Original Research Article

Response of Sweet Corn to Nano Urea under Precision Nitrogen Management

ABSTRACT

A lack of synchronization between nitrogen (N) demand and supply results in the loss of applied nitrogen from the soil-plant system. Leaf colour chart (LCC) based nano urea applicationaccording to crop specific needhas the potential to enhancethecropproductivity by reducing N losses.In this context,afield experimentwasconducted during summer seasons of 2022 and 2023 on medium black calcareous soil at Junagadh (Gujarat) to study the response of sweet cornto nano urea under precision nitrogen management. Ten treatments comprising 40 kg N as basal through??? + 40 kg N through urea at 25-30 DAS + 40 kg N through urea at 40-45 DAS, 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% (may be given as 0.4% nano urea or nano urea@ 0.4 %) when LCC ≤ 4, 40 kg N as basal + 30 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4, 40 kg N as basal + 20 kg N through urea at 25-30 DAS + four foliar spray of nano urea 0.4% when LCC ≤ 4, 40 kg N as basal + 20 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4, 40 kg N as basal + 10 kg N through urea at 25-30 DAS + four foliar spray of nano urea 0.4% when LCC ≤ 4, 40 kg N as basal + 10 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4, 40 kg N as basal + four foliar spray of nano urea 0.4% when LCC ≤ 4, 40 kg N as basal + three foliar spray of nano urea 0.4% when LCC ≤ 4 and control (without N application) in Randomized Block Design with three replications.The experimental results on the basis of two years pooled mean revealedthat significantly higher growth, green cob and fodder yields, quality, net returns and B: C ratio of sweet corn were obtained withthe application of 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4, and it remained at par with 40 kg N as basal + 30 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4 and 40 kg N as basal + 40 kg N through urea at 25-30 DAS + 40 kg N through urea at 40-45 DAS. Proper conclusion may be given

Keywords: Economics; growth; leaf colour chart; nano urea; quality; sweet corn; yield.

Key words may be given as nano urea, leaf colour chart, sweet corm, growth, yield, economics

Joining of words may be avoided

1. INTRODUCTION

The term corn denotes 'to sustain life' that offers nutrients for humans as well as animals worldwide.Of the various types of maize, sweet corn (*Zea mays* L. var*. Saccharata*) is a special type of maize bred for high sugar content.Unlike field corn varieties, which are harvested when the kernels are dry and fully mature (dent stage), sweet corn is harvested when immature (milk stage) and can be picked in 80-90 days after sowing and eaten as a vegetable, rather than grain.Sweetcorn is the new age super food for health-conscious public. The nutritive value of sweet corn is equivalent to several high-priced vegetables like cauliflower, cabbage and french beans having higher fiber content and low in cholesterol (include reference). Due to consumers demand, farmers are getting remunerative prices and hence, cultivation of sweet corn is becoming popular among farmers nowadays. After picking of green cobs, the maize plant is used as greenfodder or dry fodder.

Constraints of sweet corn production and needs of nano urea than conventional urea for sweet corn may be incorporated under introduction.

The future of Indian agriculture lies in precision agriculture and innovative modern technologies.Considering today'surgent need, there should be all-out efforts to use novel technological inputs to make the 'Green Revolution' as an 'Evergreen Revolution.'Precision agriculture is a series of strategies and tools that allow farmers to use crop inputs more effectively and optimize soil quality and productivity. More effective use of inputs means greater crop yield and quality, without polluting the environment [1].Nutrient management has taken a quantum leap with the discovery of nano fertilizers. Nano fertilizers comprise of nanomaterials, which are defined as materials in size range of 1 to 100 nm at least in one dimension. Due to greater surface area to volume size ratio, their availability and absorption is manifold.Nano urea is a nanotechnology based sustainable option for farmers towards smart agriculture and combat climate change. Nano urea can be helpful in minimizing the environmental footprint by reducing the loss of nutrients from agriculture fields through leaching and gaseous emissions.Nano urea contains 4.0% total nitrogen (w/v) as encapsulated nitrogen analogues or forms embedded on an organic matrix. The size of one nano particle of urea is 55000 times smaller than one granule of urea. By leveraging advanced nanotechnology, nano urea ensures efficient nutrient delivery to plants while minimizing nitrogen loss, thus curbing soil and water pollution [2]. Nano urea is a potential component of nutrient stewardship as it promotes precision and sustainable agriculture.

