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Nutrient Uptake of the Individual Crops in Maize and Groundnut Cropping System Grown under Different Irrigation Systems with Varied Irrigation and Nitrogen Levels

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted to assess the effects of irrigation systems, irrigation and N levels on nutrient uptake of *rabi* maize and summer groundnut during 2021-22 and 2022-23 at the College Farm, College of Agriculture, Rajendranagar, PJTAU, Hyderabad. The experiment composed of 18 treatment combinations (3 irrigation systems as main plot, 3 irrigation levels as sub-plot and 2 nitrogen levels as sub-sub-plot) in a split plot design replicated thrice. The study revealed that irrigation systems, irrigation and N levels and the interaction of irrigation systems and irrigation levels influenced the nutrient uptake of maize and groundnut crops during both the years of experimentation. Significantly higher NPK uptake was observed with sub-surface drip irrigation (M_2), irrigation level at 1.2 Epan;IW/CPE (S_1) and N level at 100 per cent RDN (N_1). The interaction of irrigation systems and irrigation levels (M x S) was significant while the interaction of N levels with irrigation systems (M x N) and irrigation levels (N x S) was not significant for both *rabi* maize and summer groundnut. The interaction of irrigation systems and irrigation levels revealed that in both maize and groundnut crops at earlier crop growth period the M_3S_1 (surface irrigation with 1.2 IW/CPE) resulted in significantly higher NPK uptake followed by M_2S_1 and M_2S_2 (sub-surface drip irrigation with 1.2 and 0.9 Epan). However at later crop growth stages due to prolonged fertigation schedules in micro irrigation systems, the higher NPK uptake was observed with M_2S_1 and M_2S_2 followed by surface drip irrigation system with 1.2 Epan (M_1S_1) and surface irrigation system with 1.2 IW/CPE (M_3S_1) while M_3S_3 resulted in lowest NPK uptake at all crop stages and in grains & stover/haulm during both the consecutive years (2021-22 and 2022-23).

Keywords: Maize; groundnut; irrigation systems; irrigation levels; N levels; nutrient uptake.

1. INTRODUCTION

Lack of freshwater resources and growing population makes it inevitable to use water more efficiently for agricultural production (Debaeke and Aboudrare, 2004) as agriculture is the largest consumer of water, using ~83% of water for irrigation (Rana et al., 2018). In India, water is one of the most limiting factors in farming and is tending to be scarcer and costlier (Hussainy and Arivokudi, 2019) pressurizing the agricultural sector to produce more food from less water, particularly in arid and semi-arid regions. The most plausible means of mitigating the scarcity of water is through increasing the productivity of existing water resources. In recent years the micro-irrigation is developing rapidly and is adopted for a variety of high-value crops in water scarcity regions. The use of drip irrigation systems can increase the crop yields significantly as compared to surface irrigation (Tiwari et al., 1998), more so in sandy loam soils of Telangana, India which comprise 45.6% of soil type in the state (Prasad Rao and Bhupal Raj, 2014) having very low water holding capacity. It has been reported that the loss of applied irrigation water from the reservoir to the field under unlined irrigation system is 71% in furrow and border irrigation systems (Navalawala, 1991) which results in enormous water loss further leading to abundant nutrient loss through deep percolation. Several research findings have revealed a significant reduction (30–70%) due to drip irrigation system with a simultaneous increase in productivity by 20–30% for different crops (Jayakumar et al. 2014; Singh et al. 2009; Thind et al. 2008).

Irrigation scheduling is also becoming an increasingly crucial decision-making task whose goal is to achieve effective and efficient use of water (Saggi and Jain, 2022) as quality and yield of crop is significantly reliant on the amount of water and timing. The objective of irrigation scheduling is to apply an adequate amount of water at the right time to a specific crop. Inefficient irrigation scheduling methods may result in over-irrigation or under-irrigation. So proper irrigation scheduling approaches may enhance crop returns while reducing environmental consequences by limiting crop water stress (Zhang et al., 2021).

On other hand, plants rarely full fill their maximum yield potential due to unsuitable environment, such as water shortage, climate change and nutrient deficiency (Hellal et al., 2019). The changes in nutrient content and uptake of plant is affected directly due to fertilizers amounts and is assumed to greater significance and sustainability of cropping system. The nitrogen fertilizers are important for plant growth and have supported the ever expanding global population by increasing crop production during the last few decades (Tilman et al., 2011), however its injudicious, unbalanced and continuous use in the intensive cropping systems is declining crop factor productivity with impairing nutrient productivity.

In Telangana, maize is cultivated during both *kharif* and *rabi* seasons in an area of 5.61 lakh ha with a production of 11.05 lakh ton and productivity of 5.34 ton ha^{-1}, whereas groundnut constitutes 2.6% of the total cropped area and 28.2% of the total oil seeds cropped area in the state with a total cultivated areas 1.11 lakh ha and production of 2.65 lakh ton (India stat, 2020). In Telangana the continuous mono cropping of cereals i.e. maize and rice has led to decline or stagnation of productivity due to emergence of multiple nutrient deficiencies and deterioration of soil physical properties as well as pest incidents (Kondabolu, 2014). The shifting from sequential cereal production system to cereal–legume cropping system could be of prime importance. Groundnut is regarded as an important crop to overcome protein energy malnutrition. It fits well in cereal-based cropping systems (Gowda et al., 2001) and is gaining popularity as post rainy or summer season crop in cereal–fallows in Telangana. The response of the succeeding crop in a cropping system is influenced greatly by the preceding crops and the inputs applied there (Makwana and Bhanvadia, 2023). Therefore, nowadays more emphasis is being laid on the cropping system as whole rather than on individual crop in a sequence (Prabvathi et al., 2024).

