INTERACTIVE EFFECT OF SOIL MOISTURE CONTENT AND NITROGEN FERTILIZER SOURCES ON GROWTH AND NITROGEN UPTAKE IN MAIZE

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Abstract. Water scarcity and soil nutrient depletion significantly constrain global maize productivity amidst recurrent droughts due to climate change. So, this study was designed in a two-factorial pot culture, comprising twelve treatments and four replications in a completely randomized design, to examine the synergistic impacts of nitrogen (N) fertilizer sources and soil moisture levels on maize growth and nitrogen uptake. The treatments included nitrogen fertilizer sources (100% Urea, 100% Nano urea, 50% Urea + 50% Nano Urea, Control) and distinct soil moisture regimes (75% FC, 50% FC, 35% FC). Elevated soil moisture positively correlated with increased plant height, leaf area, and Normalized Difference Vegetation Index (NDVI), while dry root biomass displayed opposing trends. Notably, the 50% Urea + 50% Nano Urea treatment exhibited superior aboveground biomass (350gm, 314gm, and 236gm) and N uptake (2.15%, 1.89%, and 1.99%) across all moisture regimes (75% FC, 50% FC, and 25% FC, respectively). Moreover, plants at 50% FC demonstrated enhanced water use efficiency, surpassing 35% FC and 50% FC by 52% and 63%, respectively. Overall, the combined application of 50% urea and 50% nano urea under optimal soil moisture (75% FC) notably improved growth, nitrogen uptake, and photosynthetic activity. However, their efficacy declined under water stress conditions, with singular nano urea exhibiting relatively milder susceptibility to water stress.

Keywords: Drought, Maize, Nano urea, NDVI, Nutrient uptake, WUE

Abbreviations

FC- Field Capacity
SMC- Soil Moisture Content
WUE-Water Use Efficiency
NDVI-Normalized Difference Vegetation Index
LSD-Least Significant difference
CRD-Completely Randomized Design
NUE-Nitrogen Use Efficiency

INTRODUCTION

Maize production globally plays a critical role in addressing food and fodder demand, but also faces challenges such as water scarcity due to frequent droughts owing to climate change, soil nutrition depletion, and environmental concerns of conventional fertilizers, prompting the exploration of sustainable alternatives. Maize is one of the most popular crops as it can be cultivated practically year-round and anywhere. Level of input use, availability of irrigation and disease and pest infestations are the commonly identified problems for lower productivity of maize (1). Crop output is currently constrained more by the availability of nitrogen (N) and water resources than by crop genetics in the world's major cropping systems (2). In the context of declining water resources and erratic rainfall patterns due to climate change and at the same time necessity of the intensive cultivation of maize to address the current food and fodder demand have further emphasized the optimal management of these two inputs.

40% to 60% of the world's total food production depends on the use of fertilizers, which are essential for plant nutrition and crop quality (3). Among various fertilizers supplying different nutrients required for the growth of the crop, nitrogen is a major necessity in plants as it is a component of several enzyme proteins that catalyze and control the development of plants and also an integral part of chlorophyll. (4). Proteins, nucleic acids, growth hormones, and vitamins are all synthesized from Nitrogen. An adequate supply of nitrogen is associated with vigorous vegetative growth and dark green colour (5). Maize being a C4 plant is a heavy feeder of nitrogen. It requires nitrogen at the optimum amount for its growth and development (6,7). Without N fertilizer inputs, the average yields of several cereal crops, including maize declined by 41% (3). Although Urea is the most used and demanded nitrogenous fertilizer in developing countries pertaining to its demerits which include nitrate leaching, soil denitrification, volatilization and low use efficiency leading to eutrophication, environmental pollution and emission of greenhouse gases there is a need for a sustainable alternative to the conventional urea (8–10). In this regard, Nano fertilizer comes into action. Nano fertilizers are crucial tools in agriculture for enhancing crop growth, yield, and quality metrics while lowering fertilizer application waste, environmental pollution and cultivation costs (11). Nano fertilizers are aimed to consequently increase nutrient use efficiency nutrients by making nutrients more available to leaves (12). Utilizing nanotechnology can produce fertilizers that release nitrogen when crops require it, ultimately increasing nitrogen efficiency by reducing nitrogen emissions and leaching as well as long-term absorption by soil microorganisms (13). However, nutrients supplied by fertilizers need to be taken up by the crop to utilize it for growth function.

