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RESEARCH ARTICLE

Gibberellic acid and urease inhibitor optimize nitrogen uptake and yield of maize at varying nitrogen levels under changing climate

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Abstract

Worldwide, nitrogen (N) deficiency is the main yield limiting factor owing to its losses via leaching and volatilization. Urease inhibitors slow down urea hydrolysis in soil by inhibiting urease enzyme activities whereas gibberellic acid is growth regulator. That is why, we evaluated the role of urease inhibitor [N-(n-butyl)thiophosphorictriamide (NBPT)] and gibberellic acid (GA_3) in improving nitrogen uptake and yield of maize under different N levels (120 and 150 kg ha^{-1}) along with control. Both N levels alone and in combination with GA_3 and NBPT significantly increased yield and yield components of maize over control. In addition, 150 kg N ha^{-1} + NBPT + GA_3 produced highest biological, grain, and stover yields, 1000 grain weight, plant height, and N uptake exhibiting 33.15%, 56.46%, 27.56%, 19.56%, 23.24%, and 78% increase over 150 kg N ha^{-1}, respectively. The sole use of gibberellic acid or NBPT with each level of N also improved the yield and yield components of maize compared to sole N application and control. Furthermore, application of 120 kg N ha^{-1} along with NBPT and GA_3 performed at par to 150 kg N ha^{-1} + NBPT + GA_3 but it was superior than sole applied 150 kg N ha^{-1} for all the studied traits. These results imply that application of GA_3 and/or NBPT can reduce dependence on urea and improve the yield and N uptake in maize by slowing urea hydrolysis in calcareous soils and shall be practiced.

Keywords Gibberellic acid · Nitrogen uptake · Maize · Urea and urease inhibitor

Introduction

Maize (*Zea mays* L.) belongs to family *Poaceae* and is one of the most important cultivated crop in tropical and subtropical region of the world (Nabizadeh et al. 2012; Khan et al. 2014a, b). It is the 3rd largest grain crop in Pakistan following wheat and rice (Harris et al. 2007). Maize is an exhaustive crop needs an adequate amount of essential nutrients for its abundant production, in order to fulfill the demand of the rapid increasing population of the world.

Nitrogen (N) is an essential nutrient, is a basic constituent of plant growth, and improves crop production and other nutrients uptake (Zaman et al. 2008a, b; Nasim et al. 2018). Nitrogen is a mobile nutrient, it moves and is lost easily from the soil (Junejo et al. 2011) and is usually deficient in calcarious soils (Adnan et al. 2018a; Snyder et al. 2007; Shah et al. 2012). Worldwide increase in crop yield is directly proportional to synthetic fertilizer application, though the higher N fertilizer has drastically declined nitrogen use efficiency (NUE) (Tilman et al. 2002; Liu et al. 2013; Erisman et al. 2007; Turan 2021a). Urea (fertilizer) is a predominant

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supplement of nitrogen in Pakistan. It is used due to 46% of N content, as compared to other (Dawar et al. 2011b). There are some major problems linked with N fertilizers especially urea because it is easily subjected to NO_3 leaching and NH_3 volatilization, low NUE, denitrification and fixation of ammonium nitrogen in soil etc. (Zaman et al. 2008a, b, 2009). All these N losses become a threat for economic losses and ecological system (Ledgard et al. 2008; Zhang et al. 2009). Being a component of N-cycle, these losses are unavoidable (Hayashi et al. 2008; Ahmed et al. 2008; Mohsina et al. 2004). Hence, it is too difficult task to control such losses.

