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Evaluation of yield and nitrogen utilisation with urease and nitrification inhibitors in sweet potato crop (*Ipomoea batatas* L.)

*Ioanna Kakabouki, Triantafyllos Togias, Antigoni Eleni Folina, Stella Karydogianni, Charikleia Zisi, Dimitrios Bilalis**

Department of Crop Science, Agricultural University of Athens, 75 Iera Odos Str., 11855 Athens, Greece

ABSTRACT

Sweet potato (*Ipomoea batatas* L.) is a new tuber crop grown in Greece. It constitutes an innovative dietary component for both humans and animals, due to its nutritional properties. The cultivation of sweet potato focuses on the growth of both tubers and plants. Nitrogen is considered an essential element for almost all crops. This study set out to compare the effect of nitrogen inhibitors on yield components of sweet potato. In the literature, it is stated that in sweet potato cultivation nitrogen mainly affects the plants' growth such as the tuber's yield and some quality characteristics such as dry matter and protein content. To furthermore explore this particular area, field experiments took place in West Greece, during the years 2018 and 2019. Several urea combination treatments were used in the experimental process. The treatments were urea (46-0-0), urea with urease inhibitor (UI), urea with nitrification inhibitor (NI), urea with double inhibitors (UI + NI) and control (without fertilizer) in a randomised complete block design. Leaf area index (LAI) was significantly affected by the fertilizer marking the highest value of 5.35 under urea + UI + NI treatment. Marketable yield was profoundly affected by the fertilizer in the experimental years and ranged from 18,180 to 23,230 Kg · ha^{-1} whereas non-marketable yield was not affected by the fertilizer. A considerable impact of fertilizers was noticed on yield where the highest value was 30,923 Kg · ha^{-1} under urea + NI + UI treatment. The percentage of nitrogen on tubers and upper parts was significantly affected by the fertilizers. Nitrogen markers, such as nitrogen use efficiency (NUE), nitrogen harvest index and nitrogen agronomic efficiency (NAE), were used to evaluate nitrogen release. A significant positive correlation was noticed between marketable yield and NUE (0.774). Also, the significant increase in yield showed a positive correlation with NAE (0.727). For yield components of sweet potato, the highest values were observed in urea with double inhibitors treatment in both experimental years.

Keywords: marketable yield, NHI, nitrogen inhibitor, NUE, sweet potato

Abbreviations:

DCD, dicyandiamide; DM, dry matter; LSD, least significant difference; NAE, nitrogen agronomic efficiency; NBPT, N-(n-butyl)thiophosphoric triamide; NI, nitrification inhibitor; NUE, nitrogen use efficiency; RCBD, randomised complete block design; UI, urease inhibitor; NHI, nitrogen harvest index.

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is a crop that has been cultivated since ancient times. Nowadays, it is considered as an innovative crop mainly in the dietary area due to the new trends in human nutrition in developing countries. Furthermore, scientific concerns about environmental pollution and research

*Corresponding author.
e-mail: bilalisdimitrios@gmail.com (Dimitrios Bilalis).

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on low environmental impact crops have led to an even greater positive evaluation of sweet potato crop. From a nutritional aspect, it contains many important nutrients for human health, as in all vegetables, as well as for animal feed. This is the main reason that sweet potato is a very significant crop in the food industry. Logestein (2009) reported that sweet potato is regarded as a safe food crop due to its ability to survive and grow under difficult tropical conditions and in infertile soils. The high rate of sweet potato productivity increases the importance of its economic cultivation and contribution in the food safety sector (Tumwegamire et al., 2004). According to FAOSTAT (2020), the worldwide sweet potato cultivation area in the year 2018 was 8,062,737 ha and the yield was 114,037 $Kg \cdot ha^{-1}$.

Furthermore, the main profitable part of the sweet potato plant is the root tubers. Thus, fertilizer should be applied efficiently in order to boost both aboveground and underground growth. Nitrogen is an essential factor for plant growth. Bouwkamp (1985) reported that increased nitrogen uptake may also increase the growth of storage roots. In addition, other studies support that nitrogen increases root yield and nutritional value. Concerning the quality characteristics of sweet potato, nitrogen increases tuber dry matter (DM), carotenoid and protein content.