All three mechanisms of nutrient uptake i.e., mass flow, root interception, and diffusion, all depend heavily on water. In addition to influencing the physio-chemical processes of plants, soil moisture also controls the availability and transportation of nutrients to different plant organs, altering plant growth (14). Soil water status has been shown to have a strong indirect influence on the amount of available soil N as well as the form in which it is taken up by seedlings. Foliar concentrations have been found to partially conceal nutrient shortages under conditions of soil water stress. Drought and nutrient-stressed plants lower their photosynthetic activity and gas exchanges with the environment by decreasing leaf area, closing stomata, and allocating more nutrients to the roots (15).

Since soil moisture condition affects all the mechanism of nutrient uptake by the crop different Nitrogen fertilizer Sources and their combination can likely influence the growth of maize and Nitrogen uptake. This study focuses on :(i) Finding out the interaction effect on various vegetative growth parameters of maize such as plant height, leaf area and root shoot biomass., (ii) Quantifying the impact of soil moisture level on the nitrogen uptake and crop water use and (iii) To access the impact of interaction on photosynthesis through greenness measurement. In order to develop effective fertilizer management under limited irrigation to avoid negative environmental effects, there is a lack of understanding and data regarding how the soil water status affects plant nutrient uptake and the availability of soil residual nutrients (16). Addressing this long-lasting problem of soil moisture and nutrient deficiency being the most limiting factor of crop production in recent decades, our research looks for new approaches to enhance the use efficiencies of all inputs, including water and nutrients. At the same time, research aims to adjust the fertilizer rate in accordance with the soil moisture levels and identify the efficiency of the combinations. Despite the growing importance of moisture and nutrient levels on crop production, very few studies have been done on the interaction of soil moisture and fertilizer and none have included the use of nano urea as an alternative to conventional fertilizers with slow and controlled release of nitrogen. So, this study is designed to fill these research gaps and expand the horizons of the knowledge on the interaction of different soil moisture levels and Nitrogen fertilizers on the crop early growth, photosynthesis and nutrient uptake.

MATERIALS AND METHODS

The experiment was conducted inside a plastic tunnel at Institute of Agriculture and Animal Science, Lamjung Campus, Nepal. The geographical coordinates of the experimental site are 28.13°N latitude to 84.42°E longitude and altitude of 740 meter above sea level. The maximum temperature of the experimental site is up to 42.6 ^{0}C and minimum temperature of 13.4 ^{0}C. The average temperature and humidity during the experiment period was 22.98 ^{0}C and 76.06 % respectively. The experiment was conducted in the 2023 spring maize growing season in a two factorial completely randomized design with 12 treatments, 4 different rates of urea fertilizers (Control, 100% urea, 50% urea+50% nano Urea and 10% nano urea) and 3 different soil moisture ranges (75, 50 and 35% of FC) with 4 replications.

Table 1

Nitrogen fertilizer Dose for the Treatment

Treatment	Nitrogen Fertilizer
T1	Control
T2	100% recommended fertilizer (Urea, DAP and MOP)
T3	50% Urea + 50% of Nano- Nitrogen (Usual DAP and MOP)
T4	100% Nano-Nitrogen (Usual DAP and MOP)

Table 2. Soil moisture level for the treatment

Treatment	Nitrogen Fertilizer
M1	75% FC
M2	50% FC
M3	35% FC

A total of 60 pots (cylindrical pot: 25 cm diameter and 22cm height) containing 5.125 kg of soil was filled. The soil was Sandy loam with the Ph of 5.91 and low organic matter of 1.53%. The initial NPK content of the soil is 0.076 %, 183.2 kg/ha and 778.48 kg/ha respectively. Maize seed (Arun-2) was planted at a density 3 seeds per pot on February 24th, 2023, then thinned after germination ensuring the single plant per pot.

