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Yield, Water Productivity and Economics of *Rabi* Maize as Influenced by Different Nitrogen Fertigation Levels

K. Vineela[1], K. Chandrasekhar[2], S. Pratibha Sree[3], M. Raghavendra[4]

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ABSTRACT

Background: Food security is a growing global concern as increasing population and consumption drive higher food and water demand. Efficient use of water and fertilizers is crucial to ensure sustainable food production, given the low fertilizer use efficiency worldwide. Drip irrigation emerges as a highly effective method for addressing these challenges, as it enhances crop yields while using less water and reducing tillage costs. Additionally, this practice minimizes fertilizer application and significantly improves fertilizer use efficiency, supporting both productivity and sustainability.

Methods: A field trial was conducted on clay soils of Advanced Post Graduate Centre, Lam, Guntur to study the effect of different nitrogen fertigation levels at different stages of maize on yield, total water use, water saving and water saving impact and water productivity of maize during *rabi* 2019-20. The experiment was laid out in RBD with twelve treatments and replicated thrice. The test hybrid used in the present experiment was Pioneer 3396.

Result: The results revealed that kernel and stover yield were significantly superior with the application of 100 % RDN through fertigation. The highest water use was observed in the treatment that received 100 % RDN through soil application under surface irrigation. Water saving impact *i.e.,* the amount of yield loss per unit of water saved was more under the treatment that received 50% fertigation up to 75 DAS and it was followed by the treatment that received 50% fertigation up to 60 DAS. The water productivity recorded under the treatment fertigated with 100% RDN up to 90 DAS was significantly the highest when compared with that of surface irrigation and other treatments.

Key words: Drip irrigation, Fertigation, Maize, Water productivity, Water saving impact.

INTRODUCTION

Cereals are the major source of dietary energy supply accounting to 44.8 percent of total energy, out of which maize constitute at least 15.56 per cent of total energy for developing countries (FAO, 2019) signifying the prominence of maize as a food source for many countries. Maize is thus a preeminent staple food crop in the context of global nutrition. Maize with its highest genetic yield potential among all cereals, it is considered as "Queen of cereals". Due to its wider adaptability to different agro-climatic conditions, it is cultivated in about 165 countries with nearly 190 million hectares of area under cultivation (APEDA, 2018).

Food security is a growing concern worldwide. Increasing population and consumption increase the worldwide demand for food which unavoidably increases the use of water. Improving water use efficiency is important to safeguard food security. Because of the massive contribution to increased crop production, fertilizer is being used in every region of the world and its application has been boosted by farmers all over the world. However, fertilizer use efficiency is low all over the world. Hence there is a prerequisite for efficient use of water and fertilizer resources to maintain sustainable food production. Drip irrigation is one of the most efficient methods of irrigating crops. This practice offers enhanced yields, requires a reduced amount of water, reduces cost of tillage and decreases the quantity of fertilizers applied to the crop and improves fertilizer use efficiency.

[1]Department of Agronomy, Sri Venkateswara Agricultural College, Tirupati-517 502, Andhra Pradesh, India.
[2]Department of Agronomy, Agricultural College, Bapatla-522 101, Andhra Pradesh, India.
[3]Department of Agronomy, Regional Agricultural Research Station, Lam, Guntur- 522 034, Andhra Pradesh, India.
[4]Department of Soil Science and Agricultural Chemistry, Sri Venkateswara Agricultural College, Tirupati-517 502, Andhra Pradesh, India.