However, to resolve these problems, urease inhibitors treated urea is one of the possible and best remedy. The compound urease inhibitors are used to slow down and decelerate urea hydrolysis in soil by inhibiting urease enzyme activities (Shaviv 2001; Sanz-Cobena et al. 2008; Dawar et al. 2011; Khan et al. 2014a, b) and as a result, there is enough time for urea diffusion from the place of its application to root zone. It also improves NUE by conquering nitrogen losses in the form of N_2O, NO, NO_3, and NH_3 volatilization etc. (Chen et al. 2008; Sun et al. 2004; Zhou et al. 2004; Sanz-Cobena et al. 2012). Large number of inhibitors are used now a days but N-(n-butyl)thiophosphorictriamide (NBPT), marketed as Agrotain, was found more efficient (Watson et al. 2008; Dawar et al. 2011c; Rawluk et al. 2001; Xiang et al. 2008). It slows down the urea hydrolysis process for a period between 3 and 28 days depending on humidity, temperature of soil, and other environmental conditions. Urea coated with NBPT improves the bioavailability of N and increases crop yield and N uptake by reducing N losses (Min et al. 2010; Dawar et al. 2011c; Sanz-Cobena et al. 2012; Adnan et al. 2018b). Its application does not show any effect on soil biological proprieties, which make its use more sensible (Pereira et al. 2009).

Similarly, plant growth regulators (PGRs) also improve crop yield by increasing plant growth and nutrients uptake (Turan et al. 2019). They are organic substances produced by plants or by a chemist synthetically. They influence different functions in plants, such as development of roots, flowering, fruiting, shape formation, seed formation, fruit set and drop, and other developmental processes by affecting cell division and cell elongation (Naeem et al. 2004; Nabizadeh et al. 2012; Khan et al. 2020; Turan 2021b). One of the most important PGR is gibberellic acids (GA_3) which is popular in agriculture (Mostafa and Al. Hamd 2011) because it promotes germination, crack seed dormancy, increases internodes length, enhances cell division, and also increases leaves size. It also increases the source of physiological strength through increasing chlorophyll content and affects the leaves age. GA_3 accelerates seed germination by promoting seed elongation growth in cereal seeds (Ghodrat et al. 2012). It also increases plant yield through accumulation and translocation of nutrients in plants (Karimi et al. 2012; Ud-deen 2009; Verma and Sen 2008); however, their role varies depending upon soil and climatic conditions. Hence, the present study was initiated to determine the influence of combine and sole used of urease inhibitor and gibberellic acid with different levels of N on the growth and yield of maize in calcareous soils under changing climate.

Materials and methods

Experimental site

A field experiment was conducted at the research farm of The University of Agriculture Peshawar, Pakistan (34.1°′21″ N, 71°28′5′E) during summer 2015. The soil of experimental site was silt clay loam in nature, alkaline in reaction with a pH 7.54, and non-saline having EC of 0.146 dSm^{-1}. Highly calcareous in nature with lime content of 18.37%, low in organic matter (< 1%), and was deficient in nitrogen and phosphorus as mentioned in Table 1.

Experimentation

The experiment was laid out in randomized complete block design (RCBD) with three replications and nine treatments. The treatments were composed of Control, 120 kg N ha^{-1}, 150 kg N ha^{-1}, 120 kg N ha^{-1} + GA_3, 150 kg N ha^{-1} + GA_3, 120 kg N ha^{-1} + NBPT, 150 kg N ha^{-1} + NBPT, 120 kg N ha^{-1} + GA_3 + NBPT, and 120 kg N ha^{-1} + GA_3 + NBPT. The treatments were applied as fertigation in two equal splits, i.e., half each at 10 and 30 days after sowing. GA_3 at the rate of 60 g ha^{-1} and NBPT at the rate of 1 L $tone^{-1}$ of urea were applied. For uniform application of treatments, the required amount of NBPT, GA_3, and urea was dissolved (30 min before application) in 30 L water per plot. Basal dose of phosphorus at rate of 90 kg P_2O_5 ha^{-1} as SSP and potassium at rate of 60 kg K_2O ha^{-1} as SOP were also applied at the time of sowing.