Recommended dose of the urea refers to the recommendation by Ministry of Agriculture and Livestock Development. However, the recommendation for nano urea refers to the recommendation by the manufacturer. For Maize recommended dose of fertilizer 120:60:40 kg NPK/ha which is equivalent to 2.24:1.12:0.747 gm NPK/plant assuming the optimum plant population of 53,500. So, 2.43 gm of DAP and 1.245 gm of K was incorporated in each pot of all the treatment combination. For T1, 1.48 gram of urea was used. For T2 0.74 gram of urea was used. For T3 and T4 nano urea, 2ml/liter of water and 4ml/liter of water was sprayed at 20 DAS and 40 DAS while control was left without incorporating any fertilizer. Three different moisture ranges for the experiment were considered on the basis of Field capacity. Water was poured on the soil filled pots until it dropped from the minute pores present on the bottom. To escape the loss of capillary water through evaporation, the top was covered with polythene. Then the well calibrated tensiometer was placed in the pot. Soil at field capacity was determined based on the reading by tensiometer. Then the moisture content at field capacity was determined by using gravimetric method. Also, the moisture content of the air-dried growing medium was determined by Gravimetric method. In this way amount of water required for Field capacity (100% FC) was determined. And ultimately, three different water ranges were obtained after determining the amount of water required for the 75% FC, 50% FC, and 35% FC. The reduction in weight of the pot due to evapotranspiration was measured every 2 days and the moisture levels were maintained by adding measured amounts of water. Out of total 60 12 pots were for measuring the weight of the plant at different dates for accurate addition of water for different moisture level.

Vegetative Parameters

Plant height was measured by using measuring tape from base of the shoot to base of the uppermost collar leaf at 35 and 45 DAS while at tasseling plant height was taken from base of the shoot to base of the tassel. Leaf area was estimated by multiplying leaf length, leaf maximum width and a constant (0.73) (17)

Leaf area (A) = 0.73× leaf length × maximum leaf width

Here, leaf length of 3 leaves from the base of the leaf to the tip was taken by using measuring tape and maximum leaf width was taken by using measuring scale from the same 3 leaves.

NDVI

Normalized Difference Vegetation Index (NDVI) was measured with the help of green seeker handheld crop sensor by placing it 80cm above the crop canopy at tasseling before the uprooting of the plant from the pot.

Biomass

Fresh root weight was taken after separating soil from the roots. For dry root weight, root was weighted after keeping in hot air oven at 65 ^{0}C for 72 hours. Fresh shoot weight was taken after separating shoot from the roots. For dry shoot weight, shoots were weighted after keeping in hot air oven at 65 ^{0}C for 72 hours

Nitrogen Uptake

The dried biomass of shoot was grinded and sieved with 0.4mm sieve. The sample was subjected to acid digestion with 4 M H_2So_4. Total Nitrogen content in shoot was measured by Kjeldahl method (18).

Water use efficiency

The impact of N fertilizer supply, drought stress and their interaction on the irrigation water productivity was calculated by dividing the produced shoot dry weight of each treatment on the total irrigation water used for the corresponding soil moisture level (19).

$$\text{WUE} = \frac{\textit{Shoot dry biomass}}{\textit{Total irrigation water used}}$$

Statistical analysis

The recorded data were arranged treatment-wise systematically under four replications on the basis of various observed parameters. The data were tested for assumptions of ANOVA using gvlma before the ANOVA analysis. The interactive effects of soil moisture level and N fertilizer sources on the studied variables was analyzed through factorial design (two-way ANOVA) in R version 4.3.1 and mean differences between treatments was evaluated by Duncan Multiple Range Test at 0.05 probability level. Data visualization was also done using bar graphs by using MS excel.

RESULTS AND DISCUSSIONS

Vegetative parameters

Plant height ($P<0.001$) and Leaf area ($P<0.05$) was found to be significant to the interaction of the nitrogen dose and moisture level at tasseling while stem diameter had insignificant effect. Maximum plant height of 170.63cm at 50% urea and 50% nano-urea with 75% FC moisture level was found to be significant over other combination. Plants at 100% urea in 35% FC moisture level showed minimum plant height (71.80 cm). Under adequate soil moisture (75% FC), the height of the plant with 50% nano urea +50% urea and 100% nano urea increase by 88% and 52% as compared to control. The nitrogen fertilizer form shows similar effect at mild water limited condition however the effect of all Source of nitrogen fertilizer reduces significantly at higher water stress. Leaf Area was found to be significant to the interaction of the nitrogen dose and moisture level at tasseling only. At optimum moisture level (75% FC) Leaf Area of plant with 100% urea ,50% urea +50% nano urea and 100% nano urea increase by 22%, 88% and 47% respectively as compared to unfertilized treatment. Similarly, the leaf area decreases in the other two limiting moisture condition. Maximum Leaf area of 630.67 cm2 at 50% urea and 50% nano-urea with 75% FC moisture level was found to be statistically similar with T3M2 (555.62 cm2) and T2M2 (542.15 cm2) and statistically significant over all other treatment. Minimum leaf area of 284.91 cm2 was observed for 100% urea in 35% FC moisture level.