Corresponding Author: K. Vineela, Department of Agronomy, Sri Venkateswara Agricultural College, Tirupati-517 502, Andhra Pradesh, India. Email: vineela.kodavati@gmail.com

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On the other hand, drip fertigation is a recent advanced irrigation method, by which fertilizers are applied along with irrigation water through a drip system that increases fertilizer use efficiency and enhances crop yields. An appropriately planned drip fertigation system can make best use of crop water and nutrient uptake and minimizes nutrient leaching. Water and nutrients are the important factors which influence the productivity of maize. Drip fertigation distributes nutrients directly at the site of high concentration of active roots. By introducing drip with fertigation, it is possible to increase the yield of crops by 3 times from the same quantity of water. When fertilizer is applied through drip, it was observed that besides increased yield, about 30 per cent of the fertilizer was saved (Sivanappan and Ranghaswami, 2005). Fertigation reduces the cost of cultivation and increases the economic product as high as possible. Therefore, getting maximum benefits from each unit of water and nutrient applied to crop are important. A technically feasible level of fertigation with straight and water-soluble fertilizer through drip would be economically viable for its successful adoption (Loganathan *et al.,* 2017).

Among major plant nutrients, nitrogen is an important plant nutrient that is usually limited in crop growth because of losses like leaching, volatilization and denitrification; and because of these losses, its utilization efficiency decreases considerably in conventional practices. However, frequent and periodic split applications of fertilizer reduce N losses and improves nitrogen use efficiency. Drip fertigation, together with split applications of nitrogen fertilizer not only improves nitrogen use efficiency *via* application of fertilizer to the active root zone of crops but also decreases the groundwater pollution owing to the high homogeneity of nitrogen application. Ibrahim *et al.* (2015) stated that in comparison with the conventional method, drip fertigation significantly improved the maize grain yield in Egypt. Kumar *et al.* (2016) showed that higher frequencies of fertigation of baby corn increased yield. These studies illustrated the great potential of using fertigation for maize production. However, to what extent the nitrogen application rate can be further decreased by drip fertigation is still a question that needs to be addressed. In light of these considerations, the current project aims to study the impact of nitrogen fertigation on water conservation, enhanced water productivity, increased yield as well as returns per rupee invested in *rabi* maize on clay soils of Krishna Agro-climatic Zone of Andhra Pradesh.

MATERIALS AND METHODS

An experiment was conducted during *rabi* season of 2019-20 at the Advanced Post Graduate Centre, Lam, Guntur. The experimental site was geographically situated at an altitude of 315 m above mean sea level, 16°36′ N latitude and 80°43′ E longitude and falls under Krishna Agro-climatic Zone of Andhra Pradesh, India.

The experiment was laid out in randomized block design with twelve treatments and replicated thrice. The treatments were: T_1- 100% RDN through soil application under surface irrigation, T_2- 100% RDN through soil application under drip irrigation, T_3- 75% RDN through soil application under drip irrigation, T_4- 100% RDN through fertigation up to 60 DAS, T_5- 75% RDN through fertigation up to 60 DAS, T_6- 50% RDN through fertigation up to 60 DAS, T_7- 100% RDN through fertigation up to 75 DAS, T_8- 75% RDN through fertigation up to 75 DAS, T_9- 50% RDN through fertigation up to 75DAS, T_{10}- 100% RDN through fertigation up to 90 DAS, T_{11}- 75% RDN through fertigation up to 90 DAS, T_{12}- 50% RDN through fertigation up to 90 DAS.

The soil of the experimental site was clay with moderately alkaline (pH 8.4) in reaction, low in organic carbon (0.48 %) and available phosphorus (15 kg P_2O_5 ha^{-1}), medium in available potassium (184 kg K_2Oha^{-1}) and low in available nitrogen (204 kg N ha^{-1}). The entire phosphorus and half of the potassium were applied as basal before sowing in the form of SSP and MOP respectively. Remaining half of the dose of potassium was applied at the time of flowering. Whereas, the recommended dose of fertilizer nitrogen (240 kg N ha^{-1}) was applied in the form of urea through drip fertigation from nine days after sowing as per the treatments. In soil applied treatments (T_1, T_2 and T_3), urea was applied $^1/_4$ RDN as basal, $^1/_4$ of RDN at 25 DAS, $^1/_4$ of RDN at 45 DAS, $^1/_4$ of RDN at 60 DAS.