However, the use of larger nitrogen-based fertilizer quantities than needed by the plants results in incapability of nitrogen assimilation, thus causing environmental problems (Guarda et al., 2004; Zheng et al., 2007). For this particular reason, the need for nitrogen indicators, which will be used to determine the optimum amount of nitrogen that can positively affect plant growth without causing any adverse effects on the environment, is essential. In the international reports, many researchers emphasise using indicators to assess fertilizer performance (Kakabouki et al., 2018). In addition, it is noteworthy that the indicators express the yield of fertilizers and they are, therefore, useful in improving fertilizers. One of these indicators is nitrogen use efficiency (NUE), an indicator that expresses the ratio of yield to nitrogen content in the soil as well as nitrogen utilisation efficiency (Kakabouki et al., 2014). Other indicators are nitrogen harvest index (NHI), referring to the ratio of the nitrogen content of the tubers to the nitrogen content of the whole plant, and nitrogen agronomic efficiency (NAE), representing the increase in biomass in the applied nitrogen unit in the soil. Moreover, Arregui and Quemada (2008) reported that NAE is important because it promotes the use of nitrogen fertilizers in plant growth, without adverse environmental effects.

According to Mullen (2011), nitrogen fertilizer should be applied almost a month before planting sweet potatoes to assure the most efficient use of nitrogen by the crop and reduce the losses caused by volatilisation and denitrification procedures. Urease inhibitor (UI), N-(n-butyl)thiophosphoric triamide (NBPT), and the nitrification inhibitor (NI), dicyandiamide (DCD), are the most frequently used inhibitors. They are all used as additives in urea. NI is designed to inhibit the microbes that break down ammonium (NH_4^+) to nitrate (NO_3^-) ion, whereas UI relays urea ($CO(NH_2)_2$) conversion to NO_4^+ ion. This way, the NH_3^- losses are better controlled.

While the use of new types of fertilizers is consolidated in the market and sweet potato cultivation gains space as a preferable new crop in Greece, the need for further exploring the way the fertilizers affect yield and nitrogen concentration in tubers and aboveground part has arose. Additionally, in order to evaluate the quantity of nitrogen that must be used, research must be conducted to examine the amount of nitrogen that is disposed of by the plant, both the underground and the aboveground part. For this purpose, NUE, NAE and NHI nitrogen indicators were calculated. As there is no experimental data of using fertilizers with inhibitors and no literature is available concerning their effect on sweet potato cultivation, the objective of this study is to determine the inhibitors' influence on the sweet potato cultivation and the performance of nitrogen inhibitors.

MATERIALS AND METHODS

Experimental design

The sweet potato crop was evaluated during the growing period through the years 2018 and 2019 in Katakolo Area (latitude: 37°40′44.7″ N, longitude: 21°19′ 16.3″ E, altitude: 5 m above sea level) in West Greece. The soil is classified as SCL (35.9% sand, 29.8% clay and 34.3% loam), with pH 6.85 (1:1 water H_2O) and 2.11% organic matter content (Wakley and Black, 1934). Weather data (rainfall and average temperature) of the experimental site are shown in Figure 1. The field experiment was set up in randomised complete block design (RCBD), where blocks/replicates were the various urea combination treatments (urea, urea + urease inhibitors thiophosphoric-triamide (NBPT) (UI), urea + nitrogen inhibitors dicyandiamide (DCD) (NI) + UI) and control. In both years, the rate of fertilizers was 0 $Kg \cdot N \cdot ha^{-1}$

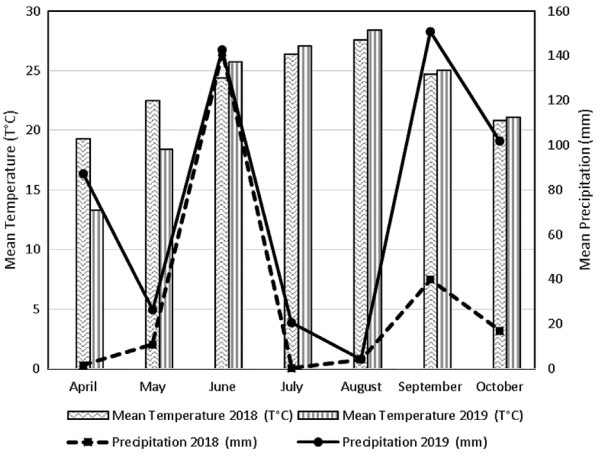


Figure 1. Meteorological data in the experimental area for the years 2018 and 2019.

for control and 120 Kg · N · ha^{-1} for urea, urea + UI and urea + NI + UI treatments. Each treatment has the same probability of capturing an experimental plot within a block. The randomisation was performed separately in each block. The whole amount of fertilizers was applied before transplanting. The NI used was DCD and the UI used was NBPT.