The smaller height of the plant at 35 % FC than corresponding plants with similar fertilizer treatment is due to the effect of dry soils making cations more tightly bound to soil colloids making nutrient less available to plants. Since diffusion occurs through water films, absorption of nano particles also depends on the soil moisture content ultimately so, it is true for nano urea too. However, small plant height at T1M1 is due to loss of nitrogen through leaching due to excess irrigation. Campelo et al. (20) found similar result who also shows the significant interaction effect of moisture and fertilizer. In terms of leaf area, Size of the leaf decreases during water stress as expansion of leaf depends upon the turgor pressure and supply of assimilates (21).

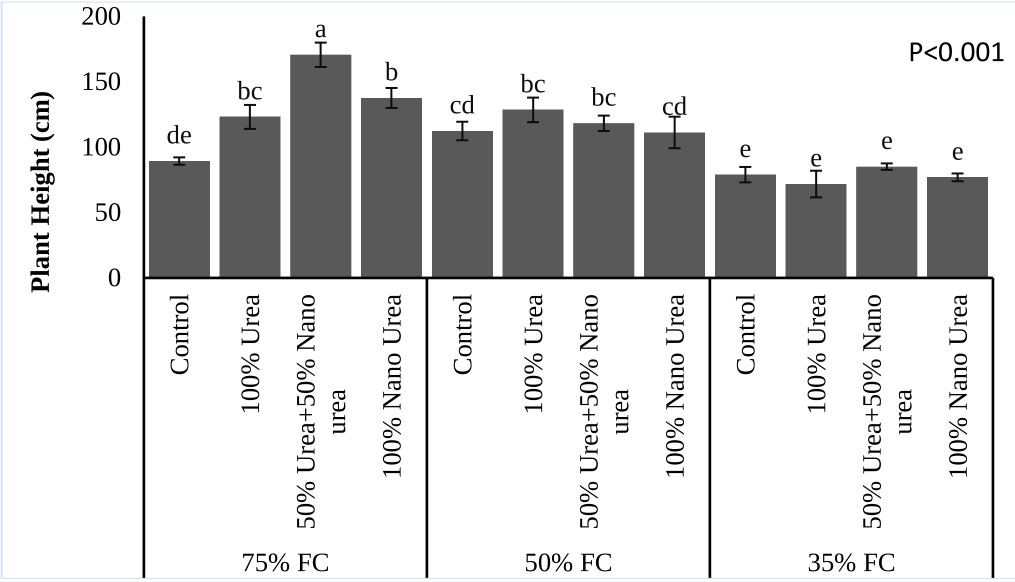

Figure 1. Interaction of Nitrogen fertilizer forms and soil moisture on plant height. Values are means of 4 replicates±SE, dissimilar letters indicate significant differences at p<0.05, according to DMRT