Irrigation scheduling

The irrigation scheduling was done based on pan evaporation replenishment. The irrigation water was applied on the basis of pan evaporation (PE) data measured from the USWB open pan evaporimeter which was installed near the field. Irrigation water was applied in all the plots based on pan evaporation readings and scheduled at 100% Epan (Pan evaporation).

Irrigation duration was calculated by arriving application rate (mm hr^{-1}).

Application rate (mm hr^{-1}) =

$$\frac{\text{Emitter discharge L hr}^{-1}}{\text{Lateral spacing (cm)} \times \text{Emitter spacing (cm)}}$$

Irrigation duration (min) =

$$\frac{\text{Depth of irrigation (mm)}}{\text{Application rate (mm hr}^{-1})} \times 60$$

Irrigation through drip was scheduled at three days interval. During rainy days, the quantity of water applied to each treatment was adjusted for the rainfall received. In case of surface irrigation treatment (T_1) a total of eight irrigations @ 60 mm depth were given based on the critical periods of irrigation *i.e.,* at pre-sowing, emergence, knee-high stage, pre-flowering, flowering, milking, grain filling, grain development and grain maturity. The total quantity of water applied during the entire crop growth period per hectare through surface irrigation and drip irrigation was presented in Table 1.

Table 1: Total quantity of water applied per hectare through surface irrigation and drip irrigation.

Treatment	Total quantity of water applied (mm)
Surface irrigated plots	480
Drip irrigated plots	307.4

Fertigation schedule

Nitrogen was supplied using Urea, a water-soluble fertilizer, as per the treatments through fertigation using a venturi fitted to the drip system up to 60,75 and 90 days after sowing as per the treatments. Entire fertilizer nitrogen was divided equally and applied through drip system in multiple split doses *i.e.*, 10 splits for the fertigation treatments up to 60 DAS, 13 splits for the fertigation treatments up to 75 DAS and 15 splits for the fertigation treatments up to 90 DAS. Fertigation schedules were administered at 6 days interval as per the treatment as given in Table 2.

RESULTS AND DISCUSSION

Kernel yield

The data presented in Table 3 clearly showed that the treatments that received 100% RDN up to 90 DAS followed by 75 and 60 DAS (T_{10}, T_7 and T_4 respectively) recorded higher kernel yield compared with that of all other treatments. Kernel produced with the treatments 50% RDN up to 75 and 60 DAS (T_9 and T_6) was significantly lower compared with the rest of the treatments. Surface irrigation with 100% RDN soil application (T_1) was found at par with T_7, T_4 and T_{11}; however, found inferior to T_{10} in kernel yield production.

The increase in kernel yield at the high N rates up to 100% RDN application might be due to cumulative effect of increase in number of kernels per cob, cob weight and test weight. Nitrogen application with increase in number of splits provides an additional source of nitrogen for a higher rate of photosynthesis and transport of photo-assimilates during grain filling stage (Singh *et al.,* 2023). The number of fertigations scheduled in the present experiment were 10, 13 and 15 times (splits) with respect to fertigations scheduled up to 60, 75 and 90 DAS, compared to 3 split applications in case of soil application either with surface or under drip irrigation (T_1, T_2 and T_3). This could be the possible reason for superior performance of drip fertigation to that of soil application in the present experiment and proves that maize plants need nitrogen during post flowering period beyond 60 DAS up to 75 and 90 DAS also. Similar views are also expressed earlier by Mueller and Vyn (2017).

Stover yield

The highest stover yield was produced in the treatment receiving 100% RDN through fertigation up to 90 DAS (T_{10}) was found at par with all other treatments, except, for the treatments receiving 75% RDN through soil application under drip irrigation (T_3) and 50% RDN through fertigation up to 75 DAS (T_9). These two treatments (T_9 and T_3) were observed with the lowest stover yield compare with the rest of the treatments; however, these were found on par with the treatments T_{12} and T_6. The data was presented in Table 3.

