativo da cana-de-açúcar em relação à fertilização para finalmente orientar os cultivadores de cana de açúcar. A idéia é esclarecê-las sobre a fertilização sustentável baseada nas necessidades com o objetivo de melhorar o uso de fertilizantes.
eficiência por ter melhor rendimento e parâmetros de qualidade, em vez de carregar o solo com muitos fertilizantes que ainda têm preocupações ambientais.

Palavras-chave: Cana de açúcar, Fertilização, Qualidade, Eficiência no uso de insumos, Rendimentos.

1 INTRODUCTION

Sugarcane is an important cash crop has the capability of accumulating the sugar in stalks, generally known for Gur, Khandsar and mostly as sugar which used as a sweetner. The typical sweet '*noble canes'* evolved from wild in New Guinea (Papua). *Saccharum spontaneum S. robustum* and *S. edule* is other three close relative having low Brix and higher fibre content. *S. sinense* and *S. barberi*, cultivated widely in India and China evolved from *S. spontaneum* and *S. officinarum* (Bull 2000) (Fig. 1). Through traders around 647 and 755 A.D., sugarcane being entered in other countries *viz.* Spain, Egypt (Malavolta 1994). However, by around 327 B.C, sugarcane considered as a vital crop in the Indian sub-continent. Throughout the world, the advanced cane cultivars are more yielding with higher resistance to insect-pests and having higher brix than earlier old cultivars. Integrated and need based fertilization depending on the soil inherent fertility decides the profits of the cane farming depending upon the textural class of soils, organic matter status being put under cultivation (Bhatt 2020; Bhatt and Sharma 2010). Even till date, fertilization aspect more commonly ignored by most of the cane farmers and even cane mills which further resulted in the lower cane yields as well as in the lower sugar recovery. On other side, the ultimate grower viz. farmer used to apply the fertilizers on the higher sides due to their inherent behavior of feeding more and more to have higher returns. Now a days, most of the countries developed and adopt integrated and need based cane fertilization programs for better profits along with better soil health (Bhatt 2020; Bhatt et al. 2020)

As per barber, 1931, moist parts of northeastern Indian might be responsible for thinner Indian canes evolution as some of these close *S. spontaneum* (Barber 1931). Unlike, wheat and rice, sugarcane, being C_4 plant, where mesophyll cells converts carbon dioxide (CO_2) to malate. However, end product in sugarcane is sucrose than starch. Later this sucrose through leaves transported to the stalk for having sweetness here (Hartt et al. 1963). Fertilization could be defined as canes nutrient requirement minus soil inherent fertility multiplied by fertilizer use efficiency (F), i.e., part of used fertilizers being absorbed by plants through soil solution for its dry biomass

$$\text{Fertilization} = (P - S) \times F$$

Here fertilizer use efficiency (F) is the proportion of applied fertilizers which is being used up by the plants root, hence higher the ‘F’ lesser will be the fertilizer requirements. Hence for determining the fertilizer requirement of any cane plot, knowledge regarding plant needs (P) (which depends on the plant cultivar, its maturing group weather early or mid-late etc), soil inherent fertility (S) (which further depends on the soil textural class, soil structure, soil organic matter etc) and finally fertilizer use efficiency (fraction of applied fertrilizer which used up in cane biomass) is a must. Variations in any of these factors *viz.* S, P and F affected the fertilization requirement of any cane field to a significant extent. Out of all, determination of S is quite important which could be easily delineated through testing of the soil samples of the concerned sugarcane field (Bhatt 2020) or either through analysis of the sugarcane leaves, juice.

Calculation of “F” based on the competition between canes and the soil plant water system for the applied fertilizers as many a times the applied fertilizers got lost through runoff, erosion, fixation, volatilization etc. Under the conventional system of sugarcane farming the factor F varied as per following Table 1.

Table 1 Macronutrient use efficiency “F” under conventional planting system.

Nutrients	Usage (%)	Factor (F)
N	50.1—60.1	2.01
P_2O_5	20.1—30.1	3.01—5.01
K_2O	70.1	1.51

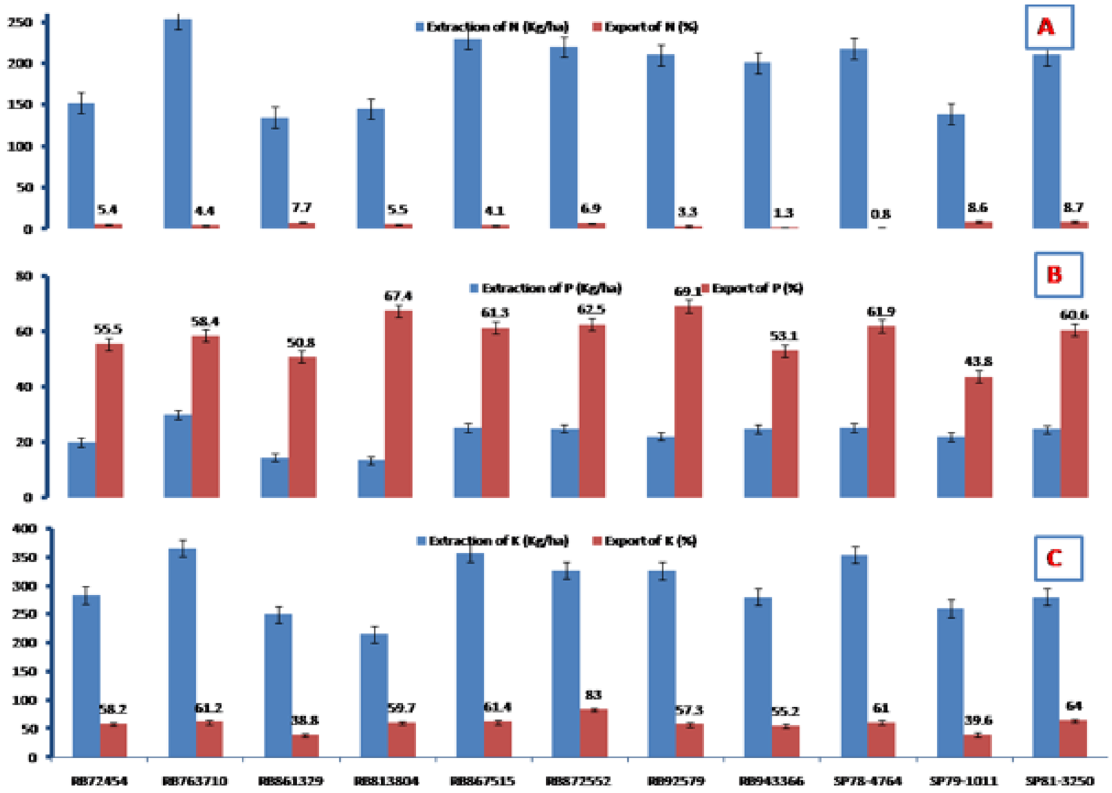
For sustainably, fertilizing the sugarcane fields for having improved growth, yield and quality parameters, normally farmers thinks regarding four important questions but at the same time he also wants to reduce the cost of cultivation. Different questions which are there in cane farmers are which fertilizer is to applied? Upto what level should it be applied? At which time, it should be applied? Which application method should be used for applying it? Answering all of them all to the farmers is not an easy assignment. First thing is regarding how much of the both macro and micronutrients are being extarcted and exported by canes for filling up their metabolic activities. In this attempt, Orlando Filho (1993) anticipated the amounts of total nutrients being extracted and exported for a stalk yield of about 100 t.

Table 2: Plant nutrients being extracted and exported for 100 t stalk yield

Plant Parts	Macronutrients (kg $100t^{-1}$)					
	N	P	K	Ca	Mg	S
Stalks	82.9	11	78	47	33	26
Foliage	60.1	8	96	40	16	18
Overall	***143***	***19***	***174***	***87***	***49***	***44***
Plant Parts	**Micronutrients (g $100t^{-1}$)**					
	B	Cu	Fe	Mn	Zn	
Stalks	149	234	1.39	1.05	369	
Foliage	86	105	5.53	1.42	223	
Overall	***235***	***339***	***6.92***	***2.47***	***592***	

Table 2 also reveals the higher S demands as compared to the P in sugarcane. Further, Oliveira (2008) working on macronutrient extraction and export pertaining to N, P and K in eleven sugarcane cultivars (Fig. 1) shows the importance of timely and proper sugarcane fertilization. Sugarcane fertilization assumed to be higher in ratoon as compared to the plant crop due to already developed roots. Therefore, farmers could go for low N and a higher P and K fertilization in plant while lower P and a higher N and K in the ratoon system.

Fig. 1 N, P and K extraction (kg ha^{-1}) and export (%) under eleven sugarcane cultivars (Source Oliveira 2008)



- **Delineation of The Soil Fertility(S)**

This is very important as far as soil inherent nutrient supply concerned for fertilizing the canes which must be evaluated before finalizing the sugarcane fertilization schedule. Following methods mostly uesd by the researchers for this purpose.