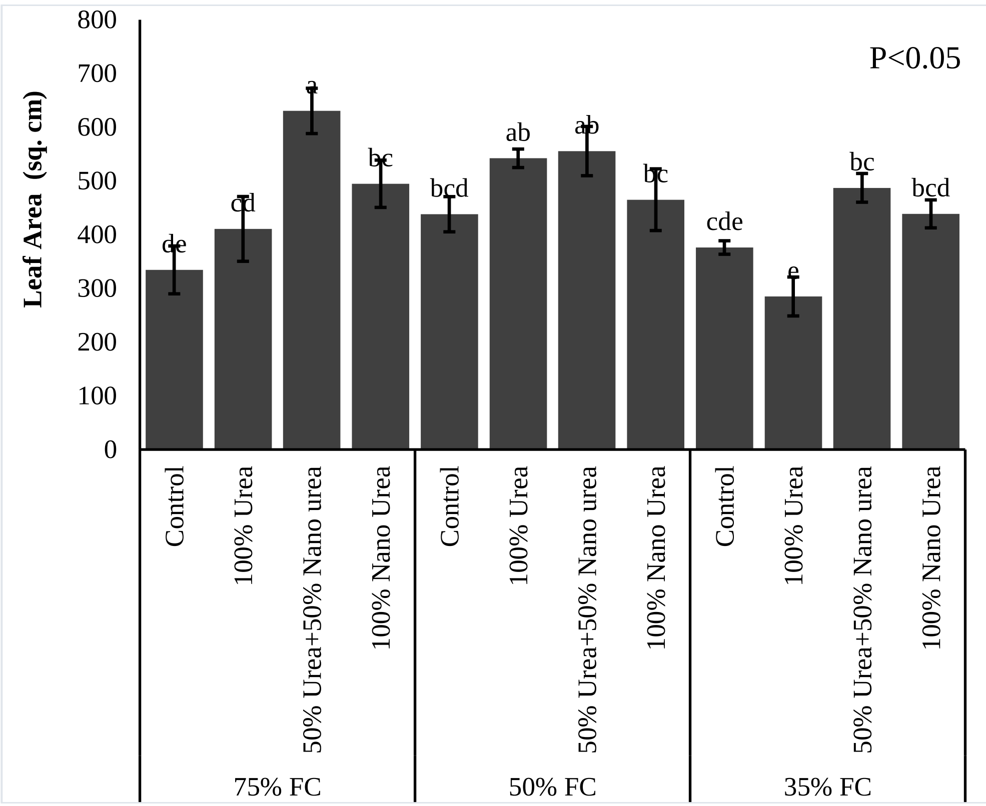

Figure 2. Interaction of Nitrogen fertilizer forms and soil moisture on Leaf area. Values are means of 4 replicates±SE, dissimilar letters indicate significant differences at p<0.05, according to DMRT

So, reduced turgor pressure and slow photosynthesis rate due to limited assimilates is the major reason behind small leaf area. Our result is supported by various works finding that concludes that proper application of Nitrogen fertilizer can to eliminate the adverse effect of mild moisture stress on LAI (22,23). Plant with Combination of urea and nano urea had increased stem diameter by 20%. Our result is in line with the findings by Khaveh et al. (24) which identifies that slow release fertilizer had significant effect on the stem diameter than the conventional urea. Quick absorption of the nano particles by he leaves and long-lasting effect is the reason behind increased stem thickness in plant with nano urea treatment.

NDVI. In terms of NDVI, result showed significant effect of nitrogen doses on NDVI of the maize at tasseling stage ($P<0.001$). 50% nano Urea + 50% Urea showed maximum NDVI of 0.73 which is statistically at par with 100% Nano -Urea with the NDVI of 0.70 and statistically superior than other two fertilizer treatment. Plants at 50% nano Urea + 50% Urea had 12.30% higher greenness than the unfertilized treatment. Our result is in line with the results by Biswas & Ma (25) which also identify that Nitrogen rates of different Nitrogen source had marginal effect on the NDVI. Further Tilak et al. (7) concluded that the chlorophyll content as well as Nitrogen uptake increase with the addition of Nano Urea. This can be explained by responses of Chlorophyll a and Chlorophyll b to different N application rates. Also increase in chlorophyll a, b and total chlorophyll content in Nano Urea is due its nano sized particles with better absorption, permeability and penetration into plant leaves. Insignificant effect of soil moisture content and its interaction with Nitrogen rates at 5 % Probability level which may be due to proper application of Nitrogen fertilizer which reduced the adverse effect of drought (22,26).

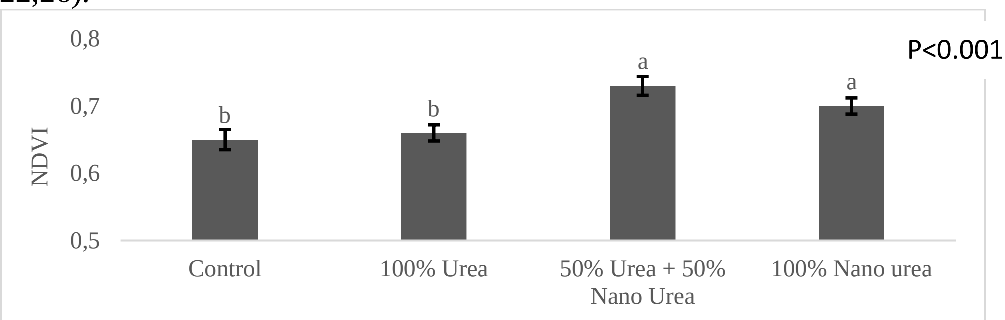

Figure 3. Effect of Nitrogen fertilizer forms on Normalized difference vegetation index. Values are means of 4 replicates±SE, dissimilar letters indicate significant differences at $p<0.05$, according to DMRT