The productivity of cereals is declining due to continuous mono-cropping system and its dependence on excessive chemical fertilizers (Singh et al., 2020). So adding a legume crop especially groundnut crop can partially solve this problem with water saving and efficient nutrients utilization, as maize-groundnut is well suited in the semi-arid tracts (Heba et al., 2020). So with assured and accurate supply of irrigation water using micro irrigation systems higher nutrient use efficiency and uptake could be achieved and a viable, sustainable and profitable legume based cereal-pulse cropping system could be cultivated, thereby increasing the cropping intensity of the state, which is as low as 1.27 on sandy loam soils of Telangana. However, information on nutrient uptake for this intensive cropping system is limited. Particularly under different irrigation systems with varied irrigation and nitrogen levels. Therefore, the present experiment on nutrient uptake in groundnut-maize crop system with varied irrigation system, irrigation levels and nitrogen levels was conducted.

2. MATERIALS AND METHODS

A field experiment was conducted during *rabi* and summer seasons of 2021-22 and 2022-23 at College farm, College of Agriculture, Rajendranagar. The soil of experimental site was sandy clay loam in texture, moderately alkaline in reaction (pH 7.90), low in available nitrogen (213.58 kg ha^{-1}), moderately high in phosphorus (25.32 kg ha^{-1}) and medium in potassium content (180.54 kg ha^{-1}). The moisture content at field capacity and permanent wilting point were 18.44 and 7.88 per cent respectively. The bulk density was 1.41 Mg cm^{-3}. The experiment consisted of three irrigation systems as main plots *viz.,* M_1 - surface drip irrigation system, M_2 - sub-surface drip irrigation system, M_3 - surface irrigation system, three irrigation levels as sub-plot *viz.,* S_1-1.2 Epan; IW/CPE, S_2-0.9 Epan; IW/CPE, S_3-0.6 Epan; IW/CPE and two nitrogen levels as sub-sub-plot *viz.,* N_1-100% RDN, N_2- 75% RDN in split plot design replicated thrice. Maize and groundnut varieties KMNH-4010141 and Leepakshi constituted the experimental material. The gross and net plot sizes were 6.0 m x 4.8 m and 4.8 m x 3.6 m, respectively. A complete drip system consisted of a head control unit (including non-return valve, air release valve, vacuum breaker, disc filter, fertigation unit, throttle valve, pressure gauge and water meter), water carrier system including PVC main pipeline, PVC sub main pipeline, control valve, flush valve and water distribution system including 16 mm dripper line and end cap was installed by Netafim Irrigation Limited. The water distribution system consisted of a main line and eighteen sub-mains, each having control valve for water regulation. Irrigation water from manifolds flowed into 16 mm dripper lines laid out on the ground surface at 0.60 m apart with spacing of 0.40 m between two inline emitters delivering 2 L hr^{-1} in surface drip irrigation system while in sub surface irrigation system the dripper lines were laid out 15 cm below the soil surface with the same spacing and specification as in surface drip irrigation system.

Control valves were fixed separately to each treatmental plot to facilitate controlling the water flow as per the treatments in the experiment. Water meter was fixed at the head control unit to quantify the amount of water delivered in each irrigation treatment. Scheduling of irrigation in M_1 and M_2 were fixed on daily basis for maize and groundnut crops based on daily evaporation data recorded from (USWB open pan Evaporimeter) obtained from the Agro Climatic Research Center, Agricultural Research Station, Rajendranagar, Hyderabad. Application rate and irrigation time of the drip system was calculated by the following formulae-

$$\text{Application rate } (\text{mm hr}^{-1}) = \frac{Q}{D_L * D_E}$$

Where,

Q = dripper discharge (L hr^{-1})
D_L= Distance between laterals (m)
D_E = Distance between drippers (m)

$$\text{Irrigation time (minutes)} = \frac{\text{Panevaporation (mm)} \times \text{Treatment}}{\text{Application rate mm hr}^{-1}} \times 60$$

In surface irrigation system (M_3) the sub treatmental plots were leveled manually, ridge & furrow and flat-bed land configurations were maintained for maize and groundnut crops respectively during both years of experiment i.e. 2021-2022 and 2022-2023. In maize and groundnut crop the irrigation was scheduled based on climatological approach when CPE reached 50 and 60 mm depth respectively. The volume of water required to be applied was calculated by the following formula-

$$W = A \text{ x } D \text{ x } 1000$$

Where,

W = Quantity of water (L)
A = Plot area in m^2
D = Depth of irrigation water in meters

Table 1. Fertigation schedule for *rabi* maize

Crop growth stage	Nutrient dose (kg ha^{-1} day^{-1})	
	Urea	**SOP**
After sowing; 20 days (10 – 30 DAS)	3.22	1.48
Grand growth period; 25 days (31-55 DAS)	8.66	2.48
Reproductive stage; 20 days (56 – 75 DAS)	8.16	1.98
Kernel development stage; 25 days (76 – 90 DAS)	4.95	1.98

Recommended doses of N, P_2O_5 and K_2O followed was 240:80:80 and 30:40:50 kg ha^{-1} NPK for maize and groundnut respectively, which were applied in the form of urea, single super phosphate and sulphate of potassium for maize while urea, single super phosphate and muriate of potash for groundnut. In both surface and sub-surface drip irrigation systems (M_1 and M_2) a comprehensive fertigation schedule was adopted for maize crop which was already developed by PJTAU based on crop growth stages and their uptake patterns (Table 1) while in groundnut nitrogen was fertigated in the form of urea in four splits at one week interval after proper crop establishment. In surface method of irrigation (M_3) for maize crop, 1/3rd N, full dose of P_2O_5 and K_2O were applied as basal while remaining 2/3rd N was applied in two splits; 1/3rd N at knee height stage and remaining 1/3rd at tasseling depending on irrigation levels in both years whereas in groundnut crop under surface method of irrigation, 2/3rd N, full dose of P_2O_5 and K_2O were applied as basal dose while remaining 1/3rd N was applied at 30 DAS.