- **Analysis of soil**

Estimating the soil inherent fertility might be one of the most important factors which must be considered in sugarcane fertilization programmes through the globe (Bhatt 2020). Punjab Agricultural University, Ludhiana, Punjab India since its establishment advocating the importance of Soil test based fertilization for sustainable sugarcane fertilization and district wise soil labs also established in the different Krishi Vigyan Kendras and also by state department. However, proper benefit of these labs not revealed and that might be due to the wrong samples collected by the farmers or non-technical persons. Further sometimes due to the huge target of collecting the soil samples, correct procedure might not be adopted. Further, a number of precautions are also there which might be kept in mind while collecting the soil samples (Bhatt and Sharma 2014).

Further, after collecting the correct samples with all the precautions, interpretation of the soil test reports is equally important as then fertilizers pertaining to different nutrients must be added as per these report. If any farmer, is not able to analyze these reports then also it is very difficult for him/her to go for sustainable fertilization. In Punjab, India farmers advocated to go for recommended dose of N-fertilizers of SOC is in between 0.4 to 0.75 however in upper and lower case, university recommended 25% lower and higher dose, respectively. Similarly for P, soils with a range from 5.0 to 9.0 applied with recommended dose of P while in upper and lower range, same recommendation is there as in case of N. However, still K dose is to be recommended for the farmers of the state which having low K soils. Preliminary experiments carried out in this regard under irrigated and unirrigated conditions revealed 80 kg K_2O ha^{-1} to be the sustainable dose for having better yields and quality as well (Bhatt et al. 2020). Several workers viz. Sousa and Lobato 1988 showed the following interpratations pertaining to the different macro and micro-nutrients in soils which indicates their abundance or deficiency in the soil (Table 3 and 4) and based on these soil fertilization schedule finalized.

Table 3: Interpretation of different soil nutrients (Source: Raij et al. 1996)

Level	Relative Yield (%)	Exchangeable K[1] ($mmol_c/dm^3$)	P Resin (mg/dm^3)
Very Low	0-70.1	0-0.7	0-6.1
Low	71.1-90.1	0.8-1.5	7.1-15.1
Average	91.1-100	1.6-3.0	16.1-40
High	>100	3.1-6.0	>40
Very high	>100	>6.0	—

Micronutrients (mg/dm^3)

	B	Cu	Fe	Mn	Zn
Micronutrient	Hot Water	DTPA			
Low	0-0.2	0-0.2	0-4	0-1.2	0-0.5
Average	0.21-0.6	0.3-0.8	5-12	1.3-5.0	0.6-1.2 (1.6)^x
High	>0.6	>0.8	>12	>5.0	>1.2 (1.6)^x

Level	Exchangeable Mg^{2+} ($mmol_c/dm^3$)	S^{xx} (mg/dm^3)
Low	0—4	<10
Average	5—8	10—15
High	>0.8	>15

Table 4 Interpretation of inherent soil P as per Mehlich 1 method (Source: Sousa and Lobato 1988).

Clay %	Very Low	Low	Average	Good
61—80	<1	1.1—2.1	2.1—3.1	>0.3
41—60	<3	3.1—6	6.1—8	>0.8
21—40	<5	5.1—10	10.1—14	>0.14
<20	<6	6.1—12	12.1—18	>0.18

- **Analysis of leaf**

Leaf diagnosis is the second important technique to delineate the soil inherent fertility where representative leaves are analysed during pre-defined periods in the plant's life. Leaves normally considered as a mirror of the cane plant and hence it clearly shows the effect of timely available nutrients either supplied by soil or fertilizers. Punjab Agricultural University, Ludhiana, India already providing this service to the farmers of the state at a nominal charges. Further, while sampling the leaves for analysis, care must be taken to sample the representative leaves from the cane plants. Further, leave sampling could be done upto 6 months from germination in plant canes while 4 months after plant cane harvesting. Raij et al. (1996) in sugarcane adequate nutrient proportions ranges to a considerable extent in the macronutrients as shown in the following table

Table 5 Adequate macro (g kg^{-1}) and micro (mg kg^{-1}) nutrient ranges in the sugarcane plants (Source: Raij et al. 1996)

N	P	K	Ca	Mg	S
18-25	1.5-3.0	10-16	2.0-8.0	1.0-3.0	1.5-3.0
B	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
10-30	6-15	40-250	25-250	0.05-0.2	10—50

- **Visual analysis**

Generally this approach helps in identifying the nutrient deficiency symptoms in the cane plants and beneficial for fertilizer management for the next crop to be taken on the same piece of land. The time upto which these symptoms appeared in different plant parts, the setback to the yield and quality parameters had already occurred. Even then, it is an important technique which helps the farmers to identifying the nutrient deficiency symptoms and they may correct some of them through bio-fortification approaches.

- **Sugarcane in India and Brazil**

Both India and Brazil, dominating in the sugarcane research and scientists are working for improving the canes growth, yield and quality parameters (Bhatt 2020). In India, sugarcane cultivated on an area of 47.3 lakh hectare with yearly production of 3769 lakh ton, employs too many laborers in cane cultivation and its industry (FAO 2020). In Brazil, in the 2019/2020 harvest, the area cultivated with sugar cane was 8.5 million hectares, with production of 642.7 million tons of cane. In addition to the production of sugar, gur and alcohol, sugarcanes has a huge scope as a fodder for dairy animals

It is also established that 28.35 grams of sugarcane juice contained many nutrients viz. around 0.36 mg of iron, 41.97 mg of potassium, and 17.02 mg of sodium, 27.52 g of carbohydrates, 0.28 g of protein, 11.24 milligrams of calcium and around 111.14 kilo Jules of energy. For proper sugarcane development and growth, 17 elements identified which also required. Some nutrients viz. micronutrients, though required in small quantities, but played a significant role in the cane nutrition and thus development. Hence, all the nutrients does played a key role in the sugarcane nutrition and hence must be supplied as per the canes requirement and soil nutrient supplying patterns (Kingston 1999; Berthelsen et al. 2001). Sugarcane nutrient requirement varied as per texturally divergent soils, climatic conditions and indigenous farmers practices (Table 6) which further showed their availability in different countries.

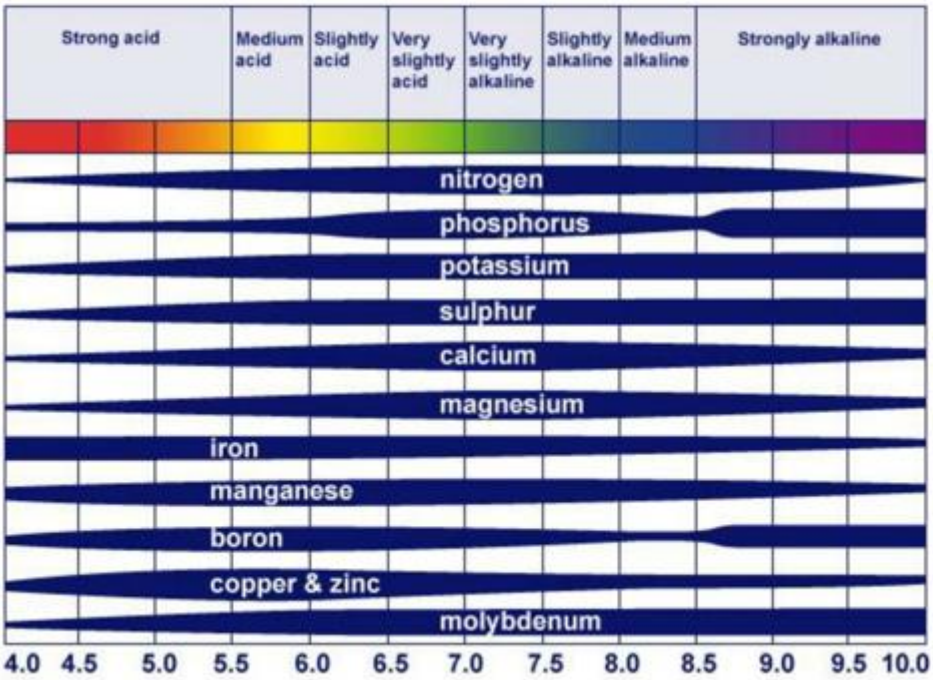
Table 6 Comparative nutrients removal rates by sugarcane in different countries (Adapted from Kingston 2000)

Country	Macro-nutrients (kg t^{-1})						**Source**
	N	**P**	**K**	**Mg**	**Ca**	**S**	
Hawati	1.14	0.28	2.23	0.34	0.44	-	Humbert (1968)
India	1.21	0.21	1. 18	-	-	-	-------
South-Africa	1.34	0. 17	3.27	0.38	0.41	-	Thompson (1988)
Brazil	1.51	0.40	1.80	0.50	0.90	0.40	Oliveira et al. (2018)
Australia	1.31	0. 17	2.22	0.23	0.28	0.35	Kingston (2000)
	Micro-nutrients (g t^{-1})						
	Fe	Mn	Zn	Cu	B	Mo	
Brazil	8.0	3.0	0.6	0.4	0.3	0.02	Oliveira et al. (2018)
Australia	78.1	42.1	4.96	0.74	-	-	Kingston (2000)
South-Africa	-	10.9	2.51	0.51	1.19	-	Thompson (1988)

Among different factors, the SOM is termed as "LORD of RINGS", which decides the soil health, soil physico-chemical properties, reduces erosion, and build-up the soil microbial population (Parsons 1962; Pribyl 2010). Further, soil pH is (Hetherington et al.