Corn being an exhaustive crop, it requires a higher fertilizer dose. Insufficient nutrient availability to plants results in low yields and significantly reduced profits compared to a properly fertilized crop.An easy, simple, and reliable method for estimating the nitrogen demand in the plant is through a leaf colour chart (LCC), which can assess the chlorophyll content of the leaf in a non-invasive and non-destructive manner, thus providing an estimation of indirect leaf N status.The intensity of leaf colour shows the relationship between nitrogen and photosynthesis, making it an indicator of the amount of nitrogen present in the plant [3]. The LCC can be used to monitor plant N status in-situ in the field and to determine the right time of N top dressing to crop.Leaf color chart has been used successfully to guide fertilizer N application inmaize[4].Integrating nanotechnology with precision tools allows farmers to adopt precision agriculture practices with ease. This synergy boosts overall farm productivity while conserving resources. So, keeping in view the significance of N on productivity, crop need based N fertilizer application through the decision support tool like LCC will reduce the N losses, cost of fertilizer and application cost.Application of nano urea using a leaf colour chart was aimed at providing precise nitrogen dosages according to the specific needs of the sweet corn crop and field.

2. MATERIALS AND METHODS

The field experiment was conducted during summer seasons of the years 2022 and 2023at the Instructional Farm, Department of Agronomy,College of Agriculture, Junagadh Agricultural University, Junagadh (Gujarat). The soil of the experimental plot wasclayey in texture and slightly alkaline in reaction with pH 8.34 and 7.97 and, EC 0.54 and 0.50 dS/m during 2022 and 2023, respectively. The soil was medium in available nitrogen (255.00 kg/ha and 250.50 kg/ha), available phosphorus (29.17 kg/ha and 31.00 kg/ha), available potassium (265.10 kg/ha and 272.70 kg/ha), available sulphur (17.00 and 16.50 mg/kg), available iron (5.90 and 5.17 mg/kg), available zinc (0.72 and 0.78 mg/kg), available manganese (9.20 and 10.00 mg/kg) and available copper (0.25 and 0.24 mg/kg) in summer 2022 and 2023, respectively. What is the need to include the above micro nutrients status when it is not included in treatments.

The mean maximum and minimum temperature during the crop growth and development period in 2022 ranged between 31.3 to 42.8 °C and 12.7 to 26.0 °C, respectively. The range of average relative humidity, bright sunshine hours, wind speed and daily evaporation were 33.5 to 56.0 %, 7.7 to 11.0 h/day, 4.1 to 8.4 km/h and 5.6 to 10.8 mm, respectively during the year 2022.While, in year 2023, the mean maximum and minimum temperature during the crop growth and development period ranged between 33.2 to 40.6 °C and 13.8 to 26.2 °C, respectively. The range of average relative humidity, bright sunshine hours, wind speed and daily evaporation were 36.0 to 63.0 %, 6.2 to 11.1 h/day, 3.6 to 5.7 km/hand 5.0 to 9.5 mm, respectively. Total 51.0 mm rainfall recorded during the crop growth and development period in summer 2023.

Theexperimentwas laid out in Randomized Block Design with ten treatments, which were replicated thrice with gross plot size of 5.0 m × 3.6 m and net plot size of 4.0 m × 2.4 m.The treatments comprised 40 kg N as basal + 40 kg N through urea at 25-30 DAS + 40 kg N through urea at 40-45 DAS (T_1), 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% (at what basis 0.4 % nano urea was chosen for foliar spray) when LCC ≤ 4 (T_2), 40 kg N as basal + 30 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4 (at how many days interval chlorophyll content was estimated for foliar spray) (T_3), 40 kg N as basal + 20 kg N through urea at 25-30 DAS + four foliar spray of nano urea 0.4% when LCC ≤ 4 (T_4), 40 kg N as basal + 20 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4 (T_5), 40 kg N as basal + 10 kg N through urea at 25-30 DAS + four foliar spray of nano urea 0.4% when LCC ≤ 4 (T_6), 40 kg N as basal + 10 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4 (T_7),40 kg N as basal + four foliar spray of nano urea 0.4% when LCC ≤ 4 (T_8), 40 kg N as basal + three foliar spray of nano urea 0.4% when LCC ≤ 4 (T_9) and control (without N application) (T_{10}).The seeds of sweet corn hybrid 'Sugar-75' were sown at the rate of 15 kg/ha at60 cm × 20 cm spacingand raised with a standard package of practices.Nutrient application was done as per the treatment.Recommended dose of 60 kg P_2O_5 and 60 kg K_2O/ha were applied uniformly to all the plots as basal application.IFFCO nano urea containing 4.0% total nitrogen (w/v) was used in this experiment. Foliar sprayof nano urea0.4% (4 ml/l water)was carried out with a knapsack sprayer using a flat fan nozzle with 500 liters of water per hectare for uniform spraying on the foliage during morning or evening hours avoiding dew.