3. RESULTS AND DISCUSSION

3.1 Effects of Irrigation Systems, Irrigation and Nitrogen Levels on NPK Uptake in *rabi* Maize and Summer Groundnut

3.1.1 Effects of irrigation systems

The effects of irrigation systems on NPK uptake showed that irrigation systems had significant impacts on NPK uptake of both *rabi* maize and summer groundnut (Table 2, 3, 4 & 5). In maize crop, the NPK uptake was non- significant at crop earlier growth stages (at 30 and 60 DAS) which may be due to the split application of N doses in M_3 upto tasselling, however at 90 DAS and in grains & stover due to prolong fertigation schedules, significantly higher NPK uptake was observed with sub-surface drip irrigation system (M_2), statistically at par with surface drip irrigation system (M_1) at 90 DAS and in stover while significantly superior to both M_1 and M_3 for maize grain. In groundnut, at 60 and 90 DAS and in haulm, the NK uptake was higher in sub-surface drip irrigation system (M_2) while higher P uptake was observed in surface drip irrigation system (M_1). However in grains significantly higher NPK uptake was observed with sub surface irrigation system (M_2). In both crops the surface irrigation system (M_3) registered lowest NPK uptake at 90 DAS, in stover/haulm and in grains during both the years (2021-22 & 2022-23) (Table 2 and 3). The higher NPK uptake in micro irrigation system could be attributes to higher irrigation frequencies in drip irrigation systems (M_1 and M_2) which resulted in improved growth characters tending plants to take more nutrients from the soil since it is available nearer to root zone with optimum moisture level. These results were in conformity with the findings of Black (1965), who observed increased nutrient uptake under high frequency drip irrigation due to increased plant growth. On the other hand, the stimulatory effects of N on P and K could also have enhanced the PK uptake as nitrogen is capable of increasing root cation exchange capacity which in turn helps the plant to absorb more P and K from the soil as (Janzen and Bettany, 1984. Many researchers (Mahdi et al., 2003; Kar et al., 2006; Hassan et al., 2010; Kumar and Pandian, 2010 and Sharan, 2012) have also further concluded that irrigation coupled with nitrogen fertigation resulted in better nutrient uptake, nutrient use efficiency and nutrient content over broadcast and side dressing of fertilizers leading to higher translocation of N to grain. Further, application of nutrients in more number of splits in drip fertigation resulted in minimum or no depletion of nutrients either through deep leaching or evaporation and led to higher uptake of nutrients. Whereas, in surface irrigated plots, band placement of fertilizers in soil with minimum number of splits (one basal and two top dressings) led to higher availability of nutrients during upto 60 days, which in turn resulted in higher growth parameters during initial stage of the crop, however at reproductive stage the applied nutrients might have been depleted resulting in low N availability to the crop and which resulted lesser NPK uptake in grains and stover. Similar results were also reported by Hussaini et al. (2008), Ponnaswamy and Santhi (2008), Amanullah et al. (2009), Oktem et al. (2010), Fanish and Muthukrishnan (2011), Hussain et al. (2016) and Bibe et al. (2017).

3.1.2 Effects of irrigation levels

The NPK uptake in *rabi* maize and summer groundnut was influenced significantly during all growth stages and in grains & stover/haulm with increased irrigation levels upto 1.2 Epan; IW/CPE (S_1) (Table 2, 3, 4 & 5). Significantly higher NPK uptake was observed with S_1 (1.2 Epan; IW/CPE) over both S_2 (0.9 Epan; IW/CPE) and S_3 (0.6 Epan; IW/CPE) at all growth stages, in grains and stover/haulm during both the years (2021-22 and 2022-23. The S_3 resulted in lesser uptake of NPK throughout the growth period during both consecutive years i.e. 2021-22 and 2022-23. The increased NPK uptake with increased irrigation levels might be due to maintenance of relatively high moisture content and high frequency irrigation which lead to greater N mobility and availability to plants (Bacon and Davey, 1982) accompanied with the synergetic and stimulatory effect of N on P and K uptake (Janzen and Bettany, 1984). Similarly, the increased N uptake could also be due to optimum availability of soil moisture accompanied with prolonged fertigation schedules which helped in solubilizing the plant nutrients due to hydrolysis of urea which could have made nutrients easily available to the plant roots and this phenomenon coupled with higher dry matter accumulation attributed to higher NPK uptake (Hussaini et al., 2008). Moreover, the higher uptake of P and K might also be due to sound root-soil relations due to optimum soil moisture content, which allowed rapid diffusion of ions by reducing the path length of ion movement on one hand and increase in the elongation, turbidity and number of root hairs which ultimately enhanced their uptake. Furthermore the availability of adequate soil moisture due to higher irrigation levels enhanced mineralization of P from native and applied sources of P, thereby more acquisition through dry matter and availability of other nutrients through dissolution and transport. These results are also in accordance with Oktem et al. (2010), Bozkurt et al. (2011), Sharan (2012), Dutta et al. (2015) and Bibe et al. (2017).