1986; PAU 2020) also an important factor affecting the nutrient supplying capacity of the soils to the sugarcane/plant roots.

Fig. 4 Soil pH fluctuation *viz-a-viz* availability of nutrient (Source: Truog 1948)



As per Mayer (2013), in between the divergent nutrient movement pathways in soil "mass flow" and "diffusion" are the most important. To use the fertilizers sustainably, inherent soil fertility and canes plant need both are very important factors which further affected by many factors viz. soil textural and structural class, rainfall etc. (Bhatt and Singh 2020 a, b). Soil test reports from soil labs clear picture pertaining to different physic-chemical properties and macro and micro-nutrients present in the soils.

2 NUTRIENTS FOR SUGARCANE

2.1 NITROGEN

Nitrogen nutrient being a crucial one played an important role in plant metabolism and finally in the yields and quality parameters. But excessive doses led to the higher attack and insect-pests and diseases as the plants becomes more succulent (Bhatt et al. 2020; Bhatt 2020) Further higher doses of N-fertilization reduces the fiber contents. Mineralization of SOM led to fulfill the plant requirements of N (covered a wide range from <70 to >140 kg N ha^{-1}) (Meyer et al. 1986). Fortunately, PAU N recommendations pertaining to the sugarcane matched the N mineralization potential of soils more particularly for the intermediate fertile soils. Thereby, dropping the jeopardy of over-applying N which might consequence in lodging which further reduces the overall juice quality. Nitrogen showed a high correlation between the number of stems and yield of sugarcane (Vale et al. 2012). Aim is to fulfill the gap in between the Plant N requirements and N-supplying inherent capacity through fertilization. However, over and under fertilization led to lower productivities and quality (Srivastava and Suarez 1992; de Geus 1973; Vuyyuru et al. 2019). Worldwide, different N-doses recommended as per their site and location specific conditions (Table 7). As a thumb rule, around 25% higher doses of N-fertilizers required for ratoon crop viz. 1 kg N t^{-1} cane required for the plant while 1.25–1.50 kg N t^{-1} cane required for ratoon crops (Meyer 2013).

Table 7 For sugar industries general N fertilizer

Country	**Inherent Organic matter**	**N mineralizing capacity**	**N-application (kg ha^{-1})**		**Remarks**
			Plant	**Ratoon**	
Hawai	General	---	224	224	As splits in drip irrigation
India	General	---	50–100	150–200	Rate lower for smaller farmers
South Africa (Meyer et al. 1986)	< 2 2–4(Red soils) 2–4(Non red soils) > 4	Low Moderate High Very high	120–140 100–120 80 60	160–200 140–160 120 100	The rate depends on moisture conditions
Florida (Anderson 1990)	Sandy OM < 35 % OM 35–85 % OM > 85 %	Low Moderate Very high Very high	200 120 34 0	200 120 34 0	Rate depends on soil textural class
Australia	< 0.7 0.7–1.4 1.4–2.1 2.1–2.8 2.8–3.5 3.5–4.2 > 4.2	Very Low Low Moderately low Moderate high High Very high	140 130 120 110 100 90 80	160 150 140 130 120 1100	Reduce rate of N fertilization under legume intercropping

In India Punjab, for plant/seed and ratoon crop, different N doses *viz.* 150 kg N ha^{-1} and 225 kg N ha^{-1}, recommended for soils with SOC between 0.4 to 0.75% while for the lower fertility soils, this dose recommended to the tune of 25%. Moreover, integration with farmyard manures @20 t ha^{-1} is also recommended for reducing N dose from 150 kg ha^{-1} to 100 kg ha^{-1} (PAU 2020).

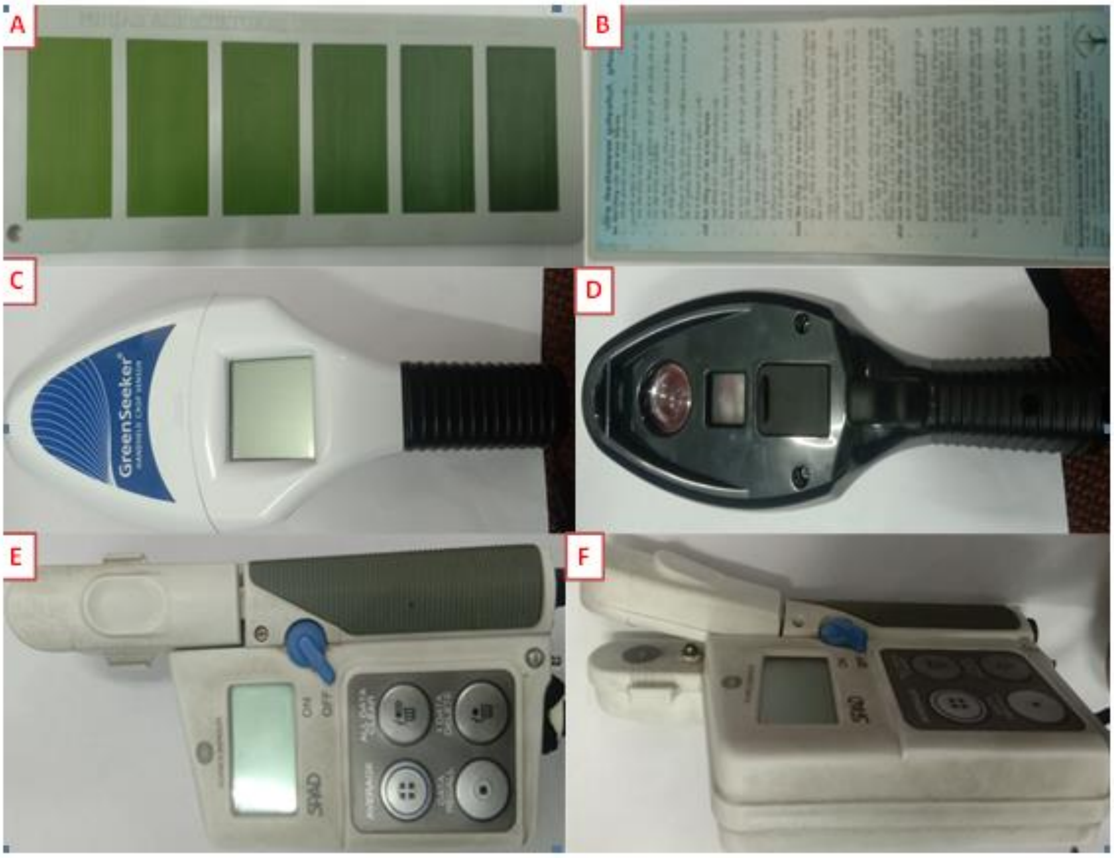
- **Gadgets for need based nutrient management**

Since careful soil sampling and its analysis is quite time consuming and required lots of skills, hence need for the optical gadgets regarded as its alternate solution as leaves explains the health condition of the plants (Wright et al. 2004). Leaves are the sites for the net primary productivity, gas exchange, and evapotranspiration (Carter 1994; Zhao et al. 2016). Different gadgets *viz.* leaf color chart, SPAD, green seeker (Fig. 6) are available and being used for research experiments pertaining to site specific nutrient management in to improve the use efficiency and to reduce the overall cost of cultivation along with mitigating the adverse effects of the climate change .

- **Leaf colour chart**

Under this approach, the plant's leaves itself diagnosed from its color to judge the plant need as leaf greenness represent its hunger for nutrients. Further, it is a non-destructive method in which leaf colour is just compared with the different shades on the leaf colour chart (LCC) (Fig.6A) while its other side contained the necessary instructions (Fig. 6B) . These gadgets really prove to be a decision-making tool for the cane farmers for judicious use of the nitrogen as lower doses result in lower cane yields with poor quality while higher doses result in the emission of GHGs or may also pollute the underground water. LCC made up from high-quality plastic strips with greenness from lighter to darker side and works as per chlorophyll meter in the field (Varinderpal-Singh et al. 2010) being tested first in Japan (Furuya 1987) and afterwards in IRRI to six-panel LCC (IRRI 2009). With further modifications, 6 panels changed to four panels in 2007 (Fairhurst et al. 2007). With time, it changed to eight- panel (3, 4, 5, 5.5, 6, 6.5, 7 and 8) (ZAU-LCC) in 2013 and then to eight- panel (1–8) (UCD-LCC) was developed (Boyd 2001) for estimating percent leaf nitrogen even in texturally divergent soils. In Punjab, LCC already recommended for many field crops like rice, wheat etc. and research trials pertaining to sugarcane still under progress at Regional research Station, Kapurthala, Punjab, India.