Table 1 Physico-chemical properties of the experimental field

Property	Unit	Value
Soil textural class	---	Silt clay loam
Soil pH	---	7.54
Electrical conductivity	dSm^{-1}	0.146
Soil organic matter	%	0.94
Lime content ($CaCO_3$)	%	18.37
Total nitrogen in soil	%	0.236
AB-DTPA extractable phosphorus	mg kg^{-1}	0.68

Seed bed preparation and crop management

A fine seed bed was prepared through cultivation with disk harrow followed by planking. Ridges were made by ridger with ridge height of 8 cm with ridge to ridge distance of 70 cm. The cultivar "Azam" was sown at the rate of 30 kg ha^{-1} on top of the ridge manually with hand. The plant to plant distance was maintained 15 cm. Weeds were controlled by manual weeding with the help of hoe. The crop was irrigated at 10 days interval. However, the irrigation interval was varied with respect to weather conditions (rainfall). The insecticide "C-Phos" was used to control stem borer at recommended rate. The crop was harvested upon maturity (yellowing of 80% plants in each plot). Data were recorded on plant height, thousand grain weight, grain yield, biological yield, and stover yield.

Laboratory analysis

Soil pH (McLean 1982) was determined in 1:5 soil water suspensions with the help of pH meter. Electrical conductivity (Richard 1954) was determined in the same suspension. Soil texture was determined through the method described by Koehler et al. (1984). Organic matter was measured with Walkley-Black procedure as described by Nelson and Sommer (1982). AB-DTPA extractable P was determined using the method described by Soltanpour and Schawab (1977). Mineral nitrogen in soil samples was determined by steam distillation method as described by Mulvaney (1996) and total nitrogen in soil and plant samples was determined by Kjeldhal method as described by Bremner (1996). The plant samples were analyzed for total N concentration and uptake.

Statistical analysis

The replicated data were statistically analyzed according to randomized complete block design using method described by Steel and Torrie (1981) with the help of statistical package Statistix 8.1. For mean comparison between treatments, least significant difference (LSD) test was applied at 5% level of probability.

Results

Yield and yield components

Statistical analysis of the data showed that application of each nitrogen level alone and in combination with plant growth regulator (GA_3) and urease inhibitor (NBPT) significantly improved maize plant height over control plots (Table 2). GA_3 applied with each N level resulted in higher plant height as compared to NBPT and N levels sole. However, the highest plant height (228 cm) was recorded in plot treated with 150 kg N ha^{-1} + GA_3 + NBPT and exhibited 23.24% increase over sole application of 150 kg N ha^{-1}. Both N levels applied with NBPT also improved maize plant height over sole N application. NBPT applied alone with both N levels was not more effective in increasing plant height as compared to the use of GA_3.

Analysis of the variance indicated that thousand grain weight of maize was significantly increased in all treated plots over control (Table 3). Results showed that as N level increased, thousand grain weight was ultimately increased. The results further illustrated that GA_3 + NBPT applied with 150 kg N ha^{-1} produced higher thousand grain weight (330 g) with 19.6% increase over sole application of 150 kg N ha^{-1} followed by 120 kg N ha^{-1} with NBPT + GA_3 where the increase recorded over sole 120 kg N ha^{-1} was 10%. It was evident that both levels of N coated with NBPT increased thousand grain weight by 15.2% and 16.2% over sole N levels, respectively. GA_3 applied with 150 and 120 kg N ha^{-1} increased thousand grain weight by 6.5% and 4.1% over sole 150 and 120 kg N ha^{-1}, respectively. N levels regardless of its application rate also significantly improved thousand grain weight over control. The performance of 120 kg N ha^{-1} + GA_3 + NBPT was either similar or superior to the rest of treatment combination especially 150 kg N ha^{-1} suggesting that GA_3 + NBPT can reduce the use of urea without having any negative impact on crop yield (Table 4).

Results demonstrated that application of different levels of N alone and treated with GA_3 and/or NBPT significantly improved maize grain yield over control plots. The combine application of NBPT + GA_3 with 150 kg N ha^{-1} produced higher grain yield (2746 kg ha^{-1}) with 56.5% increase over sole 150 kg N ha^{-1}, while application of 120 kg N ha^{-1} with NBPT + GA_3 increased grain yield of maize by 63.3% over sole application of 120 kg N ha^{-1}. NBPT application with 150 kg N ha^{-1} increased grain yield by 31.45% over the sole application of 150 kg N ha^{-1} and when applied with lower N level (120 kg N ha^{-1}) increased grain yield by 41.35% over control plots. Similarly, GA_3 applied with 150 kg N ha^{-1} enhanced grain yield by 22.73% over sole application of 150 kg N ha^{-1} and when applied with 120 kg N ha^{-1}. The increase in grain yield was 22.41% over sole application of 120 kg N ha^{-1}. Data further showed that sole application of both N levels also improved maize grain yield over untreated plots.