The six panelLeaf Colour Chart (LCC) was used in the present experiment, which was developed for maize byscientists of Punjab Agricultural University (PAU).The methodology used for taking LCC readings is as under:

1. Starting from 21 DAS, LCC readings were taken from randomly selected 5 plants in each plot.
2. Observations were taken from the third fully expanded and healthy leaf starting at the top of the sweet corn plant by matching the colour shade of LCC and average score of the 5 plants was worked out. The third fully expanded leaf from the head of maize was chosen for leaf colour measurement since this leaf is closely

associated with the nitrogen status of sweet corn plant [5]. At the time of tasselling stage, the ear leaf was used as an index leaf for measurement [6].

3. Readings were recorded by placing the middle part of the leaf on top of the LCC's colour strips for comparison.
4. Leaf was not detached.
5. Readings were taken at the same time of the day (8:00-10:00 AM).
6. The LCC was not exposed to direct sunlight during readings.
7. The same person has taken the first up to the last LCC reading.
8. If average reading below the critical LCC value, nano urea was sprayed as per treatment.
9. LCC readings were repeated after 7 days and the same 5 plants were observed up to the tasseling stage.

Total chlorophyll content of the fresh green leaf was measured and averaged at threshold value of LCC by DMSO method of chlorophyll estimation as suggested by Hiscox and Israelstam [7].The SPAD meter (Minolta SPAD-502 plus) readings were recorded at the threshold value of LCC from each 5 tagged plants and averaged for best result.

Leaf area/plantwas calculated *in-situ* by measuring the leaf blade length (L) and width (W) by the following formula given by Mokhtarpour etal.[8].The leaf area was calculated separately for all the leaves of tagged plants.Leaf area (cm^2) = K × L × W. Where, K being the "adjustment factor" the value of which was 0.67 [9].

Leaf area index (LAI) was worked out by using average leaf area/plant with help of the following formula as suggested by Watson [10]:

$$LAI = \frac{\text{Leaf area per plant}}{\text{Area occupied by plant}}$$

Crop growth rate (CGR) was calculated by using the following formula [10]:

$$CGR\ (g/m^2/day) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where,

W_1 and W_2 = Dry weight of plant at time t_1 and t_2,respectively
P = Ground area covered by plant in m^2
$t_2 - t_1$ = Time interval in days

Relative growth rate (RGR) and net assimilation rate (NAR) were calculated by using the following formulas[11]:

$$RGR\ (g/g/day) = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

$$NAR\ (g/m^2\ \text{leaf area/day}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\ln A_2 - \ln A_1}{A_2 - A_1}$$

Where,

ln = Natural logarithm
W_1 and W_2 = Dry weight per unit area at the time t_1 and t_2, respectively
A_1 and A_2 = Leaf area at the time t_1 and t_2, respectively
$t_2 - t_1$ = Time interval in days

Total soluble solids (TSS) in the kernel were determined by a hand refractometer which works on the principle of refraction. Crude protein content in cob of sweet corn was determined by multiplying nitrogen content by a factor 6.25 [12].The crude fiber content was determined by the method described by Wright [13].

The expenses incurred for all the cultivation operations from preparatory tillage to harvesting, including labour wages and the cost of inputs *viz*., seeds, fertilizers, irrigation and herbicides, pesticides *etc*. applied to each treatment were calculated based on prevailing local charges. The gross realization in terms of rupees per hectare was worked out taking into consideration the cob and fodder yields from each treatment and local market prices. Benefit: cost (B: C) ratio was calculated by dividing the gross returns by the total cost of cultivation.

3. RESULTS AND DISCUSSION

3.1 Effect on growth parametersof sweet corn

Thepooled dataof two years furnishedinTable1 revealed that all the treatments produced significantly higher plant height, number of leaves/plant, number of internodes/plant and dry matter accumulation/plant at 30 DAS over the control (without N application).The plant height at 60 DAS (203.91 cm), number of leaves/plant at 60 DAS (13.31), number of internodes/plant at 60 DAS (7.37) and at harvest (10.54) and dry matter accumulation/plant at 60 DAS (56.60 g) were observed significantly maximum with the application of 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 (T_2), which remained at par with T_3, T_1, $T_4$and T_5.The application of 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4(T_2)recorded significantly maximum plant height at harvest (220.17 cm),but it remained at par with T_3 and T_1. Significantly maximum dry matter accumulation/plant at harvest (169.97 g – It is a field experiment, why DMP is given as g/plant why not kg/ha or t/ha) was noted with T_2 (40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4), which remained at par with T_3,T_1 and T_4. Author mentioned about DMP at harvest. Kindly include other parameter too.