Fig. 6 Different gadgets advocated in the region for the site-specific nutrient management viz. Leaf colour chart A) Front and B) Rear side with guidelines in the local language; Green seeker C) Front and D) Rear side; Chlorophyll or SPAD meter E) Front side F) side view showing chamber where the leaf is to inserted (Source: Bhatt 2020 personal communication).



- **Green Seeker**

Further, green seeker also evaluates the leaf greenness in a digital mode and hereby helps us to judge the role of different RCTs in improving the land as well as water productivity (Fig.6 C and D). As per its working is concerned, the nitrogen sensors of green seeker uses sunlight as a source of passive light which calculates the spectral reflection of the cane canopy by estimating the difference between the total incident light from sun and the light which reflected back by the cane canopy. Further, transfer function between the spectral reflection parameters and the N quantity of the can canopy used by the sensors of the green seeker to calculate the N-supply to the cane plants and hence further helps in applying the N-fertilizers to the canes as per their requirement or N-supply by the soil.

- **Soil Plant Analysis Development (SPAD) chlorophyll meter**

For sustainable nitrogen management in the region in a climate-smart way, the SPAD is one of the most commonly used diagnostic tools to measure crop nitrogen status

(Fig.6 CandD). Quite often, N-demand of the plant is estimated based on soil and leaf analysis which are expensive and time consuming methods. Hence, a gadget is required which provides us spontaneous estimate regarding leaf greenness under different treatments and proved to be both time and cost cutting for reducing the overall cost of cultivation (Akhter et al. 2015). Mostly used popular SPAD meter which is a quick, non-destructive and portable is Minolta SPAD-502 which developed by Minolta Limited, Osaka, Japan (Minolta 1989) which quickly provides leaf greenness as chlorophyll content (Feibo et al. 1997; Boggs et al. 2003). Fieldscout CM 1000 is an advanced SPADbeing developed by Spectrum Technologies, Inc. (2009) and it is based on the principle of running average of multiple readings, and along with recording for each sample is recorded in a data logger (Varinderpal-Singh et al. 2012). The SPAD meter measures the difference between the transmittance of a red (650 nm) and an infrared (940 nm) light through the leaf and provide us SPAD reading (Uddling et al. 2007). by Many factors, such as cultivar, year, growth stage, leaf thickness, leaf position, and the measurement point on the leaf, further affected the performnace of the SPAD reading (Hu et al. 2014). All the optical gadgets viz. LCC, green seeker and chlorophyll meter really helps a lot in need based, site and situation specific N management in the field crops. Among all, LCC holds its promise due to its simplicity to use, comparative cheaper price and used widely by the extension functionaries for creating awareness in between farmers while the other two holds a special place in the research programs.

- **Nitrogen *viz-à-viz* Cane Quality**

Nitrogen is the basic nutrient required for the plants for their effective metabolic activities and hence the quality of the so harvested canes (Vuyyuru et al. 2019). Worldwide, scientists are working out the ways for sustainable and climate smart use of the N-fertilizers and for this trials pertaining to their effectiveness are in progress globally. The PAU already recommended leaf color chart (LCC) for the N management in cereals (PAU 2020) while for sugarcane, trails are under progress. Differently textured soils have different nutrient retaining and leaching capacities. As macro/water conducting pores increased as compared to the water retaining/micropores, retaining capacity reduced and proportionately leaching capacity hiked up (Fig. 7). Higher NUE required for higher sugar quality (Keating et al. 1997) and improving water body qualities (Bramley et al. 1996), for dropping different losses of N viz. leaching losses in the sandy soils (Thorburn et al. 2003; Oliveria et al. 2002) and reduces greenhouse gas emissions through denitrification

(Keating et al. 1997; Haynes and Hamilton 1999). Further among different factor affecting N-requirement age of cane and season (Thompson 1988), Fertigation (Weigel et al. 2008) are important ones. In Punjab, India sugarcane sown in two seasons *viz.* October-November (Autumn cane) and February-March (Spring canes) and average cane duration in 10-12 months (PAU 2020). As per the age of canes, different quantities of nutrients get accumulate in its vegetative portion (Table 8).

Fig.7 Drained solution and amounts of N leached from sandy soil cultivated with sugarcane (Source: Oliveira et al. 2002).

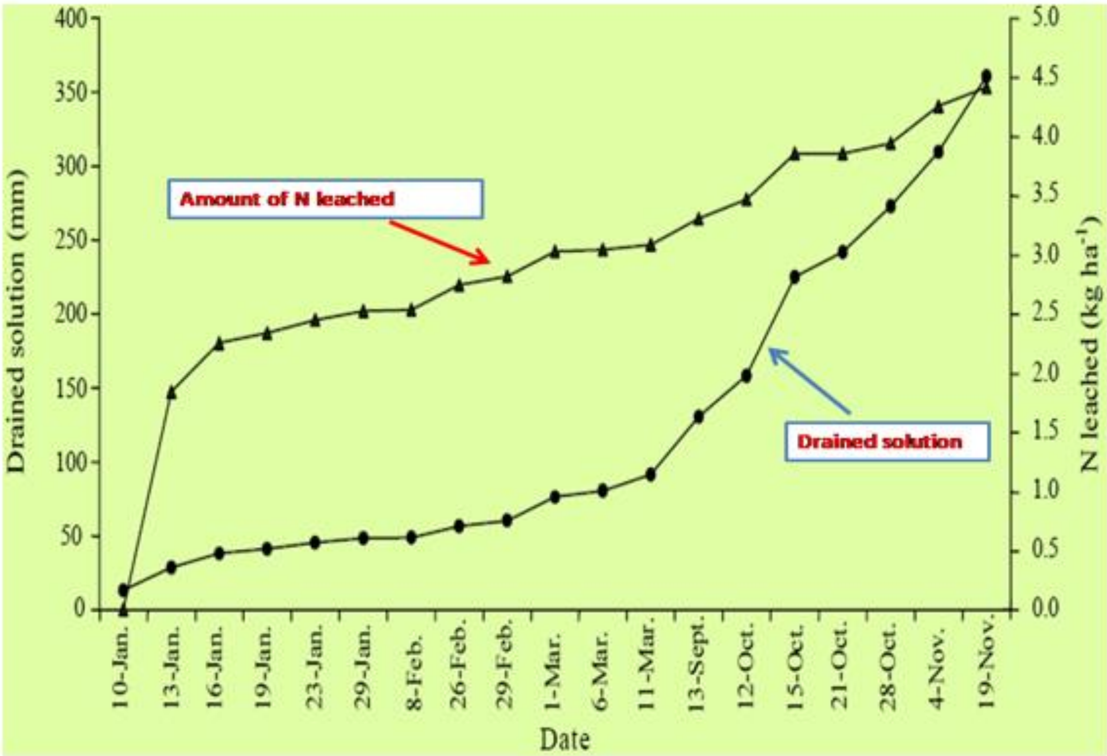


Table 8 Nutrient uptake comparisons in sugarcane crop at 4 and 6* (Adapted from Thompson 1991)

Element	Spring start in % of total uptake		Autumn start in % of total uptake	
	At 4 months	At 6 months	At 4 months	At 6 months
N	81.9	99.1	12.1	23.9
P	65.9	90.1	12.9	33.1
K	60.1	81.9	7.1	25.1
Ca	56.9	85.1	6.1	17.1
MG	78.1	94.9	7.9	23.9