3.1.3 Effects of nitrogen levels

Levels of N significantly influenced the NPK uptake in *rabi* maize and summer groundnut at all crop growth stages (Table 2, 3, 4 & 5). The N_1 (100 per cent RDN) treatment recorded more uptake of NPK during the entire growth period at 30, 60, 90 DAS and in grains & stover/haulm during both the years, 2021-22 and 2022-23 respectively, which remained statistically higher to N_2 (75 per cent RDN). Nitrogen is an important constituent of protein and is required in higher amounts. Maize plant takes most of its nitrogen between sowing and flowering; and then it will be remobilized into sink from all parts of the plant (Sayre, 1948). However, when nitrogen is deficient during this period plant will continue to take nitrogen from soil even during post flowering period also. In the present experiment the higher nitrogen uptake in grain when fertigated during post flowering periods (upto 90 DAS) validated this reason. Similar observation was also reported by Aziiba et al. (2019) who stated that “maize hybrids with delayed senescence have a greater ability to take up N during the grain-filling period since continued leaf activity stimulates uptake of N. During the grain-filling period, a decline in N supply decreases dry matter partitioning to grain. Higher nutrient uptake at application of optimum dose (100 per cent RDN) was because of high nutrient content and dry matter yield under these treatments. Similarly, Janzen and Bettany, (1984) revealed the synergetic and stimulatory effect of N on P and K uptake in order to maintain anionic balance. In general, maize accumulates phosphorus throughout the growing season until maturity. At maturity, 75 per cent of the total phosphorus of the above ground parts translocate to grain (Sayre, 1948). Results clearly indicated that higher the quantity of applied nitrogen more is the effective utilization of soil and applied phosphorus. Similar results were also reported Ponnaswamy and Santhi (2008), Amanullah et al. (2009), Oktem et al. (2010), Fanish and Muthukrishnan (2011).

3.2 Interaction

The interaction of irrigation systems and irrigation levels (M x S) was significant during all growth stages while the interaction of irrigation system and N levels (M x N), irrigation levels and N levels (M x S) and the interaction of irrigation systems, irrigation levels and N levels (M x S x N) was not significant at all growth stages for both *rabi* maize and summer groundnut during both the years, 2021-22 and 2022-23.

3.2.1 Interaction between irrigation system and irrigation levels (M x S)

The interaction effect of irrigation systems and irrigation levels revealed that in both maize and groundnut crops at earlier crop growth stages the M_3S_1 recorded significantly higher NPK uptake followed by M_2S_1 and M_2S_2 during both the years. However at crop later growth stages, due to prolonged fertigation schedules, the higher NPK uptake was observed with M_2S_1 and M_2S_2 followed by M_1S_1 and M_3S_1. Among all treatments M_3S_3 resulted in lowest NPK uptake at all crop stages and in grains & stover/haulm during both the consecutive years (2021-22 and 2022-23) (Table 6). Higher grain yield related to higher photosynthetic efficiency of crop was attributed to higher nutrient uptake and assimilation in source and translocation to the sink. Higher NPK uptake through optimum moisture status through M_2 contributed to higher dry matter production and yield in distinguished irrigation systems and irrigation levels (M_2S_1, M_2S_2 and M_1S_1). The higher NPK uptake observed under M_2 might be due to higher soil moisture content which might have facilitated to bring the nutrients to soil solution in drip irrigation systems than M_3. The increase in nutrient uptake was due to better availability of nutrients and water in root zone as a result of frequent fertigation which in turn resulted in better uptake by crop and might have reduced leaching of nutrients in drip fertigation as compared to soil application of fertilizer with M_3. Decrease in total NPK uptake observed under surface irrigation with soil application of fertilizers was due to reduced moisture level which might have reduced nitrate reductase activity, nitrification and P diffusion through the soil to root surface (Bozkurt et al., 2011).

Table 2. Effects of different irrigation systems, irrigation levels and N levels on NPK uptake (kg ha^{-1}) in *rabi* maize during 2021-22

	30 DAS			60 DAS			90 DAS			Grain			stover		
Treatment	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Main plots (M - Irrigation systems)															
M_1 (Surface drip irrigation)	3.40	1.18	1.90	15.5	5.25	7.55	33.9	11.0	17.0	85.2	19.8	39.6	63.4	11.2	15.7
M_2 (Sub Surface drip irrigation)	3.33	1.15	1.86	16.1	5.45	7.84	34.0	10.7	17.0	91.0	21.2	42.3	66.7	11.8	17.2
M_3 (Surface irrigation)	3.63	1.26	2.02	15.9	5.38	7.74	30.2	9.7	15.0	71.6	17.0	33.6	54.5	9.6	13.7
S. Em±	0.065	0.022	0.036	0.426	0.144	0.208	0.331	0.108	0.201	0.441	0.102	0.205	0.92	0.16	0.24
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	1.30	0.42	0.79	1.73	0.40	0.80	3.60	0.64	0.94
Subplots (S - Irrigation levels)															
S_1 (1.2 Epan; IW/CPE)	3.71	1.28	2.07	16.8	5.69	8.19	35.8	11.5	17.9	87.9	20.4	40.9	67.6	11.9	16.5
S_2 (0.9 Epan; IW/CPE)	3.40	1.18	1.90	16.0	5.43	7.82	33.1	10.5	16.5	84.6	19.7	39.2	64.6	11.4	16.1
S_3 (0.6 Epan; IW/CPE)	3.25	1.13	1.81	14.6	4.95	7.13	29.2	9.4	14.6	75.2	17.8	35.5	52.5	9.3	13.9
S. Em±	0.048	0.017	0.027	0.179	0.061	0.087	0.321	0.104	0.179	1.09	0.25	0.49	0.515	0.091	0.121
C.D. (P=0.05)	0.149	0.051	0.083	0.550	0.187	0.269	0.990	0.321	0.551	3.37	0.78	1.51	1.59	0.28	0.37
Sub-subplots (N - Nitrogen levels)															
N_1 (100 per cent RDN)	3.64	1.26	2.03	16.8	5.71	8.22	34.3	11.0	17.1	86.8	20.3	40.4	64.6	11.4	16.1
N_2 (75 per cent RDN)	3.27	1.13	1.82	14.8	5.00	7.20	31.1	9.9	15.5	78.3	18.3	36.6	58.5	10.3	14.9
S. Em±	0.047	0.016	0.026	0.211	0.072	0.103	0.336	0.122	0.194	0.997	0.233	0.462	0.588	0.104	0.160
C.D. (P=0.05)	0.141	0.049	0.079	0.627	0.213	0.306	0.999	0.364	0.578	2.96	0.692	1.37	1.75	0.309	0.475
Interaction effect : M x S	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**
: M x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: M x S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effects of different irrigation systems, irrigation levels and N levels on NPK uptake (kg ha^{-1}) in *rabi* maize during 2022-23