Statistical analysis of the data showed that biological yield was directly proportional to N levels from 120 to 150 kg ha^{-1} (Table 5). Analysis of the data illustrated that combined use of both GA_3 and NBPT with higher N levels produced significantly higher biological yield (12272 kg ha^{-1}) with 33.2% increase over respective N level alone and 9.4% over lower N level (120 kg N ha^{-1}) under the same treatment. Lower N level (120 kg N ha^{-1}) + GA_3 + NBPT resulted 27.3% more

Table 2 Plant height (cm) of maize crop as affected by different nitrogen levels, urease inhibitor (NBPT), and gibberellic acid (GA_3)

Treatment	Height (cm)	% ↑ over control	% ↑ over respective N levels	% ↑ N2 over N1
Control	145e	----	----	----
120 kg N ha^{-1}	177d	22.19	----	----
150 kg N ha^{-1}	185d	27.58	----	4.3
120 kg N ha^{-1} + GA_3	213c	46.89	20.33	----
150 kg N ha^{-1} + GA_3	220a	51.72	18.91	3.1
120 kg N ha^{-1} + NBPT	197b	35.86	11.29	----
150 kg N ha^{-1} + NBPT	199b	37.24	7.56	1.01
120 kg N ha^{-1} + GA_3 + NBPT	224a	54.48	26.55	----
150 kg N ha^{-1} + GA_3 + NBPT	228a	57.24	23.24	1.75
$LSD_{0.05}$	15.57			

Means with different letters in the 2nd column are significantly different from each other at 5% probability

biological yield over respective N level alone, while 150 kg N ha^{-1} treated with NBPT improved biological yield up to 11.0% over sole application of respective N level and 3.2% over 120 kg N ha^{-1} under same treatment. However, application of 120 kg N ha^{-1} coated with NBPT increased the maize biological yield by 12.7% over the sole application of 120 kg N ha^{-1}. GA_3 applied with higher N level improved yield by 6.4% over its sole use and GA_3 treated with 150 kg N ha^{-1} improved by 6.4% over 120 kg N ha^{-1} alone. Sole application of each N level also improved biological yield over control plot. The combined application of GA_3 and NBPT with urea considerably enhanced maize biological yield over their sole application.

Maize stover yield was significantly improved with application of N levels alone and in combination with GA_3 and/or NBPT over control plots (Table 6). Stover yield was increased with increasing N levels. Maximum stover yield (9526 kg ha^{-1}) was recorded in plot amended with 120 kg N ha^{-1}coated with NBPT + GA_3 with increase of 27.6% over sole application of 150 kg N ha^{-1}. Application of 120 kg N ha^{-1} along with GA_3 + NBPT increased stover yield by 19.4% over its sole application, while application of 150 kg N ha^{-1} coated with NBPT increased stover yield by 6.24% over its sole application. Similarly, 120 kg N ha^{-1} coated with NBPT increased stover yield by 6.4% over its sole application. The results further demonstrated that 150 kg N ha^{-1} applied with GA_3 improved stover yield by 2.6% over its sole application, while the application of 120 kg N ha^{-1} + GA_3 increased stover yield of maize by 2.85% over 120 kg N ha^{-1} applied alone. Both N levels alone also enhanced stover yield of maize significantly over control plots.