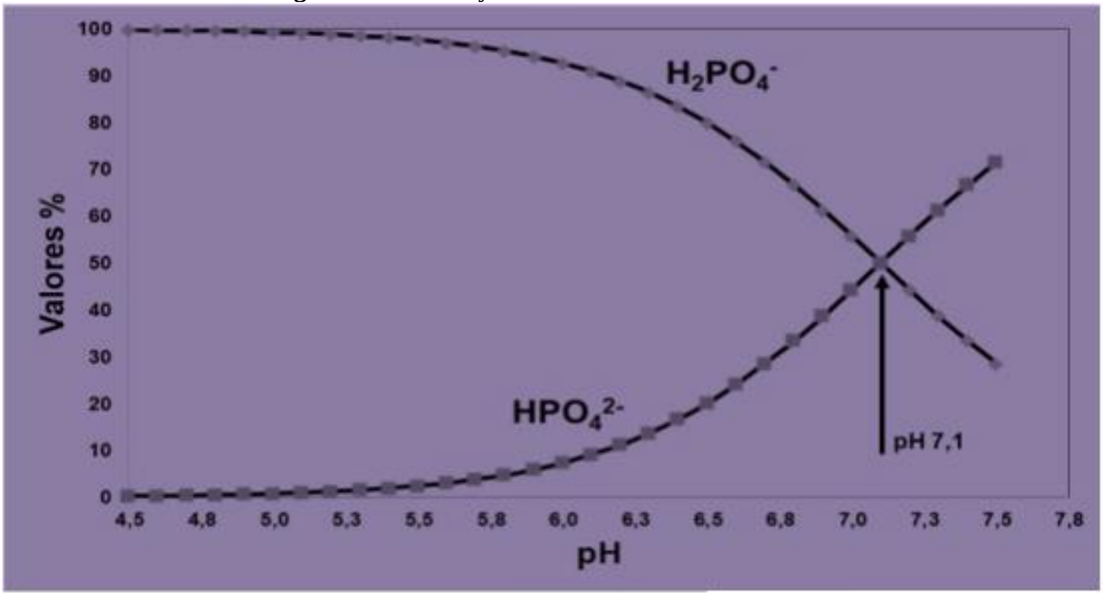
- **Soil N mineralization**

Mineralization of N results in better availability of the Soil N present in the soil. N mineralization in soils depends on several factors *viz.* soil textural class, received rainfall, inherent N supplying capability of the soil, soil organic matter content, and temperature variation trends, and mechanical manipulation of soil *i.e.* tillage intensity. N mineralization potentials and target yields are the two pillars on which cane N-requirements depends. Hence, integrated nutrient management *i.e.* use of organic manures along with inorganic fertilizers for harvesting sustainable cane yields and quality. On an average, additional one t ha^{-1} yields require about 1 kg of N, mainly when already yield potential of 100 t ha^{-1} achieved (Vuyyuru et al. 2019). Due to the mineralization of soil organic matter and the greater nutritional efficiency of the plant-cane root system, compared to the ratoon, canes showing lesser response to the applied N fertilizers (Oliveira et al. 2018). Further, Salce et al. (1985) measured the mineralization of soil C and N during the plant-cane cycle. Studied carried out by Oliveira et al. 2018; Rufty et al. 1990; Malavolta et al. 1989 critically highlighted the role of endogenous availability of phosphorus to have relative better N uptake. Canes with sufficent P supply, had higher ability to extract the nitrate from the soil solution followed by its higher uptake with higher proteins accumlation in leaves and roots (Rufty et al. 1990). Oliveira et al. 2007 in their study also highlighted the role of soil P in promoting higher N accumulation in the biomass of the plant-cane as each kg of P applied, resulted in one kilogram hike in N in biomass (Oliveira et al. 2018; Rufty et al. 1990).

- **Phosphorus**

Phosphorus being the second mostly required by cane plants in their different metabolic processes is the important nutrient which must be applied at the deficient sites for having higher growth, yields and sugar recovery. Availability of P much to plants through roots depends on several factors out of which soil textural class, soil structure, soil pH, EC, available moisture contents etc. are important (Bhatt 2020). Under acidic and alkaline soils, P absorbed as $H_2PO_4^-$ (dihydrogen phosphate) and HPO_4^{2-} (mono-hydrogen phosphate), respectively at different ranges (Fig. 7). Hence, soil conditions must be corrected for having an ideal range of available P. In Brazil, most soils put under sugarcane cultivation reported to have acidic range of soil pH, which further results in smaller absorption of the HPO_4^{2-}. The graph below was made using the Handerson Equation - Hasselbach equation; pH = pka + log [deprot] / [prot] (Fig. 8).

Fig. 8 Availability of soil available P *viz-a-viz* soil Ph



In Punjab, fertilizers pertaining to P recommended based on soil test report viz. 30 kg P_2O_5 ha^{-1} for soils having <12.5 kg ha^{-1} of available P (PAU 2020). Normally, only a small fraction of applied P used up by the sugarcane seed crop viz. 20 kg ha^{-1} in comparison to other crops. However in the deficient soils, applied P fertilizers enhance the productivity and quality of sugarcane (Fageria and Baligar 2001; Tilib et al. 2004). Red oxisol soils reported with P deficiency due to fixation of the applied P under the tropical and subtropical regions. Hence, P fertilizers must be used sustainably and judiciously for the long term sugarcane sustainability (Du Toit 1962). However due to the inherent tendency of applying higher P doses, there are chances of build-up of P stocks of the soils which further has serious ecological implications *viz.* soil and underground water pollution. This not only affected the plant but animals and human health too. Hence, soil test based sustainable use of P fertilizers is a must which on one side reduces extra loads on the farmers pockets due to use of lesser fertilizers and pesticides while on other also improves the sugar recovery of the harvested canes. But applied P fertilizers and available P to plants are entirely different as availability of applied fertilizers depends on the several factors

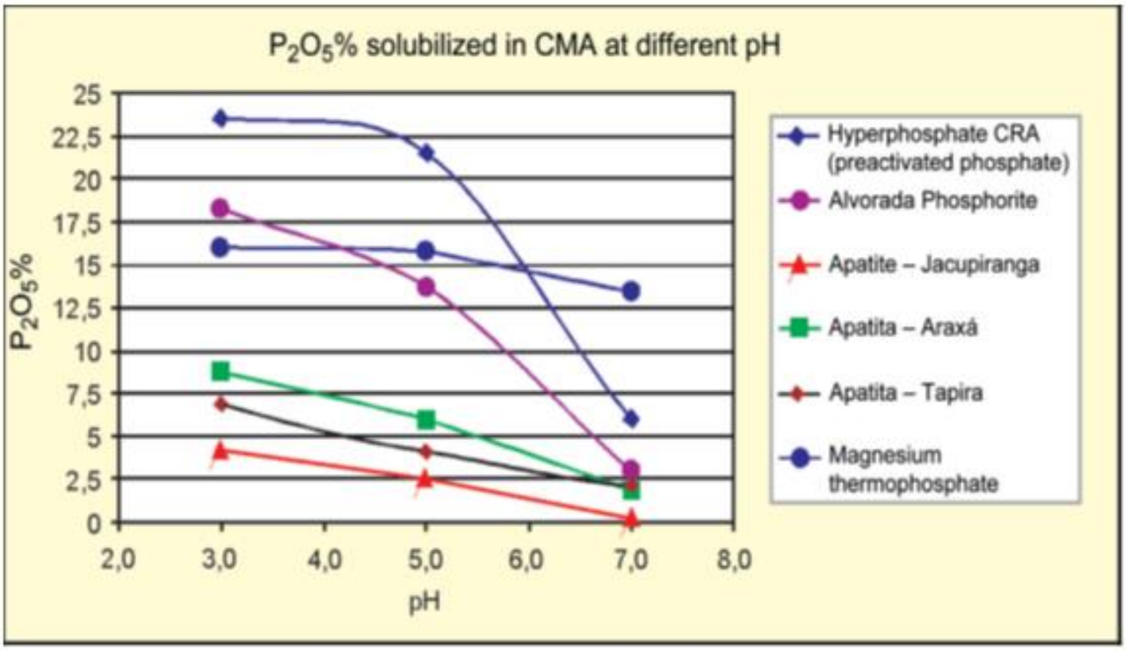
1. Among different mineral P forms, some forms *viz*., $AlPO_4$ (*aluminium phosphate*) and $Ca_3(PO_4)^{2-}$ (*tricalcium phosphate*) and $FePO_4$ (*Ferric phosphate*) are slowly and very slowly available to the canes while some viz. $H_2PO_4^-$ and HPO_4^{2-} anions (*water-soluble forms*) from $Ca(H_2PO_4)_2.H_2O$ (*mono-calcium phosphate*) are readily available to plants

(Heck 1934). Further, canes fulfilled their P requirements from $AlPO_4$ (du Toit 1957) depending on the soil pH.

2. Another factor responsible for P fixation is by the hydrous oxides which reduces the P availability and supply to the plants for meeting their requirements, which further had adverse effects on the cane yields and quality parameters (Bhatt 2020). Further, some parameter viz. phosphate desorption index (Meyer and Dicks 1979) and phosphorus buffer index (Burkitt et al. 2000) also used in literature. Hence, fixation aspect must be kept under consideration while recommended in the region.

3. Soil pH is another factor which must be considered as it also significantly affected the P availability to the cane plants even seed or ratoon crop. Under normal conditions of soil pH 5.5 to 7.2, when $H_2PO_4^-$ and HPO_4^{2-} will be concurrently available, hiked the P availability. However, under alkaline and acidic conditions, P availability to the canes becomes lesser available (Fig. 9), which could be corrected only by reclaiming them by soil test basis application of the gypsum or lime (Meyer and Wood 1989).

Fig. 9 Solubility of P_2O_5 as per varying soil pH. (Source: Alcarde and Ponchio 1979)



Studies conducted by Pavan and Oliveira (1997) revealed that a pH increase from 4.0 to 5.0 precipitate aluminum which further improved P content from 4.8 to 24.2 mg/dm3 (Table 9).