Biomass. The result showed there is no significant effect of nitrogen level or moisture level and their interaction on fresh root weight at 5% probability level while there was significant effect of the treatment combination on the dry root weight ($P<0.01$). T4M3 showed the maximum dry root weight (16.23 gm). Plant treated with 100% nano urea showed higher dry root weight at all soil moisture condition. They showed 90% ,65% and 96% increase in dry root weight compared with the unfertilized at corresponding severe, mild and adequate moisture condition.

Table 3

Effect of Interaction Nitrogen fertilizer and soil moisture content on DRW, FSW and DSW

Moisture	Fertilizer	DRW	FSW	DSW
75% FC	Control	5.9 ± 0.829[de]	196.8 ± 14.1[de]	30.4 ± 5.93[bc]
	100% Urea	11.3 ± 2.27[bc]	287.3 ± 54.6[abc]	55.3 ± 22.6[ab]
	50% Urea + 50% Nano Urea	14.1 ± 1.74[ab]	350.2 ± 21.8[a]	81.6 ± 10.8[a]
	100% Nano urea	11.6 ± 3.09[abc]	269.4 ± 35.5[bcd]	61.4 ± 21.6[ab]
50% FC	Control	8.9 ± 0.489[cde]	260.2 ± 1.90[bcd]	48.1 ± 8.43[ab]
	100% Urea	8.5 ± 1.38[cde]	255.6 ± 20.5[bcd]	83.2 ± 11.0[a]
	50% Urea + 50% Nano Urea	8.2 ± 0.318[cde]	314.3 ± 4.57[ab]	73.7 ± 12.8[a]
	100% Nano urea	14.7 ± 1.29[ab]	293.1 ± 15.6[abc]	51.5 ± 8.22[ab]
35% FC	Control	8.5 ± 0.67[cde]	180.6 ± 4.10[ef]	31.0 ± 1.42[bc]
	100% Urea	4.8 ± 1.40[e]	120.7 ± 27.2[f]	20.8 ± 2.56[c]
	50% Urea + 50% Nano Urea	10.4 ± 1.01[bcd]	236.9 ± 15.2[cde]	32.4 ± 4.67[bc]
	100% Nano urea	16.2 ± 1.37[a]	231.4 ± 6.20[cde]	43.7 ± 1.95[ab]
P value		**	*	*
LSD		4.35	67.40	32.96
CV		19.46	18.82	23.65
Mean		10.29	249.74	51.09

Note: DRW: Dry root weight, FSW: Fresh shoot weight, DSW: Dry shoot weight, LSD: least Significant Difference, CV: Coefficient of variation, '***', '**' and '*' indicates significant at 0.001, 0.01 and 0.05 probability level, ns: non-significant, value with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Regression Test)