Maize N concentration (%) and uptake (kg ha^{-1})

Data regarding maize N content and N uptake as affected by the sole application of different nitrogen levels and in combination with plant growth regulators (GA_3) and urease inhibitors (NBPT) are presented in Table 7. Application of both nitrogen levels alone and treated with GA_3 and NBPT significantly improved maize N content and uptake over control plots. N concentration in plant was directly proportional to N fertilizer application rate alone and in combination with

Table 3 Thousand grain yield (g) of maize crop as affected by different nitrogen levels, urease inhibitor (NBPT), and gibberellic acid (GA_3)

Treatment	1000 grain weight (g)	% ↑ over control	% ↑ over respective N levels	% ↑ N2 over N1
Control	234f	----	----	----
120 kg N ha^{-1}	271e	15.81	----	----
150 kg N ha^{-1}	276de	17.95	----	1.84
120 kg N ha^{-1} + GA_3	282cd	20.51	4.059	----
150 kg N ha^{-1} + GA_3	294c	25.64	6.522	4.25
120 kg N ha^{-1} + NBPT	315b	34.62	16.236	----
150 kg N ha^{-1} + NBPT	318ab	35.90	15.217	0.95
120 kg N ha^{-1} + GA_3 + NBPT	325ab	38.89	19.926	----
150 kg N ha^{-1} + GA_3 + NBPT	330a	41.03	19.565	1.53
$LSD_{0.05}$	14.137			

Means with different letters in the 2nd column are significantly different from each other at 5% probability

Table 4 Grain yield (kg ha^{-1}) of maize and increase in yield (%) by NBPT and GA_3 over control and respective N levels

Treatment	Grain yield (kg ha^{-1})	% ↑ over control	% ↑ over respective N levels	% ↑ N2 over N1
Control	1017e	----	----	----
120 kg N ha^{-1}	1584d	55.75	----	----
150 kg N ha^{-1}	1755c	72.56	----	9.74
120 kg N ha^{-1} + GA_3	1939c	90.65	22.41	----
150 kg N ha^{-1} + GA_3	2154b	111.79	22.73	9.98
120 kg N ha^{-1} + NBPT	2239b	120.15	41.35	----
150 kg N ha^{-1} + NBPT	2307b	126.84	31.45	2.94
120 kg N ha^{-1} + GA_3 + NBPT	2587a	154.37	63.32	----
150 kg N ha^{-1} + GA_3 + NBPT	2746a	170.01	56.46	6.1
$LSD_{0.05}$	209.70			

Means with different letters in the 2nd column are significantly different from each other at 5% probability

GA_3 and NBPT. The higher N content (1.15%) was recorded in plots received GA_3 + NBPT with 150 kg N ha^{-1} followed by 1.05% in plots received GA_3 + NBPT with 120 kg N ha^{-1}. The plot treated with 150 kg N ha^{-1} and 120 kg N ha^{-1} along with NBPT resulted 0.93% and 0.89% N content, respectively. In case of sole application of gibberellic acid with each 120 and 150 kg N ha^{-1} in the plant N concentration was 0.95% and 0.98% N content, respectively. However, plots treated with GA_3 were consistently higher in N content as compared to NBPT under similar N levels. These results showed that both NBPT and GA_3 improved N content alone and combination. In case of N uptake, each N level alone and in combination with GA_3 and NBPT increased N uptake over control plots. The higher N uptake (134.99 kg ha^{-1}) was recorded in plants treated with 150 kg N ha^{-1} + GA_3 + NBPT followed by 120 kg N ha^{-1} + GA_3 + NBPT (120.01 kg ha^{-1}). The plots where nitrogen was applied with NBPT alone resulted in lower N uptake than those treated with GA_3 alone under similar N level. The lowest N uptake (33.7 kg ha^{-1}) was recorded in control plots.

Discussion

Climatic and environmental conditions are crucial for plants, animals, and humans (Fahad et al. 2019a; Fahad et al. 2021a, b, c, d, e; Bilen et al. 2019; Akcura et al. 2019; Akman et al. 2019; Sayyed et al. 2019; Sonmez et al. 2016; Iftikhar et al. 2021; Tauqeer et al. 2021a, b). Application of plant growth regulators (GA_3) exerts stimulatory and beneficial effects on plant growth and development which is well studied in legumes and vegetables (Naeem et al. 2021; Rasool et al. 2021; Zubair et al. 2021). Our results confirm the improvement in plant height, thousand grain weight, grain yield, biological yield, and stover yield in response to fertigation of GA_3 and urease inhibitor (NBPT). Yield and yield components of maize were significantly increased with the sole and combine application of nitrogen fertilizer with GA_3 and NBPT. Such improvement with GA_3 application might be due to cell elongation, cell division, and lentil growth as a result of metabolic pathways of protein synthesis in plant. These results were supported by number of earlier researchers (Naeem et al. 2004; Giannakoula et al. 2012; Ghodrat et al.