Table 9 Neutralization of soil acidity with $CaCO_3$, participation of Al^{+3} and P availability in an Oxisol (Source Pavan and Oliveria 1997)

pH $CaCl^2$	Cation base Ca	Mg	K	Al^{+3} acidez trocavel	Acidez	Bases	Saturated por bases	P
				cmolc/dm^3			V (%)	mg dm^{-3}
4	1.8	0.66	0.37	1.6	12.56	2.46	16.38	4.8
4.5	4.4	0.68	0.38	1	10	5.08	33.69	5.5
5	7.6	0.7	0.35	0	6.73	8.3	55.23	24.2
6	10.6	10.6	0.36	0	3.66	11.3	75.54	16
7	15	15	0.36	0	0.2	15.66	98.74	8

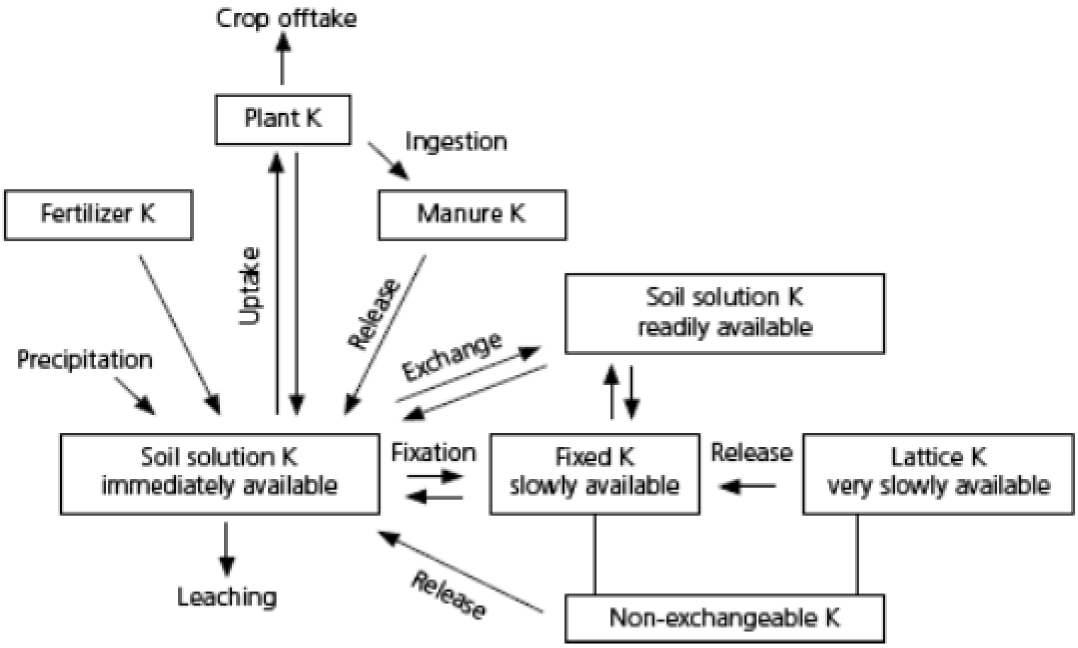
- **Potassium (K)**

Potassium is the third most important nutrient which played an important role in improving the root development, water and N use efficiency, reduces the insect-pest incidence and finally significantly improves the commercial cane sugar (t ha^{-1}) (Bhatt et al. 2020). From clay mineralogy of soils, K is mostly present in feldspars and micas as inorganic minerals and due to its lesser solubility, K deficiency appeared even at higher K levels (Brar et al. 2008; Bhatt and Sharma 2011). Normally, roots of the plants extract the K ions from the soil solution by roots, which then extract from minerals at the K deficient sites. Under these circumstances, if K fertilizers applications further skipped then K deficiency permanently appeared in soils as the case happens with N-nutrient (Bhatt 2020). Hence, K deficiency must be handled appropriately as and when appeared, with proper K-fertilization. In any condition, plants will not be allowed to suffer from the K deficiency as it will also affect the N-use efficiency, root growth and finally the overall development of the canes. Further, there are many factors on which availability of the K depends in soils

- **Potassium of Soil Solution**

In soils and lithosphere normally potash present in as 0.8 and 2.6%, respectively (Lindsay 1979). In soils, non-exchangeable K (1–10%) and mineral K (90–98%) forms dominates which is not available to canes while soluble K (0.1–0.2%), exchangeable K (1–2%) present under minority group and which supplied the K to the canes (McLaren and Cameron 1996). Following figures delineates the pattern with which the K is moved and available of fixed in the soil.

Fig. 10 Soil's potassium fate (Source: Syers 1998)



Under field conditions, only 1/10th part of the total available K is present in soil solution for plant uptake (Fig 10). Further, only small amounts of K entered through feldspars and micas weathering (Brar et al. 2008) into the soil solution where it became available to the plant roots.

- **Factors affecting K availability**

Soil Texture

Lesser the clay content of the soils, lesser will be the fixation and hence more the leaching losses beyond rhizosphere, which finally resulted in the K deficiency symptoms in sugarcane plants. However under heavy textured soils with higher clay contents, more the fixation, lesser will be the leaching losses and hence higher is the K use efficiency. Hence the medium to heavy textured soils reported with the higher K use efficiency and lesser K loss.

- **Soil Temperature and Moisture interactions**

Interaction of soil temperature and moisture affected the K availability from the soil solution to the plants (Leverington et al. 1962) as under winters lower soil temperature under moist conditions reduces the amounts of potash to sugarcane, even if soil applied with excessive doses of K (Donaldson et al. 1990).

- **Irrigated Conditions**

As compared to the water-stressed conditions, irrigated conditions results in better uptake of soil solution K which further resulted in better N-use efficiency, cane roots and better control of insect-pest. Afterwards, all this results in better growth, yield and quality parameters (Bhatt et al. 2020). As per one estimate, 214 and 790 kg K ha^{-1} $year^{-1}$ removed from the soils under water stressed and irrigated conditions, respectively under South African conditions (Wood 1990). Therefore, cane need based K fertilization is a must for attaining the improved growth, yield and quality parameters as depicted in Table 12 (Chatterjee et al. 1998).

Table 10 Effect of K manuring on height, stalk population and yields of sugarcane (Adapted from Donaldson et al. 1990)

K (kg ha^{-1})	Yield (t ha^{-1})	Pol %	CSS (t ha^{-1})	Cane length (cm)	Stalk population ($x10^3$)
0	88	13.2	11.6	240	86
300	112	13.5	15.1	273	93
600	114	13.3	15.1	278	88
LSD (p=0.05)	17	0.9	2.5	17	14

Under the deficit moisture conditions, K-uptake from the soil solution decreased which further reduces the net transpiration rates and cane yields (Filho 1985; Sudama et al. 1998; Ghaffar et al. 2013; Bhatt et al. 2020). Some workers reported no significant changes in yield parameters on applying potash (Lakholive et al. 1979; Olalla et al. 1986; Ghaffar et al. 2013; Bhatt et al. 2020), while some reported a significant increase in cane quality as well as growth and yields (Korndorfer 1990; Prasad et al. 1996; Nagarajah 2006). Further, sufficient K nutrients removed by the cane plants for meeting their K requirements from the surface as well as from the sub-surface generally where soils change in the pH. (Rabindra et al.1993).

Bhatt et al. 2020 while conducting their trials regarding role of potassium on growth, yield and quality parameters of sugarcane using mid-late cultivar (CoJ-88) at Punjab, India revealed that under both irrigated and water stressed conditions, at K-deficient sites, 80 kg K_2O ha^{-1} found to be sustainable dose which must be applied for having potential yields, quality and finally livelihoods. Further, among different doses 80 kg K_2O ha^{-1} reported to enhance the growth, yield and quality parameters significantly as compared to others while shifting to higher levels, these parameters adversely affected (Table 11).