In terms of shoot weight, both the fresh ($P<0.05$) and dry shoot weight ($P<0.05$) showed significant effect of the treatment combination. In adequate soil moisture condition i.e., 75% FC plant with 50% Urea + 50% Nano Urea was significantly apart from other fertilizer treatment. The increased in plant aboveground biomass was by 80% as compared to unfertilized treatment. Besides unfertilized treatment at adequate soil conditions all other treatment were statistically similar. Similarly at 50% FC too, all the treatment had similar effect as compared to the effect at adequate soil moisture condition. T3M1 had the maximum fresh shoot weight (350.21 gm) closely followed by T3M2 (314.39 gm) and T2M1 (287.36 gm) which are statistically at par. In contrast, Plant at T2M2 had the maximum dry shoot weight (81.56 gm) which is statistically superior than unfertilized treatment at 75% FC and all other treatment at 35% FC except the plant with 100% nano urea. All plant at various nitrogen fertilizer treatment at adequate soil conditions were statistically similar. Similarly at 50% FC too, all the treatment had similar effect as compared to the effect at adequate soil moisture condition. However, dry shoot weight was decreased due to the limiting effect of severe moisture stress 35% FC on the fertilizer treatment. Minimum dry shoot weight was observed in T2M3. The dry shoot weight was decreased by 165% compared to the same treatment at adequate soil moisture. Similarly effect on the dry weight of plants with 50% urea + 50% nano urea was decreased by 151% as compared to the plants with same treatment at 75% FC. In terms of dry root biomass, more or less plant with nano urea either singly or in combination with conventional urea showed better dry root weight in all soil moisture condition. This is due to the fact that Nano fertilizer releases the nutrient in control manner in response to moisture stress. Hammad et al. (27) reported the maximum root weight with plants at 50% FC which was the only the limited soil moisture condition in the experiment which is in line with our findings. Both fresh and dry shoot weight decreased due to the limiting effect of severe moisture stress 35% FC on the fertilizer treatment. Our result are supported by the findings of Aliarab et al.(19) that argues also on the decrease of shoot biomass when soil moisture condition was reduced from 75% FC to 25% FC regardless of Nitrogen fertilizer treatment. The reason behind the reduction in growth at the severe water stress is that water stress modifies different physiological and biological process involved in plant growth (28). Tissue turgor, stomatal conductance, nutrient uptake, photosynthesis rate, and cell division and enlargement are all reduced in water stress conditions. So that in a period of severe water stress, biomass of the crop is reduced.

Nitrogen uptake

The result showed significant effect of interaction on the Nitrogen uptake as well ($P<0.001$). T3M1 had the maximum nitrogen concentration in shoot of 2.15% which is statistically superior than all other treatment combination closely followed by T3M2 (2.00%) and T3M3 (1.99%). Plants fertilized with 50% Nano-Urea+ 50% Urea had highest N uptake in all moisture condition. At 75% FC, 50%FC and 35% FC N accumulation in plants with 50% Nano-Urea+ 50% Urea increased by 283%, 100% and 136% as compared to their respective unfertilized treatment. Crop N uptake is lower for moisture limiting condition which ultimately increases with the increasing moisture. Previous study by Lenka et al.(6) supports our result as it also concluded that N uptake decreases with increasing water stress presented in the form of crop nitrogen recovery. Despite higher soil moisture low N uptake in unfertilized is due to low available nitrogen in the soil which is further lowered due to leaching at higher moisture. Furthermore Wang et al.(29) in his study revealed N accumulation was higher for full irrigation regime across all Nitrogen fertilizer treatment. Nitrate and ammonium are the two Source of inorganic N most greatly absorbed by the roots of maize while nitrate is usually the dominant form of plant-available N in soils (30). Since soil moisture condition affects N absorption, assimilation and mobilization there was decrease in N uptake with the decreasing soil moisture. The higher N uptake in nano urea treatment is due to targeted foliar application of nitrogen and distribution of the nitrogen in different plants through phloem application.

Water Use Efficiency

The result showed significant effect of moisture levels on Water use efficiency ($P<0.001$) while there was insignificant effect of Nitrogen fertilizer and interaction on WUE. Plant grown at 75% FC were statistically more water efficient than plant at 50% FC and at 35% FC. Water use efficiency of the plants at 50% FC increased by 52% as compared to the severe soil moisture limiting condition i.e., 35% FC and by 63% as compared to plants at 75% FC. The reason behind maximum water use efficiency at 50% FC is given by Dodd (31) which emphasizes that microbial population peaks at dry soil as well as their activities is also increased which can potentially affect the plant growth. So, increased activity of beneficial microorganism such as mycorrhizae enhanced higher water uptake in mild field capacity. However, at 35% FC plant growth was severely obstructed due to poor waterflow from xylem to nearby cells reducing cell elongation. Our result is similar to the previous work of Hammad et al.(27) were similar trend of WUE was observed in maize where maximum WUE was obtained at 50% FC which was the lowest field capacity level in the study and increasing the Field capacity level decreased the Water use efficiency.