Table 5 Biological yield (kg ha^{-1}) of maize crop as affected by different nitrogen levels, urease inhibitor (NBPT), and gibberellic acid (GA_3)

Treatment	Biological yield (kg ha^{-1})	% ↑ over control	% ↑ over respective N levels	% ↑ N2 over N1
Control	5723e	----	----	----
120 kg N ha^{-1}	8811d	53.95	----	----
150 kg N ha^{-1}	9223cd	61.15	----	4.67
120 kg N ha^{-1} + GA_3	9373cd	63.77	6.37	----
150 kg N ha^{-1} + GA_3	9813c	71.46	6.39	4.69
120 kg N ha^{-1} + NBPT	9928c	73.47	12.67	----
150 kg N ha^{-1} + NBPT	10241bc	78.94	11.04	3.15
120 kg N ha^{-1} + GA_3 + NBPT	11216ab	95.98	27.29	----
150 kg N ha^{-1} + GA_3 + NBPT	12272a	114.43	33.15	9.41
$LSD_{0.05}$	1087.0			

Means with different letters in the 2nd column are significantly different from each other at 5% probability

Table 6 Stover yield (kg ha^{-1}) of maize crop as affected by different nitrogen levels, urease inhibitor (NBPT), and gibberellic acid (GA_3)

Treatment	Stover yield (kg ha^{-1})	% ↑ over control	% ↑ over respective N levels	% ↑ N2 over N1
Control	4706e	----	----	----
120 kg N ha^{-1}	7228d	53.59	----	----
150 kg N ha^{-1}	7468cd	58.69	----	3.2
120 kg N ha^{-1} + GA_3	7434cd	57.96	2.85	----
150 kg N ha^{-1} + GA_3	7659bcd	62.74	2.55	2.93
120 kg N ha^{-1} + NBPT	7689bcd	63.38	6.37	----
150 kg N ha^{-1} + NBPT	7934bc	68.59	6.24	3.08
120 kg N ha^{-1} + GA_3 + NBPT	8629ab	83.36	19.38	----
150 kg N ha^{-1} + GA_3 + NBPT	9526a	102.42	27.56	9.41
$LSD_{0.05}$	1060.1			

Means with different letters in the 2nd column are significantly different from each other at 5% probability

2012), who reported that application of GA_3 increased plant height, number of nodes, and internodes as compared to control plots. However, latest research by Rafique et al. (2021) showed that exogenous application of gibberellic acid alone and in combination with *Rhizobium* increased plant height, grain yield, stover yield, and improved nodules number and their dry biomass in chickpea, and also improved macronutrient uptake in plant. This study further showed promising result for GA_3 in combination with NBPT, may be due to continuous availability of nitrogen throughout cropping season as a result of slow release of urea in presence of NBPT (Zaman et al. 2014) and higher N uptake due to urease inhibitor (Eduardo et al. 2012; Karimi et al. 2012; Fahad et al. 2019b). These results are also in line with Dawar et al. (2011) who reported that application of urease inhibitor improved yield and yield component up to 20% as compared to sole application of urea. Secondly, GA_3 increased macronutrient uptake by enhancing metabolism activities in plant. Gupta et al. (2007) also reported that application of plant growth regulators increased N and P contents by increasing fertilizers use efficiency. Recently, Rafique et al. (2021) observed that application of GA_3 alone and in combination with *Rhizobium* increased N, P, and K contents by 18, 47, and 15% in stover of chickpea. Earlier, Nabizadeh et al. (2012) and Giannakoula et al. (2012) also observed that application of growth regulators improved maize thousand grain weight as compared to untreated plots. The increase in grain, stover, and biological yields may be due to increase in NUE by NBPT.