Per cent increase in DMP over RDF and over No N application may be included

The two primary physiological processes responsible for growth are cell division and cell expansion. Nitrogen is an absolute necessity for these two. Due to a timely and balanced supply of nitrogen, there were significant differences between the various treatments.The timely supply of the desired amount of nutrients helped the plant to uptake more nutrients, which effectively move from source to sink organs that might haveincreased cell division andinternodal length, led to increased plant height.The plant height increased significantly with the growth of a crop. LCC based nano nitrogen application according to crop specific need could be the reason for greater plant height as nitrogen promoted plant growth, increased the number and length of internodes which progressively increased the plant height in the above mentioned treatments.The present findings are within the close vicinity of those reported with LCC byBhavana et al.[14],Kaviyazhagan et al.[15] and Avinash et al. [16] who explained that increased plant height at LCC 4 might be due to a steady supply of N that helped to produce a favorable effect on growth parameters.

Nano urea treatment based on LCC resulted in a greater leaf number might be due to the maintenance of a balanced nitrogen concentration, which improved the process of cell division and elongation, led to an increased in both the number and size of leaves [17,3].Further the application of nano urea avoided the losses of nitrogen through the processes of nitrate leaching, denitrification and ammonia volatilization and got directly available to plants. The dry matter production depends upon the photosynthetic ability and nutrient use efficiency of the plant. The gradual increase in the growth parameters increased the dry matter accumulation.This could be attributed to better synchronization of nitrogen supply with crop nitrogen demand which led to higher dry matter accumulation. Nano urea has higher surface area to volume size ratio, they have high availability and absorption which facilitates better uptake from leaves, resulted in production of more photosynthesis and biomass required for healthy crops. The optimal combination of conventional fertilizers and nano urea produced the highest values of plant height, number of leaves/plant, number of internodes/plant and dry matter accumulation/plant. These results verify the findings of Maurya et al.[18], Aanoor et al.[19] and Ojha et al.[20].

Further, the data (Table1) revealed that different precision nitrogen management treatments did not exert their significant influence on days to 50 per cent tassellingand days to 50 per cent silking.These traits might be genetically controlled, thus various treatments could not affect on them. Similar results were also reported by Chaudhary [21] and Bhadu [22].

3.2 Effect on physiological parameters of sweet corn

An appraisal of pooled datagiven inTable2 showed thatall the treatments produced significantly maximum leaf area/plant at 30 DAS, leaf area index at 30 DAS and crop growth rate at 0-30 DAS over the control (without N application).It could be due to the application of same basal N dose andadequate N supply from native soil sources during early vegetative growth stages.Similar findings were also reported by Singh et al. [23] (what is the need to include these lines).Further the data revealed that application of 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 (T_2) recordedsignificantly the highest total leaf chlorophyll content at threshold value of LCC (3.55 mg/g),leaf area/plant at 60 DAS (5737 cm^2) and crop growth rate at 30-60 DAS (15.89 g/m^2/day),whichremained at par with T_3,T_1,T_4andT_5.Significantly the highest SPAD valueat threshold value of LCC (49.92), leaf area index at 60 DAS (4.11), crop growth rate at 60 DAS-harvest (23.88 g/m^2/day) and net assimilation rate at 30-60 DAS (0.333 g/m^2 leaf area/day) and 60 DAS-harvest(0.200 g/m^2 leaf area/day) were registered with 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 (T_2),and itremained at par with T_3, $T_1$and T_4.

Higher accumulation of total leaf chlorophyll content was reported under above-said treatments containing nano urea which might bedue to lowersize of nano particles has higher surface area along with reactive surfaces which led to activation of plant enzymes involved in the metabolism.Increased supply of nitrogen to the crop might increase the total leaf chlorophyll content. The increase in total leaf chlorophyll content was noticed because of the direct and indirect role of N for increase in the formation of amino acids, RNA, DNA and energy compounds such as ATP as well as enzymes which led to increased chlorophyll content. Same results were also reported by Bolashetti et al.[24], Jadhav et al.[25] and Tilak et al.[26]. Application of nano urea increased the SPAD value of sweet corn. It might be due to the adequate supply of nutrients and metabolites for growth and development. The results confirm with the findings of Navya et al.[27] and Saud et al. [28].