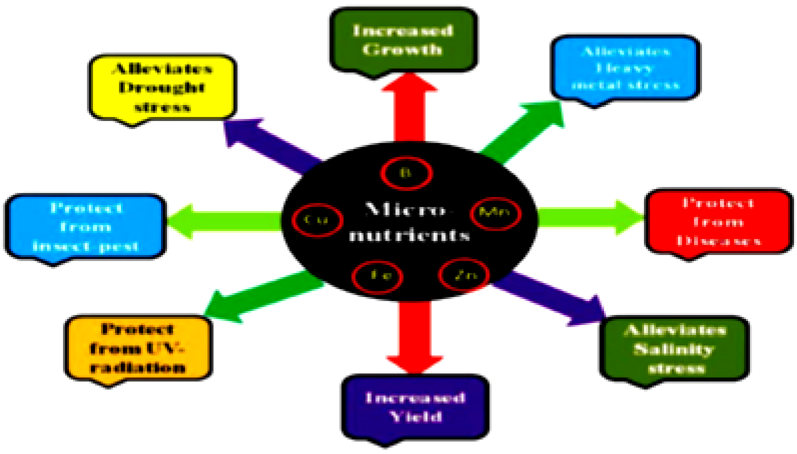
Table 11 Different sugarcane quality parameters at 10th and 12th month as affected by different irrigation and potash levels (Source: Bhatt et al. 2020)

		10th months			12th months		
Treatments	Yield (t/ha)	Purity (%)	Extraction (%)	CCS (t/ha)	Purity (%)	Extraction (%)	CCS (t/ha)
Irrigated	77.55	91.86	43.93	10.16	92.02	53.33	10.39
Water stressed	77.20	93.25	42.23	10.03	90.48	51.59	10.34
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
0	76.30	91.91	40.45	9.47	90.85	51.63	9.97
40	76.86	91.86	42.97	9.87	91.16	52.44	10.18
80	77.96	93.2	44.17	10.48	91.47	53.12	10.66
120	78.38	93.25	44.74	10.56	91.52	53.09	10.65
CD (p=0.05)	0.58	NS	NS	0.33	NS	NS	0.28
K at same I	NS	2.44	NS	NS	NS	NS	NS
I at same K	NS	2.18	NS	NS	NS	NS	NS

- **Micronutrients**

Micronutrients are the nutrients which required in the lower doses though played a critical role in the plant metabolism to the extent that under their deficiency plants are not able to attain the potential yields along with sugar recovery. Hence, it is equally important though required in lesser quantities for the proper sugarcane growth and development. In Fig. 11, Tripathi et al. 2015 identifies some important nutrients claimed as micronutrients and which played an important role in plant metabolism.

Fig. 11 Functions of micronutrients in adverse conditions (Source: Tripathi et al. 2015)



In sugarcane micronutrients, produce non-significant increases or decreases in the Brix. Madhuri et al. 2013 showed significant yield responses when Zn applied at the deficient sites but not with the quality parameters while Fe sprays results in significantly improvements in both yield as well as quality parameters when sprayed at the deficient sites (Madhuri et al. 2013). Hence for obtaining the maximum recovery from the canes, soil must be tested for micronutrients and micronutrients must be sprayed at the deficient sites. Plant physiological processes triggered by the sustainable sugarcane production technologies. (Malavolta et al. 1974; Epstein 1975).

Micronutrients seems to be lesser effective in significantly improving the cane yieldsas earlier reported by Azeredo and Bolsanello 1981; Madhru et al. 2013, while Cu and Zn application at some sites seems to have significant effects (Alvarez 1984; Cambria et al. 1989). Cu acts as activators of many enzymes and controlled the photosynthesis process (Taiz and Zeiger 2004). Hence, identifying the critical limits of the different micronutrients is a must which might differs in the texturally different soils under different agro-climatic and moisture conditions (Marinho and Albuquerque 1981). Further, Alvarez and Wutke (1963) in their experiments observed boron functions at deficient sites up to the first ratoon crop (Sobral and Weber 1983). Orlando et al. 2001 in their experiments revealed the 'Hidden hunger' and need to attend it with proper sprays more particularly in the deficient soils in sugarcane crop. Several factors identified which affects the availability of the micronutrient and their absorption like soil textural class, cultivar selected and rainfall, and temperature conditions (Orlando et al. 2001; Madhuri et al. 2013).

As far as sequence of export of micronutrients concerned the pattern revealed as Fe> Mn > Zn > Cu > B > Mo. Hence, hidden hunger particularly of micronutrients must be handled for overall improving the overall cane yields and quality (Orlando et al. 2001). Role of manganese (Mn) identified for the cell proliferation, photosynthesis, and enzyme activation (Sobral and Weber 1983). Further, Molybdenum (Mo) involved in the sugarcane biological N fixation control which further affected nitrate reductase enzyme the nitrate assimilation (Sobral and Weber 1983; Orlando et al. 2001), while Zn being essential for generation indole acetic acid (Orlando et al. 2001; Taiz and Zeiger 2004) and also affected the carbonic anhydrase. Among different factors, affecting the cane leaf nutrient concentration, canes age, ambient temperature, rainfall frequency and patterns, time of day, cultivar selected, and inherent soil fertility are the critical factors to be kept under consideration. Hence, plant based approach is also important to judge the hidden hunger before it shows its effects on the cane's yield and quality parameters.

One another concept is the spray of the micro-nutrients on the cane crop known as "biofortification" which fulfill the plant micro-nutrient requirements at the critical growth stages for ultimately having higher yields with better sugar recovery. This approach seems to be more effective than the soil application as leaves directly consumed them at a faster rate as the root absorption from the soil solution. Alvarez and Wutke (1963) revealed from their experiments a positive relation between micronutrients sprays *viz.* B, Mo, Fe, and Cu and sugarcane yields. Further, under the light textured soils, Alvarez (1984) revealed from their study that Cu and Zn chelate encourages the sugarcane yields and juice quality. Azeredo and Bolsanello (1981) also showed around 30% higher cane yields on spraying 5 g liter^{-1} of micronutrients. Franco et al. (2011) revealed higher girth of canes and improves the cane juice when B @ 2 and 4 kg ha^{-1} applied at the deficient sites. Response of plant cane for Cu, Zn, Mn, and Mo in sugarcane reported to enhance the yields upto 18% (Mellis et al. (2008). Hence, the micronutrient application played an important role at the deficient sites for harvesting potential yield and quality (Mellis et al. 2010). Spraying of micronutrients *viz*. Cu, Mn, and Zn chelate at doses of 1.0 and 1.5 lt ha^{-1} enhanced the cane productivity by 10, and 15%, respectively, though not reflected in the recoverable sugars (Fernanda et al. 2017). Further in North-Western Indian Punjab, due to light textured calcareous soils, iron deficiency more frequently reported which appeared as yellow strips and if not attended, finally led to reduces yields, which is not required. Hence, to ameliorate iron deficiency, 2-3 sprays of 1% ferrous sulfate at weekly intervals required on sunny days, as and when symptoms appeared (PAU 2020).

In northeastern Brazil, especially in Alagoas, it is common to spray sugarcane with micronutrients, especially copper and manganese. There is an improvement in the nutritional status of the plants, but most times rain washes away most of the applied nutrients. Furthermore, in deficient plants the remobilization of copper and manganese applied to the leaves is very small.

- **Fertigation**

Fertigation- comparatively a new technique involves application of fertilizers alongwith irrigation water and hence, prove to enhance the N and water-use efficiency, which finally resulted in sustainable and climate smart agriculture. It also saved a significant proportion of the labour and hence, reduces the cost of cultivation (Haynes 1985; Bachchhav 1995; Bhatt 2020). However, some researchers reported at par cane yields (Parikh et al. 1996; Selvaraj et al. 1997) unlike Shinde et al. 1998 reported significant results alongwith 50% reduction in costly fertilizers. Selvaraj et al. 1997 and Shinde et al. 1999 reported 40% irrigation water saving with 175 kg N ha^{-1} than the conventional flood irrigation. Cane yields improved upo 20.8% (Shinde et al. 1999) while in another study fertilizer saving (upto 25%) along with a yield increment (upto 20.74%) reported with drip irrigation (Patil et al. 2001). Vaishnava et al. (2002) reported higher land productivity of canes with 20% fertilizer saving under fertigation approach. Further, Mahendran and Dhanalakshmi (2003) highlighted higher cane growth, yield and quality parameters with the drip fertigation due to lesser leaching losses which further has environmental concerns. Under conventional irrigation higher leaching losses and mineralization of ammonical N into nitrates' is the main reasons for lesser water and N use efficiency, which could be enhanced by adopting drip irrigation (Batta et al. 2005). Further, quality parameters of canes improved when fertigation replaces the conventional flood irrigation practices (Bangar and Chaudhari 2001; Mahendran et al. 2005). Thereby, in sugarcane farming, as far as irrigation is concerned, more site specific research with texturally divergent soils must be carried out on fertigation for improving the sugarcane yields sustainably.

- **Benefits of Fertigation**
- **Fertigation and water use efficiency**

Water use efficiency as compared to the conventional flood irrigation improved while on shifting to the fertigation approach (Hapase et al. 1992; Hapase et al. 1993; More et al. 1995) which might be due to the reduced leaching, drainage, seepage and evaporation losses. Drip irrigation resulted in higher water use efficiency varied from 42 to 52 per cent (Raskar and Bhoi 2001) to 30.6 per cent (Mahadkar et al. (2005) compared to flood irrigation (Deshmukh et al. 1996), which might be site and situation-specific as in Patna; it became double than the conventional system of irrigation (Bhatt 2020) which further resulted significantly higher cane yields (Selvaraj et al. 1997). Hence, more particularly for the water-stressed regions *viz*. central Punjab, India, the government must provide incentives to the cane farmers for adopting the fertigation approach which not only cut down the irrigation while N usage which further has its environmental concerns (Bhatt 2020). Further some extension demonstration must also be carried out at the farmer's field for encouraging others (Bhatt 2020).