The range of experimental area was 800 m^2, which was devised in four blocks with four plots (40 m^2) each. Soil tillage encompasses agronomic chisel at a depth of 40 cm, followed by secondary tillage with a disc harrow. The sweet potato variety used was Beauregard 'B-63'. The plants were manually sown on 10 April 2018 and 12 April 2019. Plant density was 3,200 plants per ha, row spacing 80 cm and intra-row spacing 40 cm.

The irrigation system used was a drip line that was applied over the soil surface and water was distributed every 15 days. The sweet potato tubers were manually harvested in the first week of October. Curing period for the roots was 1 week under the climate conditions of 28°C and 80–90% relative humidity.

Sampling and analytical methods

The sampling date to determine the agronomical traits, yields and nitrogen indicators was harvest day. Measurement of LAI was estimated using Sunshine Sensor type BF5, SunScan ΔT devices. The classification of marketable yield (Kg · ha^{-1}) and non-marketable yield (Kg · ha^{-1}) was done according to the weight of the harvested tubers. If the weight of the tubers was >100 g then it was characterised as marketable and if it is <100 g, it was classified as non-marketable sweet potato tubers. Mean fresh weight tuber (Kg) was determined after harvest. DM tuber (Kg · ha^{-1}) and DM upper, leaves and stems (Kg · ha^{-1}) were determined after drying for 72 h at 75°C. Samples were chosen randomly within each plot. The tuber nitrogen content (%), upper parts (stems and leaves) nitrogen content (%) and protein content were determined by the Kjeldahl method (Bremmer, 1960) using a K-316 Distillation Unit device, Büchi.

Calculations and statistics

Marketable tubers are expressed as a percentage according to Eq. (1).

$$\%\ \text{of marketable} = \left(\frac{\text{marketable yield}}{\text{yield}}\right) * 100 \tag{1}$$

Furthermore, yield (Kg · ha^{-1}) was calculated by adding marketable and non-marketable yields.

To estimate the nitrogen uptake in tuber (Kg · ha^{-1}), the nitrogen content in tubers (%) was multiplied by DM tuber (Kg · ha^{-1}). Accordingly, nitrogen uptake in upper parts (Kg · ha^{-1}) is the multiplication result of DM upper, leaves and stems (Kg · ha^{-1}) and upper parts (stems and leaves) nitrogen content (%). nitrogen total uptake Kg · ha^{-1} is derived by adding the nitrogen uptake in upper parts (Kg · ha^{-1}) and nitrogen uptake in tuber (Kg · ha^{-1}).

Tuber protein yield (Kg · ha^{-1}) was estimated by the following mathematical equation:

$$\text{Tuber protein yield} = \left(\frac{\text{DM tuber (Kg} \cdot \text{ha}^{-1}) * \text{N tuber (\%)} * 6.38}{100}\right) \tag{2}$$

One of the nitrogen indicators that was used is NUE according to the following equation:

$$\text{NUE} = \{\text{N total uptake (Kg} \cdot \text{ha}^{-1}) - \text{N total updake}_{\text{control}}\text{(Kg} \cdot \text{ha}^{-1})\}\ \text{Kg} \cdot \text{N} \cdot \text{ha}^{-1} \tag{3}$$

Another nitrogen indicator is NHI, which was defined as the ratio of the concentration of nitrogen in the tubers (tuber nitrogen uptake) to the total nitrogen in the plant (total plan nitrogen uptake). NHI is an important indicator in determining crop yield, mainly because it is positively related to tubers yield (Eq. (4)).

$$\text{NHI} = \frac{\text{tuber N uptake (Kg)}}{\text{total plan N uptake (Kg)}} \tag{4}$$

The index of NAE expresses the amount of seed produced per Kg of nitrogen fertilizer and is calculated by Eq. (5).

$$\text{NAE} = \frac{[\{\text{yield of fert plot (Kg)} - \text{yield of unfert plot (Kg)}\}]}{\text{quant of N applied (Kg)}} \tag{5}$$

Analysis of variance was carried out on data using the Statsoft (2011) logistic package as an RCBD. The significance of differences between treatments was estimated using Fisher's least significant difference (LSD) test, where probabilities ≤ 0.05 are considered as significant. The tests of correlation coefficients and linear regression by Statistica software were set at two levels with significance (α = 0.05) and remarkable significance (α = 0.01).