A healthy crop nutritionally requires about 2-5% of nitrogen of its dry weight in its foliage tissues to maintain its physiological process [29]. The higher number of leaves in the LCC based above said treatments, suggested a higher nitrogen assimilation rate in leaf. Supply of the required amount of nitrogen to crop led to increased plant height and number of leaves per plant with good canopy cover, it facilitated the higher leaf area index. Leaf area was enhanced by increasing in nitrogen content, biomass and photosynthetic rate was positively associated with leaf nitrogen accumulation. These outcomes are consistent with many previous studies conducted byMaurya et al.[18] and Lamsal et al.[3].The nano urea spray led to increased LAI due to enhanced nutrient uptake and utilization, which influenced with enhanced chlorophyll formation, rate of photosynthesis and overall growth in plant which might result in formation of a greater number of leaves. The present findings are in accordance with those reported earlier byAnushka et al.[30], Balachandar et al.[31] and Chinnappa et al.[32].

The crop growth rate might be increased because of the activities of meristem and function of protoplasm could be accelerated due to the timely supply of nitrogen.The superior crop growth rate and net assimilation rate were also due to the fact that nano nutrientsupplied through foliage have mobilized more efficiently by the plant resulted in improved growth parameters and ultimately enhanced the crop growth rate and net assimilation rate of sweet corn. These results of present investigation are in close agreements with the findings ofMirji et al.[33], Pal et al.[34] and Sneha et al.[35].

3.3 Effect on yield attributes and yield of sweet corn

The pooleddata of the years 2022 and 2023(Table3 and4) indicated thatsignificantly the higher length of cob with husk (29.89 cm)and number of kernels/row(44.38)wereregistered with 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 (T_2),whichremained at par with T_3,T_1,T_4andT_5.The treatment comprising 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 (T_2) recorded significantly maximum length of cob without husk (22.90 cm),girth of cob with husk (26.44 cm) and without husk (21.21 cm),fresh weight of cob with husk (428.63 g)and without husk (320.85 g),number of kernels/cob (728.26),fresh kernel weight/cob (219.19 g),weight of 100 kernels (36.58 g), green cob yield(13003kg/ha), green fodder yield (27867 kg/ha) and biological yield (40870 kg/ha),which remained statistically analogous with T_3, T_1 and T_4.Fresh kernel yieldof sweet corn(2849 kg/ha)was found significantly higher with T_2(40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4) and it remained statistically similar with T_3 andT_1.
Per cent increase in green cob yield over RDF and over No N application may be included

LCC based precision nitrogen management provided simple and quick way to assess N deficiency of crop during its growth stage which helped in application of N based on the site-specific nutrient management principle ‘feeding crops with nutrient as and when they are needed,’ and ensured optimal crop growth and development which might led to improved yield attributes and yield of sweet corn.The enhancement of yield attributes, which in turn increased the yield, was presumably caused by an adequate N supply during the reproductive growth phase. The improved yield attributing characters *viz.,* length of cob with and without husk, girth of cob with and without husk and fresh weight of cob with and without husk might be due to higher production of photosynthates because of more number of leaves and leaf area/plant of sweet corn.Because of their large surface area, nanoparticles play an integrated role with other elements and served as a catalyst to speed up the enzymatic reactions. The nitrogen in nano form especially provided at the later phases of the plant life cycle might also have resulted in higher yield since that might have resulted in availability of nutrient for a longer period of time. These results are in close conformity with those ofPatel et al.[36], Riar et al.[37], Singh et al. [38], Sunil et al.[39], Thite et al.[40] and Rawat et al.[41].

Nanofertilizers have a higher surface and reactive areabecause they contain very small or tiny particles, which provided them more sites to promote diverse metabolic processes in the plant system, led to enhanced photosyntheticproduction and ultimately increased the yield of sweet corn. The increased availability of photosynthate,metabolites and nutrients to develop reproductive structures might have increased green cob yield. This could be due to application of conventional fertilizer as basal dose along with nano urea that has been sprayed on plant surface which led to the storage of remaining nitrogen in plant cells that might release slowly which resulted in prevention of the plant biotic and abiotic stress[42,43].Nano urea application might positively affect hormonal balance, led to an increased number of kernels/cob [44].Nano urea has the potential to increase pollination and fertilization in sweet corn [45,46].It could be promoted pollen viability, germination and pollen tube expansion, which resulted in more efficient fertilization and potentially enhanced number of kernels/row, number of kernels/cob, fresh kernel weight/cob and weight of 100 kernels of sweet corn. The higher weight of 100 kernels might be because the combination of traditional fertilizers and nano urea increased the food conversion, caused the kernel to fill and increased its weight. These results are in close vicinity with those obtained byBarkha-Rani et al.[47],Yogendrakumar et al.[48],Krishna and Chhabra [49], Sharma et al.[50], Sowmya et al.[51]and Upadhyay et al.[52].