Increased growth parameters like plant height and drymatter accumulation at higher rates of nitrogen application could be the reason for the increased stover yield. These results are in consistency with the findings of Tyagi *et al.* (1998) and Padmaja *et al.* (1999).

Soil moisture studies

Total water use

Amount of water consumptively used by the crop to meet the ET demand of the atmosphere was given based on the pan evaporation. It was slightly higher than the ET requirement of the crop. A total of 307.4 mm water was applied to drip irrigated plots based on the pan evaporation. Surface irrigation treatment (T_1) received more quantity of irrigation water (480 mm) than all other treatments. Treatments with drip irrigation and drip fertigation received same quantity of irrigation water (307.4 mm). It was about 64% of the water applied through surface irrigation given in the treatment T_1. Irrigation water applied to each treatment during the crop growth period was measured with the help of pan evaporimeter and presented in Table 4.

Kernel yields recorded with the treatments T_2 (6806 kg ha^{-1}) and T_3 (5947 kg ha^{-1}) under drip irrigation with 100% and 75% RDN with same quantity of water applied in drip were comparatively lower against the corresponding treatments

Table 2: Fertigation schedule for different treatments.

<table>
<tr><th rowspan="2">Days after sowing</th><th rowspan="2">Date of fertigation</th><th colspan="3">Number of fertigations</th></tr>
<tr><th>T_4, T_5 and T_6</th><th>T_7, T_8 and T_9</th><th>T_{10}, T_{11} and T_{12}</th></tr>
<tr><td>9</td><td>06.12.19</td><td rowspan="10">T_4, T_5 and T_6</td><td rowspan="13">T_7, T_8 and T_9</td><td rowspan="15">T_{10}, T_{11} and T_{12}</td></tr>
<tr><td>15</td><td>12.12.19</td></tr>
<tr><td>21</td><td>18.12.19</td></tr>
<tr><td>27</td><td>24.12.19</td></tr>
<tr><td>33</td><td>30.12.19</td></tr>
<tr><td>40</td><td>06.01.20</td></tr>
<tr><td>47</td><td>13.01.20</td></tr>
<tr><td>51</td><td>17.01.20</td></tr>
<tr><td>57</td><td>23.01.20</td></tr>
<tr><td>63</td><td>29.01.20</td></tr>
<tr><td>69</td><td>04.02.20</td><td></td></tr>
<tr><td>75</td><td>10.02.20</td><td></td></tr>
<tr><td>82</td><td>17.02.20</td><td></td></tr>
<tr><td>87</td><td>22.02.20</td><td></td><td></td></tr>
<tr><td>94</td><td>28.02.20</td><td></td><td></td></tr>
</table>

under fertigation (T_{10}, T_7, T^4, T_{11}, T_8 and T_6). This might be due to frequent and periodical application of nitrogen in small amounts with irrigation water in the root zone under fertigation compared to soil application of N with drip irrigation. This could be the same reason for the better performance of fertigation treatments against soil application of N under surface irrigation. Lu *et al.* (2016) and Kumar *et al.* (2016) expressed that drip irrigation combined with fertigation is highly efficient because of the direct application of water and N within the rooting zone. Earlier Dongfeng Ning *et al.* (2019) also reported that the regulation of N fertilizer application can increase yield of maize with the available soil water content.

Water saving and water saving impact

Data on water saving and water saving impact presented in Table 4 revealed that water saving of 172.6 mm with drip irrigation which was 34.9 % of that water applied under surface irrigation (T_1).

Water saving impact is the amount of kernel yield loss per unit amount of water saved and expressed as kg kernel yield loss per m^3 of water saved in each treatment when compared to surface irrigation (T_1). The data clearly showed that with each unit of water saved the amount of yield loss was more under the treatment that received 50% fertigation up to 75 DAS (T_9) and it was next only to the treatment that received 50% fertigation up to 60 DAS (T_6). On the other

Table 3: Kernel and stover yield (kg ha^{-1}) of maize as influenced by different nitrogen fertigation levels.