RESULTS

Regarding LAI, values ranged from 5 to 5.14 during the first year of cultivation (2018) and from 4.9 to 5.35 during the second year (2019) (Table 1). The maximum LAI value was 5.35, when urea with double inhibitors treatment was applied, and the lowest value was 4.9 in control, during the second year (2019). In both years A and B, urea and urea with inhibitors urease and nitrification treatment had statistically significant difference with the urea + UI treatment. Regarding the number of tubers per plant, the highest value was 6.39 per plant in urea with double inhibitors treatment (year 2018) and the lowest 5.25 per plant in control (year 2019). In both years, urea + NI + UI and the urea with inhibitor urease treatment had statistically significant difference with all other treatments. Concerning

Table 1. Effect of fertilizer (urea, urea + UI, urea + NI + UI, control) and both years of experiment (year A: 2018 and year B: 2019) on LAI, number of tuber per plant, marketable yield (Kg · ha^{-1}), non-marketable yield (Kg · ha^{-1}), percentage of marketable, tubers (no · ha^{-1}), mean fresh weight tuber (Kg), yield (Kg · ha^{-1}), DM upper leaves and stems (Kg · ha^{-1}), N% tuber, N% upper parts by Fisher's LSD

	LAI	No tuber per plant	Marketable yield (Kg · ha^{-1})	Non-marketable yield (Kg · ha^{-1})	Percentage of marketable	Tubers (no · ha^{-1})	Mean fresh weight tuber (Kg)	Yield (Kg · ha^{-1})	DM upper leaves and stems (Kg · ha^{-1})	N% tuber	N% upper parts
Year A											
Urea	5 ac	5.75 a	20,072 a	7,273 ns	73 ns	184,122 a	0.149 ns	27,346 a	5,150 ac	1.026 a	0.470 a
Urea + UI	5.07 b	6.23 b	22,285 b	7,530 ns	75 ns	201,739 b	0.148 ns	29,815 b	5,406 bc	1.169 b	0.476 b
Urea + NI + UI	5.14 a	6.39 b	23,230 b	7,694 ns	75 ns	204,522 b	0.151 ns	30,923 b	5,411 b	1.330 c	0.490 b
Control	5.05 c	5.50 a	18,412 c	6,866 ns	73 ns	175,304 a	0.144 ns	25,433 c	5,111 a	1.076 ab	0.436 a
Year B											
Urea	5.11 ac	5.42 a	19,700 a	7,963 ns	71 ns	173,280 a	0.160 ns	27,663 a	5,288 ac	1.083 a	0.493 a
Urea + UI	5.25 b	5.75 b	20,902 ab	8,103 ns	72 ns	183,760 b	0.158 ns	29,005 b	5,488 bc	1.158 b	0.480 b
Urea + NI + UI	5.35 a	6.08 b	21,273 b	8,518 ns	72 ns	194,800 b	0.152 ns	29,515 b	5,705 b	1.293 c	0.483 b
Control	4.90 c	5.25 a	18,180 c	7,990 ns	74 ns	168,240 a	0.109 ns	18,440 c	5,017 a	0.825 ab	0.325 a
$F_{fertilization}$	7.88***	35.759***	57.504***	1.615 ns	0.23 ns	35.759***	1.795 ns	40.776***	11.376***	26.702***	3.419*
F_{year}	5.088*	28.603***	17.664***	12.394**	2.316 ns	28.603***	5.072*	2.653 ns	2.523 ns	0.002 ns	0.163 ns
$F_{fertilization \times year}$	0.917 ns	1.196 ns	3.097*	0.272 ns	0.545 ns	1.196 ns	0.881 ns	1.007 ns	1.47 ns	0.99 ns	0.25 ns