Greater yields at higher nitrogen application were probably due to better vegetative growth of sweet corn.The enhanced yield attributing characters directly influenced the green cob yield, fresh kernel yield, green fodder yield as well as the biological yield of sweet corn (Table4).These results are more or less similar to those reported byChavan et al.[53],Rajesh et al.[54], Borah et al.[55] and Kale et al. [56].

The experimental findings indicated that the concurrent use of nano urea through LCC has the potential to reduce N fertilization. This could be due to the fact that the LCC based N was able to synchronize the plant N demand due to the split application of N in small doses. Applying nitrogen more than required might reduce crop yields and was toxic to plants [57]. Through LCC based foliar application of nano urea, nitrogen could be supplied as per plant demand and could reduce fertilizer losses. These results are in harmony with those obtained byGautam et al.[58],Thite et al.[40] and Rawat et al.[41].

Table 1. Effect of precision nitrogen management on growth parameters of sweet corn(pooled dataof two years)

Treatments	Plant height at 30 DAS (cm)	Plant height at 60 DAS (cm)	Plant height at harvest (cm)	Number of leaves/plant at30 DAS	Number of leaves/plantat60 DAS	Number of internodes/plant at 30 DAS	Number of internodes/plant at 60 DAS	Number of internodes/plant at harvest	Dry matter accumulation at 30 DAS (g/plant)	Dry matter accumulation at 60 DAS (g/plant)	Dry matter accumulation at harvest (g/plant)	Days to 50 per cent tasselling	Days to 50 per cent silking
T_1	65.08	194.33	204.83	9.18	13.28	3.66	7.31	10.46	29.21	53.58	162.18	57.22	66.32
T_2	64.49	203.91	220.17	9.16	13.31	3.64	7.37	10.54	29.07	56.60	169.97	56.92	66.02
T_3	63.50	201.33	213.83	9.01	13.16	3.60	7.33	10.51	28.01	54.88	167.70	56.52	65.62
T_4	62.13	188.17	198.42	8.94	13.09	3.57	7.25	10.42	27.05	51.73	160.23	56.13	65.24
T_5	61.79	185.91	191.00	8.74	12.89	3.49	7.14	10.31	26.73	51.64	146.92	56.12	65.22
T_6	61.17	165.93	176.50	8.48	11.64	3.36	6.45	9.53	26.56	47.12	146.32	56.10	65.21
T_7	60.33	165.76	174.17	8.38	11.53	3.31	6.39	9.49	26.19	48.45	143.92	55.12	64.22
T_8	59.06	157.28	171.17	8.27	11.50	3.30	6.37	9.47	25.97	47.80	132.90	54.43	63.54
T_9	58.35	155.17	169.83	8.23	11.48	3.29	6.36	9.46	25.92	48.28	128.75	54.47	63.57
T_{10}	32.67	112.63	134.67	6.50	9.80	2.59	5.43	8.28	15.37	37.20	85.92	53.42	62.52
SEm±	2.40	6.42	6.54	0.34	0.34	0.13	0.18	0.23	1.15	1.74	5.22	1.45	2.03
CD (P=0.05)	6.88	18.40	18.75	0.98	0.96	0.38	0.53	0.67	3.30	4.99	14.98	NS	NS
CV (%)	9.99	9.08	8.64	9.86	6.75	9.56	6.71	5.78	10.85	8.57	8.85	6.37	7.70

Table2. Effect of precision nitrogen management on physiological parameters ofsweetcorn(pooled data of two years)

Treatments	Total leafchlorophyllcontent at threshold value of LCC (mg/g)	SPAD value at threshold value ofLCC	Leaf area/plant at 30 DAS (cm^2)	Leaf area/plant at 60 DAS (cm^2)	Leaf area index at 30 DAS	Leaf area index at 60 DAS	CGR at 0-30 DAS ($g/m^2/day$)	CGR at 30-60 DAS ($g/m^2/day$)	CGR at 60 DAS-harvest ($g/m^2/day$)	RGR at 30-60 DAS (g/g/day)	RGR at 60 DAS-harvest (g/g/day)	NAR at 30-60 DAS (g/m^2 leaf area/day)	NAR at 60 DAS-harvest (g/m^2 leaf area/day)
T_1	3.38	48.18	2571	5506	2.24	4.09	7.13	15.57	23.58	0.0264	0.0151	0.315	0.193
T_2	3.55	49.92	2526	5737	2.23	4.11	7.12	15.89	23.88	0.0271	0.0157	0.333	0.200
T_3	3.48	49.78	2464	5631	2.23	4.09	6.96	15.73	23.74	0.0268	0.0152	0.322	0.199
T_4	3.35	47.17	2508	5479	2.21	4.00	6.77	14.91	22.33	0.0261	0.0150	0.305	0.192
T_5	3.31	44.86	2419	5386	2.24	3.79	6.68	14.77	20.40	0.0259	0.0147	0.287	0.167
T_6	2.96	44.65	2376	4940	2.22	3.75	6.64	14.00	19.91	0.0250	0.0142	0.279	0.163
T_7	2.83	44.62	2383	4910	2.21	3.71	6.59	13.79	19.58	0.0245	0.0141	0.273	0.162
T_8	2.76	43.08	2423	4813	2.22	3.68	6.53	13.39	19.18	0.0239	0.0140	0.263	0.161
T_9	2.63	42.65	2417	4757	2.23	3.62	6.46	13.17	18.96	0.0238	0.0139	0.255	0.158
T_{10}	1.37	31.01	1425	1967	1.59	2.34	4.04	9.92	15.72	0.0227	0.0135	0.227	0.128
SEm ±	0.09	1.08	82	160	0.05	0.08	0.25	0.44	0.73	0.0010	0.0005	0.010	0.006
CD (P=0.05)	0.26	3.11	234	458	0.15	0.22	0.72	1.26	2.10	NS	NS	0.028	0.016
CV (%)	7.59	5.95	8.49	7.96	5.74	4.96	9.45	7.61	8.67	9.75	9.04	8.29	8.13