Treatment	30 DAS			60 DAS			90 DAS			Grain			stover		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Main plots (M - Irrigation systems)															
M_1 (Surface drip irrigation)	4.09	1.16	2.07	19.0	6.08	8.98	38.4	11.9	18.7	87.4	21.9	42.4	67.7	12.2	16.1
M_2 (Sub Surface drip irrigation)	4.09	1.20	2.02	19.8	6.26	9.30	38.7	12.1	18.8	93.2	23.9	45.3	71.5	13.3	17.0
M_3 (Surface irrigation)	4.39	1.15	2.21	19.5	5.86	8.75	34.2	10.1	16.7	67.9	18.5	36.0	58.0	10.4	13.8
S. Em±	0.078	0.011	0.039	0.524	0.186	0.242	0.344	0.143	0.152	0.471	0.267	0.219	1.31	0.19	0.31
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	1.35	0.56	0.60	1.85	1.05	0.86	5.14	0.73	1.22
Subplots (S - Irrigation levels)															
S_1 (1.2 Epan; IW/CPE)	4.46	1.20	2.25	20.7	6.32	9.42	39.9	12.4	19.8	90.1	22.4	43.7	71.7	12.9	17.0
S_2 (0.9 Epan; IW/CPE)	4.13	1.16	2.07	19.7	6.16	9.28	38.0	11.7	18.2	86.5	22.0	41.9	68.3	12.5	16.2
S_3 (0.6 Epan; IW/CPE)	3.97	1.15	1.98	18.0	5.72	8.32	33.4	9.9	16.2	71.9	19.9	38.0	57.1	10.4	13.6
S. Em±	0.053	0.023	0.029	0.220	0.106	0.138	0.411	0.123	0.132	1.05	0.196	0.52	0.551	0.105	0.131
C.D. (P=0.05)	0.163	NS	0.090	0.677	0.327	0.425	1.27	0.38	0.41	3.24	0.602	1.62	1.70	0.322	0.404
Sub-subplots (N - Nitrogen levels)															
N_1 (100 per cent RDN)	4.43	1.22	2.21	20.7	6.40	9.33	39.1	11.9	18.9	86.9	22.7	43.2	69.6	12.5	16.5
N_2 (75 per cent RDN)	3.95	1.12	1.99	18.1	5.73	8.68	35.0	10.8	17.2	78.8	20.2	39.2	61.9	11.4	14.7
S. Em±	0.057	0.023	0.029	0.260	0.072	0.095	0.446	0.119	0.203	0.992	0.245	0.495	0.647	0.097	0.154
C.D. (P=0.05)	0.169	0.067	0.086	0.772	0.215	0.281	1.33	0.354	0.603	2.95	0.729	1.47	1.92	0.287	0.457
Interaction effect : M x S	**S**	**NS**	**S**	**S**	**NS**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**
: M x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: M x S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4. Effects of different irrigation systems, irrigation levels and N levels on NPK uptake (kg ha^{-1}) in summer groundnut during 2022

Treatment	30 DAS			60 DAS			90 DAS			Grain			stover		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Main plots (M - Irrigation systems)															
M_1 (Surface drip irrigation)	1.03	0.97	0.95	9.01	5.77	3.29	22.42	9.21	4.77	63.47	17.53	12.88	33.15	10.27	7.39
M_2 (Sub Surface drip irrigation)	1.03	0.95	0.97	9.34	5.98	3.40	22.53	9.00	5.11	67.79	18.72	13.89	33.90	10.82	7.95
M_3 (Surface irrigation)	1.10	1.04	0.96	8.86	5.91	3.23	19.88	8.15	4.16	53.32	15.01	10.80	31.18	8.84	6.28
S. Em±	0.026	0.018	0.013	0.168	0.159	0.054	0.225	0.090	0.098	0.329	0.090	0.137	0.205	0.149	0.153
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	0.882	0.355	0.385	1.29	0.35	0.54	0.805	0.584	0.600
Subplots (S - Irrigation levels)															
S_1 (1.2 Epan; IW/CPE)	1.14	1.06	1.01	9.64	6.25	3.47	23.52	9.68	5.03	65.50	18.09	13.31	34.10	10.96	7.77
S_2 (0.9 Epan; IW/CPE)	1.02	0.97	0.96	9.07	5.97	3.34	21.90	8.82	4.68	63.06	17.41	12.72	33.42	10.47	7.52
S_3 (0.6 Epan; IW/CPE)	0.99	0.93	0.92	8.51	5.44	3.11	19.42	7.86	4.34	56.0	15.8	11.6	30.7	8.5	6.3
S. Em±	0.013	0.014	0.022	0.107	0.067	0.044	0.190	0.088	0.095	0.814	0.225	0.123	0.115	0.083	0.085
C.D. (P=0.05)	0.039	0.042	0.067	0.329	0.205	0.136	0.585	0.270	0.292	2.51	0.69	0.38	0.354	0.257	0.262
Sub-subplots (N - Nitrogen levels)															
N_1 (100 per cent RDN)	1.11	1.04	1.00	9.53	6.28	3.49	22.54	9.22	4.90	64.69	17.96	13.10	33.43	10.47	7.55
N_2 (75 per cent RDN)	1.00	0.93	0.93	8.61	5.50	3.13	20.69	8.35	4.46	58.36	16.21	11.96	32.06	9.48	6.87
S. Em±	0.016	0.014	0.013	0.133	0.079	0.050	0.24	0.10	0.05	0.743	0.206	0.152	0.131	0.095	0.063
C.D. (P=0.05)	0.047	0.040	0.040	0.395	0.234	0.150	0.71	0.31	0.16	2.21	0.61	0.45	0.390	0.283	0.188
Interaction effect : M x S	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
: M x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: M x S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5. Effects of different irrigation systems, irrigation levels and N levels on NPK uptake (kg ha^{-1}) in summer groundnut during 2023