Urease inhibitors slow down the urea hydrolysis and reduce nitrification, denitrification and immobilization processes, and NH_3 volatilization (Zaman et al. 2013). It also makes N available throughout cropping season. Similar results were found by different scientists (Rawluk et al. 2001; Jiao et al. 2004; Hou et al. 2006; Zhao et al. 2007; Zaman et al. 2009; Dawar et al. 2011; Shah et al. 2012; Liu et al. 2013) who reported that urea treated with urease inhibitor minimized NH_3 volatilization up to 15%, 79%, and 10% and N_2O emission up to 38%, 66%, and 29% during summer, autumn, and spring, respectively, over urine alone, which directly

Table 7 Plant N content (%) and N uptake (kg ha^{-1}) as affected by different nitrogen levels, urease inhibitor (NBPT), and gibberellic acid (GA_3)

Treatment	Plant N content (%)	N uptake (kg ha^{-1})
Control	0.59f	33.77e
120 kg N ha^{-1}	0.77e	67.84d
150 kg N ha^{-1}	0.82d	75.63cd
120 kg N ha^{-1} + GA_3	0.95bc	89.04c
150 kg N ha^{-1} + GA_3	0.98b	96.17c
120 kg N ha^{-1} + NBPT	0.89d	88.36c
150 kg N ha^{-1} + NBPT	0.93c	95.24c
120 kg N ha^{-1} + GA_3 + NBPT	1.07ab	120.01b
150 kg N ha^{-1} + GA_3 + NBPT	1.1a	134.99a
$LSD_{0.05}$	0.115	13.4

Means with different letters in each column are significantly different from each other at 5% probability improved pastured production. Number of scientists (Zhao et al. 2007; Khalil et al. 2009; Dawar et al. 2011; Sanz-Cobena et al. 2012; Shah et al. 2012; Khan et al. 2014a, b) reported that use of urease inhibitor can increase yield and yield component and also reduced nitrogen losses. Secondly, GA_3 also increased the plant N uptake by increasing cell division. It also increases the length and growth rate of cells and hence biological yield (Ghodrat et al. 2012). Similar results were found by Giannakoula et al. (2012); Azizi et al. (2012); and Nabizadeh et al. (2012). They reported that plant growth regulators significantly improved biological yield of different crops over control plots. Thakare et al. (2011) observed that application of GA_3 has a positive effect on shoot and root length in chickpea and concluded that it might be due to the role of gibberellins in cell multiplication, elongation, and metabolic pathways of protein synthesis. It has been observed that plants have potential to store excess of exogenously applied hormones as reversible conjugates and are released during the growth period as active hormone where and when plants need them. Mustafa et al. (2016) and Solaimalai et al. (2001) found that PGRs play important role in source and sink dynamics of field crops through improving distribution and transportation of accumulates.

Conclusion

The application of GA_3 and/or NBPT improved maize yield and N uptake from urea irrespective of their levels (120/150 kg N ha^{-1}). Their (GA_3 and NBPT) combine application was more effective than their individual application for improving crop growth. It was also evident that their application can minimize the use of synthetic N fertilizers under calcareous soils without compromising crop yield. Therefore, combined application of both plant growth regulator (GA_3) and urease inhibitor (NBPT) would be an efficient approach to reduce nitrogen losses and enhance maize productivity in calcareous soils. However, multisite field trials on different crops and different levels of both GA_3 and NBPT are required for economical perspectives and sustainable use prior to commercial use on large scale and for more attractive performance of the technology under different field conditions.

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Author contribution Muhammad Adnan and Shah Fahad conceived the idea of the experiment and provided technical guidance. Ikram Ullah, Khadim Dawar, Muhammad Tariq, Muhammad Sharif, Haroon Ilahi, Taufiq Nawaz, and Mukhtar Alam had a major contribution to the overall preparation and carrying out of the research. Amanullah and Muhammad Arif contributed to arranging the data for different attributes and provided support for the experiment. Shah Fahad revised and edited the manuscript and provided technical guidance and editing support.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate We all declare that manuscript reporting studies do not involve any human participants, human data, or human tissue. So it is not applicable.

Consent for publication Our manuscript does not contain data from any person, so it is "Not applicable."

Competing interests The authors declare no competing interests.

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