Treatments	Kernel yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_1- 100% RDN - soil application - surface irrigation	6806	8663
T_2- 100% RDN - soil application - drip irrigation	6271	8256
T_3- 75% RDN - soil application - drip irrigation	5947	7870
T_4- 100% RDN - fertigation -sowing to 60 DAS	6975	8976
T_5- 75% RDN - fertigation -sowing to 60 DAS	6034	8539
T_6- 50% RDN - fertigation -sowing to 60 DAS	5108	7948
T_7- 100% RDN - fertigation - sowing to 75 DAS	7361	8693
T_8- 75 % RDN - fertigation - sowing to 75 DAS	6739	8513
T_9- 50% RDN - fertigation - sowing to 75 DAS	5098	6867
T_{10}- 100% RDN - fertigation -sowing to 90 DAS	7814	9105
T_{11}- 75% RDN - fertigation - sowing to 90 DAS	6914	8374
T_{12}- 50% RDN - fertigation - sowing to 90 DAS	5633	7937
SEm±	296.82	399.43
CD (P=0.05)	876	1179
CV %	8	8

Table 4: Water saving, water saving impact and water productivity of maize as influenced by different fertigation levels.

Treatments	Irrigation water (mm)	Effective rainfall (mm)	Total water used (mm)	Water saving (mm)	Water saving (%)	Water saving impact (kg m^{-3})	Water Productivity (kg m^{-3})
T_1	480	14	494	-	-	-	1.38
T_2	307.4	14	321.4	172.6	34.9	0.31	1.95
T_3	307.4	14	321.4	172.6	34.9	0.50	1.85
T_4	307.4	14	321.4	172.6	34.9	-0.10	2.17
T_5	307.4	14	321.4	172.6	34.9	0.45	1.88
T_6	307.4	14	321.4	172.6	34.9	0.98	1.59
T_7	307.4	14	321.4	172.6	34.9	-0.32	2.29
T_8	307.4	14	321.4	172.6	34.9	0.04	2.10
T_9	307.4	14	321.4	172.6	34.9	0.99	1.59
T_{10}	307.4	14	321.4	172.6	34.9	-0.58	2.43
T_{11}	307.4	14	321.4	172.6	34.9	-0.06	2.15
T_{12}	307.4	14	321.4	172.6	34.9	0.68	1.75
SEm±							0.90
CD (P=0.05)							2.7
CV %							8.0

hand, there was a considerable lesser yield reduction with the same quantity of water saved in T_8, T_2 and T_5. It is obvious from the data presented in Table 4 that apart from the influence of 'water saving', nitrogen fertigation also would have played a role on impacting the increase or decreasing the yield per unit amount of water used. This is evident from the positive impact of water saving due to higher doses of fertigation in case of treatments T_{10}, T_7, T_{11} and T_4.

Water productivity

The water productivity was significantly higher under the treatment fertigated with 100% RDN up to 90 DAS (T_{10}) when compared with that of surface irrigation (T_1) and other treatments. However, it was at par with the treatments receiving 100% RDN through fertigation up to 75 and 60 DAS (T_7 and T_4 respectively). Whereas, the lowest water productivity was recorded with 100% RDN through soil application under surface irrigation (T_1). The increase in water productivity in all drip fertigated treatments over surface irrigation (T_1) might be due to greater increase in kernel yield of maize under N fertigation and considerable saving of irrigation water. Similar findings were reported with Fanish *et al.* (2011), Krishnasamy *et al.* (2012), Ibrahim *et al.* (2015) and Kadasiddappa and Praveen Rao (2018).

Economics

Data on economics of maize influenced by different fertigation schedules are presented in Table 5.