Treatment	30 DAS			60 DAS			90 DAS			Grain			stover		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Main plots (M - Irrigation systems)															
M_1 (Surface drip irrigation)	1.09	0.89	0.94	7.44	5.42	3.07	20.92	8.70	4.45	58.07	16.38	11.52	33.28	11.26	6.72
M_2 (Sub Surface drip irrigation)	1.18	0.91	0.94	7.96	5.88	3.25	20.95	8.67	4.42	61.87	17.39	12.49	33.30	12.12	7.01
M_3 (Surface irrigation)	1.16	0.94	0.96	7.36	5.26	3.02	18.41	7.59	3.95	48.18	13.24	9.79	31.48	9.52	5.54
S. Em±	0.027	0.013	0.016	0.094	0.122	0.095	0.140	0.037	0.029	0.641	0.099	0.119	0.055	0.178	0.099
C.D. (P=0.05)	NS	NS	NS	0.37	0.48	NS	0.550	0.147	0.114	2.52	0.39	0.47	0.215	0.700	0.388
Subplots (S - Irrigation levels)															
S_1 (1.2 Epan; IW/CPE)	1.22	0.96	1.02	7.85	5.73	3.26	21.63	9.10	4.65	59.60	16.64	11.94	33.65	11.93	6.97
S_2 (0.9 Epan; IW/CPE)	1.10	0.90	0.94	7.59	5.62	3.14	20.19	8.39	4.33	58.13	16.24	11.52	33.18	11.56	6.78
S_3 (0.6 Epan; IW/CPE)	1.11	0.87	0.88	7.33	5.20	2.93	18.46	7.47	3.84	50.4	14.1	10.3	31.2	9.4	5.5
S. Em±	0.017	0.014	0.024	0.126	0.074	0.043	0.216	0.071	0.047	0.627	0.218	0.159	0.113	0.094	0.118
C.D. (P=0.05)	0.052	0.043	0.073	0.388	0.228	0.131	0.665	0.220	0.144	1.933	0.671	0.489	0.347	0.291	0.362
Sub-subplots (N - Nitrogen levels)															
N_1 (100 per cent RDN)	1.20	0.95	0.98	7.83	5.82	3.27	20.77	8.67	4.48	58.08	16.37	11.70	33.21	11.39	6.66
N_2 (75 per cent RDN)	1.09	0.88	0.91	7.34	5.21	2.96	19.42	7.98	4.06	54.00	14.97	10.83	32.16	10.55	6.18
S. Em±	0.019	0.011	0.015	0.09	0.08	0.04	0.16	0.09	0.05	0.489	0.170	0.124	0.105	0.075	0.055
C.D. (P=0.05)	0.056	0.034	0.045	0.26	0.25	0.11	0.48	0.28	0.14	1.452	0.506	0.368	0.313	0.223	0.164
Interaction effect : M x S	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
: M x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
: M x S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 6. Interaction effects of irrigation system (M) and irrigation level (S) on NPK uptake (kg ha^{-1}) in *rabi* maize (2021-22 and 2022-23)