Mean values and the Fisher's LSD ($p = 0.05$) for fertilizer and year are presented.
Different letters within a column indicate significant differences according to LSD test ($p = 0.05$).
Significance levels: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns, not significant ($p > 0.05$).
F-test ratios are from ANOVA.

the marketable yield values, a range from 18,412 to 23,230 Kg · ha^{-1} during year A and a range from 18,180 to 21,273 Kg · ha^{-1} during year B were marketed. The highest value estimated was 23,230 Kg · ha^{-1} in year A and the lowest was 18,180 Kg · ha^{-1} in year B. During the first year of experimenting, urea + UI and the urea + NI + UI treatments had statistically significant difference with all the other treatments but during the second year urea with double inhibitors treatment had statistically significant difference with the urea and control treatment (Table 1). It is worth noting that in both non-marketable yield and marketable percentage, none of the treatments had statistically significant difference during both years. Also, the values of tubers ranged from 175,304 to 204,522 ha^{-1} in year A and from 168,240 to 194,800 ha^{-1} in year B. Urea + NI + UI and the urea + UI treatment had statistically significant difference with all other treatments. The highest value was 204,522 ha^{-1} in urea with double inhibitors treatment, year A, and the lowest was 168,240 ha^{-1} in control, year B.

In Table 1, the treatments in mean weight fresh tuber did not mark statistically significant difference between them in both years. The values ranged from 0.144 to 0.151 Kg during year A and from 0.109 to 0.160 Kg during year B. Moreover, the yield's values ranged from 25,433 to 30,923 Kg · ha^{-1} in year A and from 18,440 to 29,515 Kg · ha^{-1} in year B. Urea with double inhibitors and urea + UI treatment had statistically significant difference with all other treatments in both years. The highest value was marked at 30,923 Kg · ha^{-1} for urea + NI + UI treatment during year A. Also, the values for DM leaves and stems, ranged from 5,111 to 5,411 Kg · ha^{-1} during the first year and from 5,017 to 5,488 Kg · ha^{-1} during the second year. The highest value was 5,488 Kg · ha^{-1} in urea with inhibitor urease treatment and the lowest was 5,017 Kg · ha^{-1} in control, during year B (Table 1). In both years, urea did not mark statistically significant difference with control and urea + UI treatment. Urea with double inhibitors marked statistically significant difference with control and urea treatment (Table 1). Concerning the percentage of nitrogen in tuber, the highest value was 1.330% in urea + NI + UI treatment (year A) and the lowest was 0.825% in control (year B). During the first and second years, urea with double inhibitors treatment showed statistically significant difference with all other treatments. However, control showed no statistically significant difference with urea and with urea + UI treatment. The values of the nitrogen percentage in upper parts of sweet potato ranged from 0.436 to 0.490% in year A and from 0.325 to 0.493% in year B. The highest value was 0.493% in urea + NI + UI treatment (year A) and the lowest was 0.325% in control (year B). Urea with double inhibitors and urea with inhibitor urease showed statistically significant difference with all other treatments (Table 1).

Urea + NI + UI and urea + UI treatment concerning nitrogen uptake in upper parts showed statistically significant difference with urea and with control treatment in both years A and B. The values ranged from 22,494 to 26,540 Kg · ha^{-1} in the first year and from 16,112 to 27,546 Kg · ha^{-1} in the second year. The highest value was 27,546 Kg · ha^{-1} and the lowest value was 16,112 Kg · ha^{-1} in the second year (Table 2). As for the nitrogen uptake in tuber, in both experiments, urea showed no statistically significant difference with control. However, urea with double inhibitors showed statistically significant difference with urea + UI, and with all other treatments. The highest value was 169 Kg · ha^{-1} in urea + NI + UI treatment (year A) and the lowest value was 81 Kg · ha^{-1} (year B).