Table3. Effect of precision nitrogen management on yield attributes of sweet corn (pooled data of two years)

Treatments	Number of cobs/plant	Length of cob with husk (cm)	Length of cob without husk (cm)	Girth of cob with husk (cm)	Girth of cob without husk (cm)	Fresh weight of cob with husk (g)	Fresh weight of cob without husk (g)	Number of kernel rows/cob	Number of kernels/row	Number of kernels/cob	Fresh kernel weight/cob (g)	Weight of 100 kernels (g)	Per cent of barren plants
T_1	1.05	29.11	22.12	25.39	20.53	414.54	308.18	16.61	43.22	695.71	213.15	35.26	2.16
T_2	1.10	29.89	22.90	26.44	21.21	428.63	320.85	16.93	44.38	728.26	219.19	36.58	2.14
T_3	1.07	29.78	22.73	25.50	20.75	418.44	312.47	16.66	43.83	712.28	214.85	35.78	2.17
T_4	1.04	28.45	21.46	23.74	19.56	392.37	294.00	16.40	43.05	688.36	211.18	34.73	2.19
T_5	1.02	27.42	20.41	22.06	18.73	363.64	253.91	16.26	40.99	648.54	182.29	32.74	2.22
T_6	1.00	25.80	19.14	21.72	18.00	355.52	240.73	16.14	39.11	610.83	160.14	31.37	2.23
T_7	1.00	25.49	18.83	21.99	18.00	310.56	232.75	16.08	38.00	591.64	140.46	31.30	2.30
T_8	1.00	25.37	18.71	21.84	17.94	307.00	218.77	15.88	36.07	553.52	135.26	30.98	2.34
T_9	1.00	23.96	17.30	21.36	17.83	284.75	205.58	15.44	36.03	538.86	130.33	30.65	2.38
T_{10}	1.00	16.80	9.90	14.30	12.53	150.40	58.25	13.19	17.22	241.40	47.03	22.79	2.52
SEm ±	0.02	0.86	0.74	0.95	0.74	12.70	9.93	0.74	1.25	18.47	4.55	1.23	0.08
CD (P=0.05)	NS	2.48	2.12	2.72	2.11	36.41	28.47	NS	3.57	52.99	13.04	3.53	NS
CV (%)	5.86	8.07	9.37	10.36	9.75	9.08	9.94	11.29	7.99	7.53	6.73	9.36	8.92

Table4.Effect of precision nitrogen management on yield, quality and economics of sweet corn (pooled data of two years)

Treatments	Green cob yield (kg/ha)	Fresh kernel yield (kg/ha)	Green fodder yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)	Total soluble solids inkernel (°Brix)	Crude protein content (%)	Crude fiber content (%)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B: C ratio
T_1	12153	2594	27138	39291	30.98	17.44	10.76	24.91	104215	297341	193126	2.85
T_2	13003	2849	27867	40870	31.84	17.66	10.63	24.82	106205	315798	209593	2.97
T_3	12476	2680	27589	40065	31.13	17.48	10.50	24.77	107545	304696	197151	2.83
T_4	11848	2505	26933	38782	30.52	17.39	10.21	24.04	108898	290834	181936	2.67
T_5	10493	1916	24421	34914	30.06	16.93	9.77	23.13	107399	258709	151311	2.41
T_6	10304	1651	23316	33620	30.80	16.22	9.64	22.63	108752	252720	143968	2.32
T_7	9031	1271	22222	31253	28.87	16.09	9.49	22.49	107253	225057	117804	2.10
T_8	8988	1214	21076	30063	29.90	16.04	9.38	22.17	108195	221907	113712	2.05
T_9	8300	1084	18815	27116	30.65	15.60	9.25	21.77	106696	203631	96936	1.91
T_{10}	4389	204	9935	14323	30.55	13.61	5.31	21.40	101707	107641	5934	1.06
SEm ±	408	92	733	862	1.13	0.34	0.22	0.51	-	8376	8376	0.08
CD (P=0.05)	1169	265	2103	2471	NS	0.97	0.64	1.47	-	24024	24024	0.22
CV (%)	9.89	12.59	7.83	6.39	9.07	5.04	5.80	5.41	-	8.28	14.54	8.28