Treatment	30 DAS			60 DAS			90 DAS			In Grain			In Stover		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
2021-22															
M_1S_1	3.54	1.22	1.97	15.92	5.40	7.77	36.0	11.67	18.09	87.8	20.41	40.8	66.5	11.75	16.64
M_1S_2	3.28	1.13	1.83	15.28	5.18	7.46	33.4	10.71	16.60	85.5	19.88	39.8	64.1	11.33	15.80
M_1S_3	3.39	1.17	1.89	15.23	5.16	7.44	32.4	10.49	16.25	82.3	19.13	38.3	59.5	10.50	14.75
M_2S_1	3.70	1.28	2.07	17.00	5.76	8.30	37.2	11.92	18.69	93.5	21.74	43.5	70.8	12.50	17.20
M_2S_2	3.33	1.15	1.86	16.63	5.64	8.12	34.6	10.73	17.20	95.4	22.18	44.4	69.4	12.27	17.61
M_2S_3	2.95	1.02	1.64	14.57	4.94	7.11	30.1	9.49	15.13	84.1	19.54	39.1	60.0	10.60	16.74
M_3S_1	3.88	1.34	2.16	17.45	5.92	8.52	34.2	10.96	16.98	82.5	19.17	38.3	65.6	11.59	15.80
M_3S_2	3.59	1.24	2.00	16.13	5.47	7.87	31.3	10.05	15.56	73.0	16.97	33.4	60.1	10.62	14.88
M_3S_3	3.42	1.18	1.91	14.00	4.75	6.83	25.2	8.08	12.52	59.2	14.74	29.1	37.9	6.69	10.29
Irrigation levels means at the same or different levels of irrigation systems															
S. Em±	0.082	0.028	0.046	0.393	0.133	0.192	0.51	0.166	0.290	1.58	0.367	0.71	0.98	0.172	0.241
C.D. (P = 0.05)	0.286	0.099	0.159	1.456	0.494	0.711	1.72	0.560	0.989	4.96	1.15	2.23	3.51	0.620	0.88
Irrigation systems means at the same or different levels of irrigation levels															
S. Em±	0.084	0.029	0.047	0.309	0.105	0.151	0.56	0.181	0.309	1.89	0.440	0.85	0.89	0.157	0.210
C.D. (P = 0.05)	0.257	0.089	0.144	0.953	0.323	0.465	1.72	0.556	0.954	5.83	1.36	2.62	2.75	0.485	0.65
2022-23															
M_1S_1	4.21	1.19	2.15	19.6	6.14	8.78	40.4	12.60	19.9	90.0	22.7	43.7	72.1	12.5	17.1
M_1S_2	3.97	1.14	1.99	18.8	6.08	9.11	37.8	11.56	18.4	87.7	22.1	42.5	67.0	12.5	15.9
M_1S_3	4.10	1.15	2.06	18.7	6.00	9.04	37.0	11.40	17.9	84.5	21.1	40.9	64.0	11.5	15.2
M_2S_1	4.48	1.24	2.25	20.9	6.56	9.85	40.7	12.92	20.7	95.7	23.7	46.5	74.6	13.7	17.7
M_2S_2	4.10	1.18	2.03	20.5	6.33	9.83	40.7	12.64	18.8	97.6	25.4	47.5	73.5	13.7	17.4
M_2S_3	3.68	1.17	1.79	17.9	5.89	8.20	34.8	10.66	16.8	86.3	22.6	41.8	66.4	12.5	15.8
M_3S_1	4.69	1.16	2.36	21.5	6.25	9.62	38.6	11.80	18.8	84.7	20.9	41.0	68.5	12.5	16.3
M_3S_2	4.34	1.17	2.18	19.8	6.07	8.90	35.4	10.94	17.3	74.1	18.5	35.7	64.5	11.5	15.3
M_3S_3	4.14	1.12	2.08	17.2	5.27	7.72	28.5	7.52	13.9	44.9	16.1	31.1	41.0	7.2	9.7
Irrigation levels means at the same or different levels of irrigation systems															
S. Em±	0.093	0.033	0.050	0.483	0.199	0.259	0.63	0.201	0.215	1.52	0.335	0.76	1.21	0.198	0.288
C.D. (P = 0.05)	0.328	NS	0.174	1.791	NS	0.932	2.08	0.687	0.735	4.82	1.17	2.39	4.49	0.711	1.07
Irrigation systems means at the same or different levels of irrigation levels															
S. Em±	0.092	0.039	0.051	0.381	0.184	0.239	0.712	0.212	0.228	1.82	0.339	0.909	0.955	0.181	0.227
C.D. (P = 0.05)	0.283	NS	0.156	1.173	NS	0.737	2.19	0.654	0.704	5.61	1.04	2.80	2.94	0.558	0.70

4. CONCLUSION

Based on the forgoing findings of the investigation, it could be concluded that among irrigation systems, irrigation levels and N levels the sub-surface drip irrigation (M_2), irrigation level at 1.2 Epan;IW/CPE (S_1) and increased N level (100 per cent RDN-N_1) leads to significantly higher NPK uptake in both maize and groundnut crops. It could be further inferred that among irrigation systems and nitrogen levels the increased levels of irrigation (1.2 and 0.9 Epan;IW/CPE) could enhance the NPK uptake amidst micro irrigation systems (subsurface and surface drip irrigation systems) while decreased irrigation levels couldn't exhibit significant impact on NPK uptake specifically with surface irrigation method.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Amanullah, Khattak, R. A., & Khalil, S. K. (2009). Plant density and nitrogen effects on maize phenology and grain yield. *Journal of Plant Nutrition, 32*(2), 246-260.

Aziiba, E. A., Qiang, C., & Coulter, J. A. (2019). Mechanisms of nitrogen use in maize. *Agronomy, 9*(775), 1-16.

Bacon, P. E., & Davey, B. G. (1982). Nutrient availability under trickle irrigation. II. Mineral nitrogen. *Soil Science Society of America Journal, 46*, 987-993.

Bibe, S. M., Jadhav, K. T., & Chavan, A. S. (2017). Response of irrigation and fertigation management on growth and yield of maize. *International Journal of Current Microbiology and Applied Sciences, 6*(11), 4054-4060.

Black, C. A. (1965). *Methods of Soil Analysis: Part I. Physical and mineralogical properties*. American Society of Agronomy.

Bozkurt, S., Yazar, A., & Mansuroglu, G. S. (2011). Effects of different drip irrigation levels on yield and some agronomic characteristics of raised bed planted corn. *African Journal of Agricultural Research, 6*(23), 5291-5300.

Debaeke, P., & Aboudrare, A. (2004). Adaptation of crop management to water-limited environment. *European Journal of Agronomy, 21*, 433–446.

Dutta, D., Mudi, D. D., & Thentu, T. L. (2015). Effect of irrigation levels and planting geometry on growth, cob yield and water use efficiency of baby corn (Zea mays L.). *Journal of Crop and Weed, 11*(2), 105-110.

Fanish, S. A., & Muthukrishnan, P. (2011). Effect of drip fertigation and intercropping on growth, yield and water use efficiency of maize (Zea mays L.). *Madras Agricultural Journal, 98*(7/9), 238-242.

Gowda, C. L. L., Ramakrishna, A., Rupela, O. P., & Wani, S. P. (Eds.). (2001). *Legumes in rice-based cropping systems in tropical Asia: Constraints and opportunities*. International Crops Research Institute for the Semi-arid Tropics.

Hassan, S. W., Oad, F. C., Tunio, S. D., Gandahi, A. W., Siddiqui, M. H., Oad, S. M., et al. (2010). Impact of nitrogen levels and application methods on agronomic, physiological and nutrient uptake traits of maize fodder. *Pakistan Journal of Botany, 42*(6), 4095-4101.

Heba, M. N., Rana, D. S., Choudhary, A. K., Rajanna, G. A., & Pande, P. (2021). Influence of sulphur and zinc nutrition on productivity, quality and biofortification in groundnut (Arachis hypogea L.) in south-Asian alluvial soil. *Journal of Plant Nutrition, 44*(8), 1151-1174.