Table 2. Nitrogen uptake in upper parts (Kg · ha^{-1}), nitrogen uptake in tuber (Kg · ha^{-1}), nitrogen total uptake (Kg · ha^{-1}), NUE, NHI and NAE as affected by fertilizer treatments (urea, urea + UI, urea NI + UI) and years (year A: 2018 and year B: 2019)

	Nitrogen uptake in upper parts (Kg · ha^{-1})	Nitrogen uptake in tuber (Kg · ha^{-1})	Nitrogen total uptake (Kg · ha^{-1})	NUE	NHI	NAE
Year A						
Urea	24.230 a	112 a	136 a	0.016 a	0.822 a	17.237 a
Urea + UI	25.760 b	139 b	165 b	0.276 b	0.844 ab	37.809 b
Urea + NI + UI	26.540 b	165 c	191 c	0.492 c	0.861 b	47.047 b
Control	22.494 a	110 a	132 a	–	0.829 c	–
Year B						
Urea	26.055 a	120 a	146 a	0.034 a	0.821 a	23.542 a
Urea + UI	26.435 b	134 b	161 b	0.263 b	0.836 ab	34.729 b
Urea + NI + UI	27.546 b	153 c	180 c	0.425 c	0.847 b	38.979 b
Control	16.112 a	81 a	97 a	–	0.625 c	–
$F_{fertilization}$	5.888**	68.165***	69.300***	65.327***	6.482**	24.464***
F_{year}	0.842 ns	1.222 ns	0.571 ns	0.323 ns	1.199 ns	0.103 ns
$F_{fertilization \times year}$	0.251 ns	2.216 ns	2.117 ns	0.452 ns	0.311 ns	0.658 ns

Mean values and the Fisher's LSD ($p = 0.05$) for fertilization and year are presented.
Different letters within a column indicate significant differences according to LSD test ($p = 0.05$).
Significance levels: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns, not significant ($p > 0.05$).
F-test ratios are from ANOVA.

Regarding the total nitrogen uptake, the values ranged from 132 to 191 Kg · ha^{-1} in the first year and from 97 to 180 Kg · ha^{-1} in the second year. The highest value was 191 Kg · ha^{-1} in year A and the lowest was 81 Kg · ha^{-1} in year B. About NUE, urea had no statistically significant difference with control. Urea + NI + UI treatment had statistically significant difference with the urea + UI treatment in both years A and B. The highest value was 0.492 in urea with double inhibitors treatment and the lowest value was 0.016 in urea treatment, in the first year (Table 2). With regard to NHI, urea + NI + UI treatment had statistically significant difference with urea, whereas urea had no statistically significant difference with urea + UI in both years A and B. Also, urea with double inhibitors had no statistically significant difference with urea + UI treatment. The lowest value was 0.625 in control, in the second year, and the highest value was 0.861 in urea + NI + UI treatment, in the first year. With respect to NAE, the values ranged from 17.237 to 47.047 in year A and from 23,542 to 38,979 in year B. The lowest value was 17,237 in urea and the highest was 47,047 during year A. Urea + NI + UI treatment had no statistically significant difference with urea + UI treatment. Moreover, urea had no statistically significant difference with control, in both first and second years (Table 2).

DISCUSSION

LAI was significantly increased by all applied inhibitors through fertilizers and was affected by the years. For fertilization rate of 125 Kg · N · ha^{-1}, Pushpalatha et al. (2018) evaluated LAI at 2.14, 120 days after planting. In the results of the present study, LAI ranged from 5 to 5.14 for 120 Kg · N · ha^{-1} application in the year 2018 and 5.11 to 5.35 in the year 2019. The marked increase in leaf area is also confirmed by Lebot's (2010) study. Still, other researchers suggest that the leaf surface index is affected by a variety of factors rather than only by fertilizer (Vosawai et al., 2015; Costantine, 2016).

As specified by our results, the marketable yield (Kg · ha^{-1}) was significantly affected by fertilizers and experimental year. These results also agree with the ones by Walker and Woodson (1987), Mortley and Hill (1990) and Fernandes et al. (2018). More specifically, Fernandes et al. (2018) and Mortley and Hill (1990) suggest that the nitrogen application greatly increases the marketable yield up to 13.5 t · ha^{-1}. However, these results disagree with Hartemink et al. (2000), who suggest that the marketable sweet potato yield was highest at 100 Kg · N · ha^{-1} application and lowest at 400 Kg · N · ha^{-1} application. There is a definite relationship among marketable yield, percentage of nitrogen in tuber and nitrogen uptake in tuber as shown in Table 3. Fernandes et al. (2018) mention that the relationship between marketable storage root and nitrogen uptake (Kg · ha^{-1}) was higher (R^2 = 0.63) than the one in storage root (R^2 = 0.6).