- **Fertigation and nutrient use efficiency**

A major portion of the applied fertilizers particularly N, lost from the cane rhizosphere with flood irrigation water, thereby improving the N-use efficiency is the major area of attention now a days (Bhatt et al. 2020). Further, mostly higher doses of fertilizers ingeniously being applied to the sugarcane crop on the light textured soils with flood irrigation. Hence, there is urgent need to improve NUE. Fertigation proved an important technology as it drops the fertilizer along with the irrigation water where it is required (Prasad et al. 1983) due to application of water and N-nutrient as per plant demand (Ng Kee Kwong and Deville 1994). Drip irrigation results in better results even with 50% fertilization (Bangar and Chaudhari 2001). Further, Goel et al. 2005 reported with higher N, K and P contents in the index leaf with drip method at 1.0, 0.8 and 1.0 IW/CPE (irrigation water to cumulative pan evaporation) ratio, because of the reported higher nutrient use efficiency as compared to the flood irrigation where a majority of nutrients get lost beyond the rhizosphere. Hence, for better N and water use efficiency and for higher growth, yield and quality parameters, fertigation must be adopted particularly under the water stressed regions (Bhatt et al. 2020).

- **Sustainable Sugarcane Fertilization practices:**

Sustainable sugarcane fertilization practices serve the farmers and ecosystem former by reducing the cost of cultivation by cutting down the conventional applied fertilizers and pesticides, thereby improving the livelihoods of the farmers while on other reduces the generation of the green house gases and thus mitigate the effect of the global warming. As a thumb rule, sustainable sugarcane fertilization practices involved the four aspects *viz.* right dose, right place, right time and right method, which could be discussed as below

- **Sustainable fertilizer amounts**

Generally cultivator conventionally applied higher doses of fertilizers ignoring plant needs and inherent tendency of the soil to supply those nutrients. In that case, higher portion of these applied nutrients got wasted and polluting underground water and evolve higher green house gases which further causes the global warming. Therefore, fertilizers must be applied as per soil test reports and plant type *viz*. plant or ratoon as later one required higher quantum of fertilizers due to its well developed root system (PAU 2020). Further, the mentioned dose is for soils having soil organic carbon ranges between 0.4 to 0.75% while in case of lower and higher side, N fertilizer dose adjusted at 25% higher and lower, respectively. Hence, the fertilizer demands of the sugarcane crop being influenced by the plant type, soil textural class, agro-climatic conditions and present soil organic carbon (%).

- **Placement of fertilizers**

For getting the higher nutrient use efficiency, placement of the fertilizer is very important and must be considered during applying it in the sugarcane fields (Bhatt 2020). Further, micronutrients reported better with the biofortification *viz.* spraying the recommended micronutrients. Further, fertilizers application close to row reported with lesser N leaching losses and therefore higher N use efficiency. Further, splitting N-fertilization doses reported with higher use efficiency more particularly in the light textured soils than a single or two splits, which further sustainably, improved the overall land and water productivity.

- **Time of fertilizer application**

The time of applying the fertilizer is very crucial factor, generally discussed at different stages. In some crops, seed contained enough food for the initial growth and there applying fertilizer with seed generally prohibited and reverse is true for the reverse case. As per one intervention, as N runs, P walks, and K sits in soil, therefore focus must be there for having better use efficiency of these nutrients. As per Ruiz et al. 1999, generally the machenism of mass flow and diffusion involved in the nutrient transport to the plant roots depending on nutrient activity in the soil solution, and plant nutrient demand. Experoments finally revealed that potassium was transported predominantly by diffusion, while Ca^{+2} and Mg^{+2} were transported by mass flow. As per their conclusion under nromal conditions, diffusion was the main machenism for potassium transport, however diffusion dominated when potassium concentration was quite high in the soil solution. Therefore, fertilization timing in sugarcane must consider nutrient consumption behavior of plants at different growth stages and the indigenous soil fertility to supply those nutrients at particular stages. Therefore, N-fertilizers must apply in splits which further depend on the soil textural class while P and K must applied at sowing (Bhatt 2020).

- **Integrated Nutrient Management**

It is also very important practices which simultaneously feed plant as well as improved the soil organic matter-the ultimate food for soil microorganisms which converts the fertilizers to the available forms for the plants and hereby also improves the NUE (Bhatt 2020). Further, use of farm yard manure @ 20 t ha^{-1} with chemical fertilizers also very important for improving the soil health and its physic-chemical properties by sequestering higher fraction of C instead of burning it for fuel purpose. Further, Azotobacter @ 10 kg ha^{-1} also improves the available nutrient which earlier fixed in soil and improved the cane yield and quality as well. Further, filter cake, poultry manure etc. also used by the cane farmers for fertilizing their cane crop as these supplied good quantity of both macro as well as micro-nutrients (Table 12) which further helps in improving the soil organic matter status of the soil which further inturn improves the soil biological, chemixal and physical properties for having overall higher net yields.

Table 12 Available and supplied nutrients in the filter cake (%), polutry litter and cake

	N	P_2O_5	K_2O	Ca	Mg	S
Average	1.478	1.71	0.33	4.60	0.46	0.62
CV	29.88	57.19	93.69	154.78	66.38	181.32
	Fe	Mn	Cu	Zn	Na	B
			(mg/dm^3)			
Average	22.188	576.91	119.1	142.8	872.2	11.3
SD	13.883	270.9	67.9	87.8	699.1	8.8
CV	62.2	46.8	56.8	61.4	80.2	77.7

Nutrients of poultry litter (%)

N	P_2O_5	K_2O	Ca	Mg	S	C/N	SOM	Moisture
2.62	2.25	2.58	6.18	0.54	0.35	10.92	66.02	21.74

Poultry cake fertility (kg ha^{-1})

Amount (t ha^{-1})	N	P_2O_5	K_2O	Ca	Mg	S
3	79	67	77	185	16	10
3.5	92	78	90	216	18	12
4	105	89	103	247	21	14
4.5	119	101	116	278	24	15
5	132	112	129	309	26	17

3 CONCLUSION

"Sustainable Sugarcane Fertilization" mostly ignored by the cane farmers, which indeed most important for sustainable farming of sugarcane. Majority of the farmers applying the different fertilizers as per their knowledge which they got from their former generations that might works at their times and a complete failure now due to evolution, recommendation and adoption of higher yielding cane cultivars and change of the soil fertility. Hence, farmers must establish a good linkage with the extension centers which provides them latest knowledge regarding different sugarcane fertilization approaches viz. soil sampling and testing, integrated nutrient management, need based fertilizer management using leaf color chart, SPAD and other new approaches which helps them to improve their livelihoods on one side while extenuating the adverse effects green house gases on other. Therefore, sustainable sugarcane fertilization is the single most important factor which could affect both yield and quality parameters of the crop.

Further, natural resources viz. land, water and air must be exploited to the minimum while to meet the sugar demand of the escalating population in a sustainable manner, and the fertilization must be taken care of. There is urgent need to organize trainings pertaining to the sustainable sugarcane fertilization in the villages at farmers' levels and the farmers adopting new fertilization techniques must be awarded and their success stories must be published in local news paper for encouraging others in villages and then district, state, country level. Further, synchronicity between demand, supply and availability of nutrients and water to sugarcane must be improved. There is an urgent need to improve the use efficiency of different inputs *viz.* water, fertilizers and pesticides in sugarcane farming rather to increase their quantities for higher yield and quality with lesser water and C footprints.

- **Future prospective**

"Sustainable Sugarcane Fertilization" has several challenges both for the scientists as well as for the farmers. Generally farmers used higher quantities of water, fertilizers and pesticides etc. for higher desired yields, which on the long run led to many ecological implications *viz.* soil pollution, higher percentage of the resides might not be safe for human consumption, deepening of under-ground water levels, water pollution, climate change and many others. Ultimate goal is to advance use efficiency of applied inputs sustainably with new improved techniques with their reduced usage, which further reduces the overall cost of cultivation, improved yields, commercial cane sugar (t ha^{-1}) etc in a climate smart way. Degraded and waste lands must be brought under cane cultivation by improving their soil health through better SOC (%) by different practices which must be tested and recommended by the soil scientists. Further, plant breeders needs to evolve new lines which could perform better under biotic and abiotic stressed conditions, and able to produce potential yields. Hence for sustainable sugarcane farming, cultivators should well equip with different climate smart interventions to reduce their cost of cultivation. Timely analysis of soil, leaf or plant samples in the region having lesser yields with lower recovery also helps in diagnosing the problem and which could be tackled timely for having yields very near to the potential yields. Several other factors viz. primary particle percentage, prevailing climatic conditions, cultivated plant type seed or ratoon, mineralogical make-up of soils, status of soil organic matter, quality of the irrigation water, and financial conditions and land holdings of the farmers must be given due consideration while planning programs for "*Sustainable Sugarcane Fertilization*".

Further, local farmer's participation is a must, for which these programs being planned and stared, otherwise these proved to be a great failure. Finally, new research must be focused on the farmer and their site specific conditions and problems, only then sustainability goals of yield cane yields and quality with higher input use efficiencies, lesser cost of cultivation ,better livelihoods could be achieved in a climate smart way.

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