Hellal, F., Abdel-Hady, M., Khatab, I., El-Sayed, S., & Abdelly, C. (2019). Yield characterization of Mediterranean barley under drought stress condition. *AIMS Agriculture & Food, 4*(3), 518-533.

Hussain, B., Khadim, D., Khan, I., & Abbas, A. (2016). Effect of various levels of NK fertilizers on maize under different moisture conditions. *International Journal of Agronomy and Agricultural Research, 8*(4), 54-66.

Hussaini, M. A., Ogunlela, V. B., Ramalam, A. A., & Falaki, A. M. (2008). Mineral composition of dry season maize (*Zea mays* L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. *World Journal of Agricultural Sciences, 4*(6), 775-780.

Hussainy, S. A. H., & Arivukodi, S. (2019). Effect of irrigation regimes on the growth, yield and water use efficiency under groundnut-based intercropping system: A review. *International Journal of Conservation Science, 7*(6), 691-698.

IndiaStat. (2020). State and season wise area, production and productivity of Maize, Groundnut and Greengram (2020). Retrieved 8-5-2021, from https://www.indiastatagri.com/data/agriculture/agricultural-production

Janzen, H. H., & Bettany, J. R. (1984). Influence of fertilizer nitrogen and sulphur rate on sulphur nutrition of rapeseed. *American Society of Soil Science Journal, 48*, 100-105.

Jayakumar, M., Surendran, U., & Manickasundaram, P. (2014). Drip fertigation effects on yield, nutrient uptake and soil fertility of Bt cotton in semi-arid tropics. *International Journal of Plant Production, 8*(3), 375-390.

Kar, G., Verma, H. N., & Singh, R. (2006). Effects of winter crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice-based cropping system of eastern India. *Agricultural Water Management, 79*(3), 280-292.

Kondabolu, S. (2014). A case study of changing cropping diversity and agricultural risk in the Doulthabad Mandal of Telangana State in India.

Kumar, S. T., & Pandian, B. J. (2010). Effect of fertigation frequencies and levels on growth and yield of maize. *Madras Agricultural Journal, 97*(7-9), 245-248.

Mahdi, M., Al-Kaisi, M., & Yin, H. (2003). Effect of nitrogen rate, irrigation rate and plant populations on corn yield and water use efficiency. *Agronomy Journal, 95*, 1475-1482.

Makwana, N. D., & Bhanvadia, A. S. (2023). Residual effect of integrated nutrient management to preceding maize on yield of succeeding groundnut under maize-groundnut cropping sequence. *International Journal of Plant and Soil Science, 35*(21), 022-1029.

Navalawala, B. N. (1991). Waterlogging and its related issues in India. *Irrigation and Power Journal, 48*(1), 55–64.

Oktem, A., & Emeklier, H. Y. (2010). Effect of nitrogen on yield and some quality parameters of sweet corn. *Communications in Soil Science and Plant Analysis, 41*(7), 832-847.

Ponnuswamy, K., & Santhi, P. (2008). Drip fertigation for enhancing productivity in maize (Zea mays L.). *Green Farming, 2*(3), 148-149.

Prabvathi, N., Naga, M. K. V., Ratna, P. P., Reddy, M. R., & Niranjan, B. N. (2024). Combined effect of organic waste and inorganic fertilizers in the environment on major nutrient content and uptake in maize-groundnut cropping sequence. *Journal of Experimental Agriculture International, 46*(4), 95-104.

Prasad Rao, A., & Bhupal Raj, G. (2014). *Soil based technologies to optimise land productivity in Telangana and Andhra Pradesh*. ANGRAU and PJTSAU, Hyderabad.

Rana, K. S., Choudhary, A. K., & Bana, R. S. (2018). *Climate resilient agro-technologies for enhanced crop and water productivity under water-deficit agro-ecologies*. ICAR-IARI, New Delhi Publication. pp. 206.

Saggi, M. K., & Jain, S. (2022). A survey towards decision support system on smart irrigation scheduling using machine learning approaches. *Archives of Computational Methods in Engineering, 29*(6), 4455-4478.

Sayre, J. D. (1948). Mineral nutrition in corn. *Plant Physiology, 23*(3), 267-281.

Sharan, B. (2012). *Performance of sweet corn hybrid under different levels of irrigation and nitrogen applied through drip system* (M.Sc. Ag. thesis). Acharya N. G. Ranga Agricultural University, Hyderabad, India.

Singh, R., Kumar, S., Nangare, D. D., & Meena, M. S. (2009). Drip irrigation and black polyethylene mulch influence on growth, yield and water-use efficiency of tomato. *African Journal of Agricultural Research, 4*(12), 1427-1430.

Singh, U., Choudhary, A. K., & Sharma, S. (2020). Comparative performance of conservation agriculture vis-a-vis organic and conventional farming in enhancing plant attributes and rhizospheric bacterial diversity in Cajanus cajan: A field study. *European Journal of Soil Biology, 99*, 103197.

Thind, H. S., Aujla, M. S., & Buttar, G. S. (2008). Response of cotton to various levels of nitrogen and water applied to normal and paired sown cotton under drip irrigation in relation to check-basin. *Agricultural Water Management, 95*(1), 25-34.

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences, 108*(50), 20260-20264.

Tiwari, K. N., Mal, P. K., Singh, R. L., & Chattopadhyay, A. (1998). Response of okra to drip irrigation under mulch and non-mulched conditions. *Agricultural Water Management, 38*, 91–102.

Zhang, J., Guan, K., Peng, B., Jiang, C., Zhou, W., Yang, Y., et al. (2021). Challenges and opportunities in precision irrigation decision-support systems for center pivots. *Environmental Research Letters, 16*(5), 053003.

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