Table 3. Pearson's correlation coefficient (r) of yield measurements and nitrogen measurement indices

	N% tuber	N% upper parts	Nitrogen uptake in upper parts Kg · ha^{-1}	Nitrogen uptake in tuber Kg · ha^{-1}	Nitrogen total uptake Kg · ha^{-1}	Tuber protein yield Kg.ha^{-1}	NUE	NHI	NAE
LAI	0.530**	0.152 ns	0.309 ns	0.430*	0.446*	0.430*	0.488*	0.269 ns	0.370 ns
No tuber/plant	0.657***	−0.080 ns	0.046 ns	0.693***	0.666***	0.693***	0.631**	0.680***	0.284 ns
Marketable yield Kg · ha^{-1}	0.705***	0.148 ns	0.242 ns	0.819***	0.809***	0.819***	0.774***	0.643**	0.658***
Non-marketable yield Kg · ha^{-1}	0.185 ns	0.470*	0.634**	0.257 ns	0.321 ns	0.257 ns	0.269 ns	−0.133 ns	0.342 ns
% of marketable	0.281 ns	−0.344 ns	−0.386 ns	0.261 ns	0.202 ns	0.261 ns	0.249 ns	0.489*	0.154 ns
Tubers no ha^{-1}	0.657***	−0.080 ns	0.046 ns	0.693***	0.665***	0.693***	0.631**	0.680***	0.284 ns
Mean fresh weight tuber Kg	−0.163 ns	0.472*	0.452*	−0.059 ns	−0.001 ns	−0.058 ns	−0.023 ns	−0.383 ns	0.348 ns
Yield Kg · ha^{-1}	0.702***	0.399 ns	0.546**	0.858***	0.883***	0.858***	0.814***	0.495*	0.727***
DM tuber Kg · ha^{-1}	0.422*	0.433*	0.479*	0.511*	0.545**	0.512*	0.422*	0.199 ns	0.504*
DM upper Kg · ha^{-1} (leaves and stems)	0.382 ns	0.389 ns	0.756***	0.460*	0.529**	0.460*	0.565**	−0.0143 ns	0.420*

Correlation coefficients are significant at the 0.05 probability level.
Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant.

Table 1 presents that non-marketable yield ($Kg \cdot ha^{-1}$) was significantly affected by the experimental year and not by the fertilizer. This is something that is not confirmed by Hartemink et al.'s (2000) study, where it is noticed that nitrogen application significantly decreases non-marketable yield during two experimental years. In general, the performance of the inhibitor that significantly affected the sweet potato yield presents a slight decrease in the second year.

The results of this study observed that DM of leaves and stems ($Kg \cdot ha^{-1}$) was affected by the fertilizer and not by year. Vosawai et al. (2015) refer that the DM of upper part of the sweet potato is not affected by nitrogen fertilizer.

Nitrogen content was increased in upper parts of the plant compared with control in both years. Similar results were observed by Osaki et al. (1995). During 2018, we observed that the highest nitrogen content in upper parts was under urea plus two inhibitors (0.49%) treatment and the difference with control was 0.054. Nevertheless, in the year 2019, the highest nitrogen content in upper parts was noticed under urea fertilization treatment (0.493%) and the difference with control was 0.168%. These differences are lower than the ones in Pushpalatha et al.'s (2018) study, who observed that the difference of nitrogen content in the leaf is at the rate of 125 $Kg \cdot N \cdot ha^{-1}$ and control at 0.409%. However, in both cases, the nitrogen fertilizer application increases the nitrogen content in the above ground part of the sweet potato.

The percentage of nitrogen content in tuber was affected only by fertilizer. The significant influence of nitrogen fertilizers in tuber nitrogen content (%) was also observed by Pushpalatha et al.'s (2018) study. Specifically, the results of the current study for both years showed that higher nitrogen content in tuber was mentioned under urea + NI + UI treatment, 1.33% (2018) and 1.293% (2019). Similar results were observed by Pushpalatha et al. (2018), where the highest percentage of tuber nitrogen was noticed at 125 $Kg \cdot N \cdot ha^{-1}$ with 1.595% N.