3.4 Effect on quality parameters of sweet corn

It was evident form the pooled data furnished in Table4 that application of 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 (T_2) significantly increased the total soluble solids in kernel (17.66 °Brix), which remained at par with T_3, T_1, T_4 and T_5. Further, significantly maximum crude protein content (10.76%) and crude fiber content (24.91%) of sweet corn were obtained with 40 kg N as basal + 40 kg N through urea at 25-30 DAS + 40 kg N through urea at 40-45 DAS (T_1), being statistically similar with T_2, T_3 and T_4.

Foliar applied nano urea increased nutritional quality of crop through bio-fortification [59].The crude protein content ultimately depends on the uptake of nitrogen by the crop [37].The protein content varied significantly with higher levels of N application along with foliar sprays of nano urea based on LCC, which could be due to increased N content in kernels. The higher dose of nitrogen fertilizer provided more availability of nutrients to crop which might have increased the crude protein content of sweet corn by enhancing the rate of reaction or synthesis process in the plant system. The better physiological and biochemical activity of sweet corn under adequate and balanced nutrient supply of N might have enhanced the crude protein and fiber content of sweet corn.The findings are in close conformity with the results reported by Mathukia et al.[60],Umesh et al.[61], Salama and Badry [62]and Sanjaykumar et al.[63].

3.5 Effect on economics of sweet corn production

The pooled data regarding the economics of sweet corn production presented in Table4 revealed that significantly maximum gross returns (₹ 315798/ha), net returns (₹ 209593/ha) and B: C ratio (2.97) were obtained with the application of 40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4, which remained at par with 40 kg N as basal + 30 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4 and 40 kg N as basal + 40 kg N through urea at 25-30 DAS + 40 kg N through urea at 40-45 DAS.The higher cost of cultivation (₹ 108898/ha) was incurred with 40 kg N as basal + 20 kg N through urea at 25-30 DAS + four foliar spray of nano urea 0.4% when LCC ≤ 4.

Nitrogen is commonly the most limiting nutrient factor for crop production in the majority of the world's agricultural areas and therefore adoption of good N management strategies often resulted in large economic benefits to farmers [64]. Excessive nitrogenous fertilization in years resulted in larger nitrogen and profit losses [65,66]. Nitrogen management using LCC assisted in the real-time and the right amount of N application and helped to increase productivity and profitability of crop. Higher monetary returns were realized due to use of nano urea under LCC based precision nitrogen management. The basal application of conventional and foliar application of nano urea supplied the required amount of nutrients adequately and resulted in production of higher yields which fetched higher returns. Greater net returns were fetched due to the effective use of foliar sprays of nano urea 0.4% when LCC ≤ 4, which resulted in higher green cob and fodder yields and as a result, higher net returns and B: C ratio. The results obtained in present study are in close agreement with those reported byYogendrakumaret al.[67],Thite et al.[40] and Arunkumar et al.[68].

4. CONCLUSION

On the basis of the results obtained from the present two years experimentation, it seems quite logical to conclude thathighergrowth, green cob and fodder yields, quality, net returns and B: C ratio of sweet corn can be secured bytheapplicationof40 kg N as basal + 40 kg N through urea at 25-30 DAS + two foliar spray of nano urea 0.4% when LCC ≤ 4 or 40 kg N as basal + 30 kg N through urea at 25-30 DAS + three foliar spray of nano urea 0.4% when LCC ≤ 4 or 40 kg N as basal + 40 kg N through urea at 25-30 DAS + 40 kg N through urea at 40-45 DAS. multiple recommendation may be avoided

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s)herebydeclarethatNOgenerativeAItechnologiessuchasLargeLanguageModels(ChatGPT,COPILOT,etc)andtext-to-imagegeneratorshavebeenusedduringwritingoreditingofmanuscripts.

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