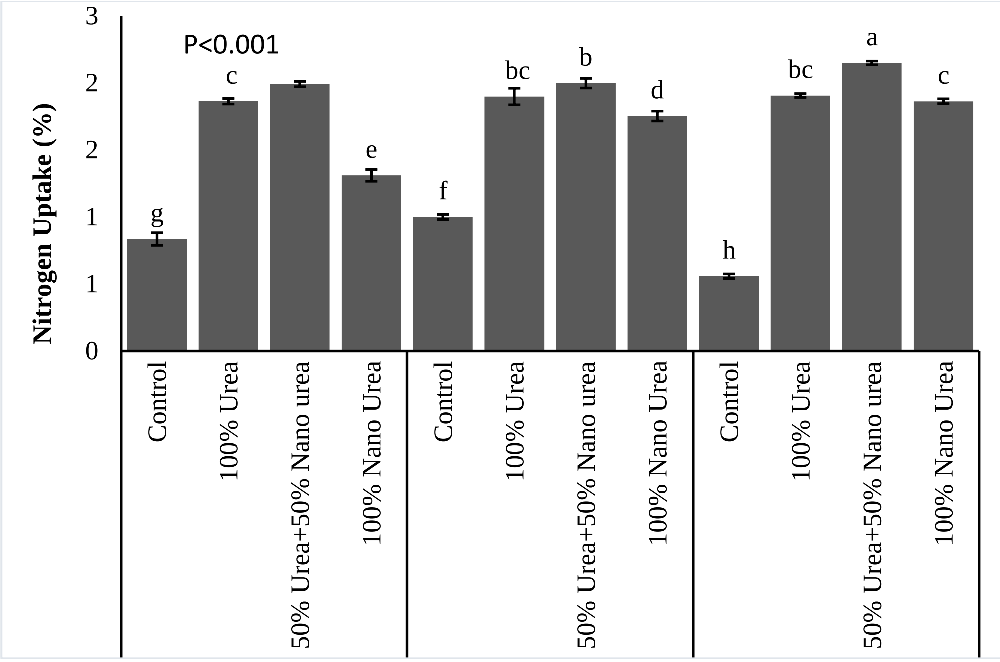

Figure 2. Interaction of Nitrogen fertilizer forms and soil moisture on Nitrogen uptake. Values are means of 4 replicates±SE, dissimilar letters indicate significant differences at p<0.05, according to DMRT

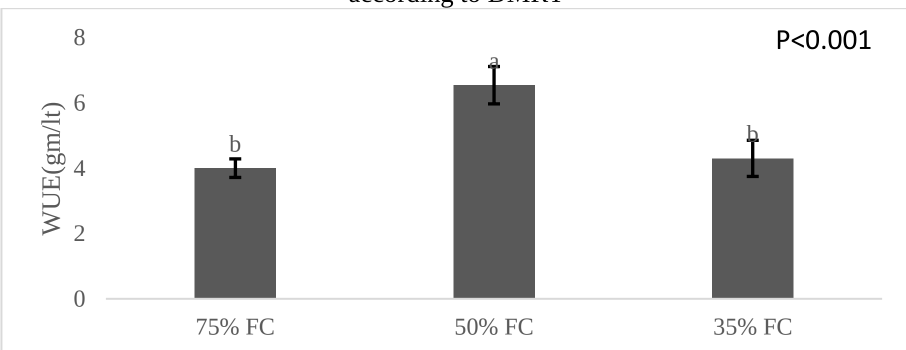

Figure 5. Effect of soil moisture levels on Water use efficiency. Values are means of 4 replicates±SE, dissimilar letters indicate significant differences at p<0.05, according to DMRT

CONCLUSIONS

Soil moisture condition affects all the mechanism of nutrient uptake by maize different so, Nitrogen fertilizer Source and their combination were found to influence growth of maize and Nitrogen uptake. Our research finding suggest that various vegetative growth parameters of maize which includes plant height and leaf area, stem diameter, significantly impacted due to severe water stress i.e., 35% FC. However, in terms of root biomass plants treated with nano urea shows better results at all moisture level. The aboveground biomass lowers with the decreasing soil moisture. However, changing soil moisture have no impact on greenness as measured by NDVI as well as in Water use efficiency. Also, all the crops fertilized with the nitrogen treatment are water efficient as compared to the unfertilized crops. Moreover, Plants fertilized with 50% Nano-Urea+ 50% Urea had highest N uptake in all moisture condition with steady decrease in N accumulation with the increasing soil moisture stress. Hence, rather than use of granular urea alone, foliar application of nano urea can be done at adequate soil moisture condition. Nevertheless, mild moisture depletion is also significantly beneficial as per our results. As Nano urea is cheaper to buy and leads to lower pollution due to leaching its combination with urea can be justified.

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