The cost of cultivation showed that the treatment receiving 100% RDN through soil application under drip irrigation (T_2) recorded higher cost of cultivation and it was followed by the treatment receiving 75% RDN through soil application under drip irrigation (T_3) as these treatments incurred additional cost of application of four split doses of fertilizers along with cost of maintenance of drip system. Among all the treatments, the treatments that received 50% RDN through fertigation up to 60, 75 and 90 DAS (T_6, T_9 and T_{12}) were found with lower cost of cultivation was primarily due to reduction in quantity of N fertilizer application.

In case of gross returns, the treatment T10 followed by the treatments that received 100% RDN through drip fertigation up to 75 and 60 DAS (T_7 and T_4) realized higher gross returns. The lower gross returns were observed under the treatments fertigated with 50% RDN up to 75, 60 and 90 DAS (T_9, T_6 and T_{12}) because of significant reduction of yield with the application of 50% RDN. Similarly, the net returns were also higher with the treatment T_{10}, followed by T_7 and T_4. These results are in concurrence with that of Bibe *et al.* (2017), Krishnasamy *et al.* (2012) and Basava *et al.* (2012).

The plants that received 100% RDN through fertigation up to 90 DAS (T_{10}) was found with significantly the highest B:C ratio (2.31) despite more cost of cultivation because of the highest crop yield recovered under this treatment compared with other treatments. However, it was at par with the treatments T_7, T_{11}, T_4 and T_8. The lowest B:C ratio (1.24) recorded with the treatment that received 50% RDN through fertigation up to 75 DAS (T_9) due to less net returns as compared to the other treatments. Though higher rates and prolonged N fertigation (T_{10}) resulted in higher gross

Table 5: Economics of maize as influenced by different fertigation levels.

Treatments	Cost of cultivation (` ha^{-1})	Gross returns (` ha^{-1})	Net returns (` ha^{-1})	Returns per rupee investment
T_1	43853	125903	82050	1.87
T_2	40153	116006	75853	1.89
T_3	39383	110010	70627	1.79
T_4	43653	129043	85390	1.96
T_5	42883	111628	68745	1.60
T_6	42113	94498	52385	1.24
T_7	43653	136181	92528	2.12
T_8	42883	124666	81783	1.91
T_9	42113	94308	52195	1.24
T_{10}	43653	144555	100902	2.31
T_{11}	42883	127901	85018	1.98
T_{12}	42113	104205	62092	1.47
SEm±				0.13
CD (p=0.05)				0.4
CV %				12.7

Input cost:

Cost of Seed : ` 337.5.00 kg^{-1}
Urea : ` 5.9 kg^{-1}
SSP :` 9 kg^{-1}
MOP :` 17.4 kg^{-1}

Output cost:

Price of maize kernels: ` 18.50 kg^{-1}

returns, net returns and BCR, the increase was only marginal compared with the treatments fertigated up to 75 DAS and 60 DAS as well. These results might be establishing the beneficial effect of N application beyond the flowering stage of maize. Mueller and Vyn (2017) also opined that corn can compensate for early-season N stress by increasing the amount of N it accumulates after silking.

CONCLUSION

Fertigation with 100% RDN up to 90 DAS (T_{10}) emerged as the most effective treatment, achieving the highest kernel and stover yields, maximum water productivity and the highest economic returns (B:C ratio of 2.31). This treatment also demonstrated efficient water use, saving 34.9% of water compared to surface irrigation. However, treatments fertigated with 100% RDN up to 60, 75 and 90 DAS showed no significant differences in performance, indicating that maize responds positively to periodic and extended N fertigations beyond flowering, up to 75-90 DAS. The combination of drip irrigation with optimal nitrogen fertigation schedules proved superior in enhancing resource efficiency, sustainability and profitability, underscoring the potential of integrated water-nutrient management in improving *rabi* maize productivity.

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Disclaimers

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Conflict of interest

The all authors declared that they have no conflict of interest.

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