In coherence with our results, Villagarcia et al. (1998) also mentioned that nitrogen uptake in tuber was significantly affected by fertilizers. However, Pushpalatha et al. (2018) noticed a 95.6 $Kg \cdot ha^{-1}$ nitrogen uptake in tuber at the rate of 125 $Kg \cdot N \cdot ha^{-1}$ application, which is opposite to the results of the present study, where tuber nitrogen uptake values of 110 $Kg \cdot ha^{-1}$ and 81 $Kg \cdot ha^{-1}$ were noticed in control. Under the fertilization of 120 $Kg \cdot N \cdot ha^{-1}$, whether it was with inhibitors or not, nitrogen uptake in tuber ranged from 112 (urea treatment) to 165 (urea NI + UI treatment) in 2018 and 120 (urea treatment) to 153 (urea NI + UI treatment) in 2019. Table 3 presents an upward trend of nitrogen uptake in the tuber. The difference in the measurements between 2000 and 2001 might be related to differences in rainfall patterns. This increase is also referred in Phillips et al.'s (2005) study. Researches around reduced levels of nitrogen reveal the increase in sweet potato nitrogen uptake (Du et al., 2019). Contrariwise were the results for total uptake nitrogen marked by Pushpalatha et al. (2018). In our data, total nitrogen update was noticed at 191 $Kg \cdot N \cdot ha^{-1}$ application (under urea + NI + UI fertilizers in the year 2018) and 197.09 $Kg \cdot N \cdot ha^{-1}$ application at Pushpalatha et al.'s (2018) study.

According to our findings, the tuber yield of sweet potato was significantly affected only by fertilizers and ranged from 25,433 $Kg \cdot ha^{-1}$ to 30,923 $Kg \cdot ha^{-1}$ in the year 2018. Loebenstein et al. (2009) mention that for 37,000–52,500 $Kg \cdot ha^{-1}$ the need is almost 200 $Kg \cdot N \cdot ha^{-1}$. The lowest tuber yield (control 25,433 $Kg \cdot ha^{-1}$) is close to the findings by Pushpalatha et al. (2017), 22,398 $Kg \cdot ha^{-1}$ tuber yield under 125 $Kg \cdot N \cdot ha^{-1}$. Hartemink et al. (2000) disconfirm the increase of yield due to nitrogen fertilizer whereas Abidin et al. (2017) and Bourke (1985) confirm it. Loebenstein et al. (2009) and Vosawai et al. (2015) state that fertilization rose tuber yield up to a limit. The fact that the sweet potato is not affected by nitrogen fertilization may be right as Stathers et al. (2013) and Dumbuya (2015) refer that potassium is more important. However, they state that the potassium nitrogen ratio should be 1:3.

Some researchers say that the availability of nitrogen helps the growth of shoots and leaves (Hartemink et al., 2000; Oliveira et al., 2010). The use of inhibitors in fertilizers promotes the growth of the tuber more than the growth of the aboveground part in sweet potato. Our results are in accordance with the studies of O'Sullivan et al. (1993) and Kays and Bouwkamp (1985), who noted that the reduction of nitrogen causes a reduction of the leaf surface and consequently a reduction of the production by 15–25%.

In this study, the number of tubers per plant that were recorded ranged from 5.5 to 6.39 in 2018 and from 5.25 to 6.08 in 2019. Pushpalatha et al. (2017) observed almost three tubers more per plant. Instead, Duan et al. (2019) observed more tubers per plant in control (4.23) and less under 150 Kg fertilizer ha^{-1} (2.9 tubers/plant).

Table 2 reveals information about tuber fresh weight. The highest was noted under urea + NI + UI fertilizer (0.151 Kg). Pushpalatha et al. (2017) beheld quadruple tuber fresh weight under 125 $Kg \cdot N \cdot ha^{-1}$ (0.45 Kg) application. Additionally, Bourke (1985) mentioned that more the nitrogen is added to the fertilizer, the greater the fresh weight of the tuber produced. Duan et al. (2019) confirm the above statement and mentioned that fresh storage root yield ($Kg \cdot ha^{-1}$) under 150 $Kg \cdot N \cdot ha^{-1}$ application was 36,265.72.

Many researchers have studied different factors (rates, dates of application) to increase nitrogen utilization in crops such as sweet potato. One of these research, Du et al. (2019), describes the application of nitrogen to various combinations. Our research mentions another important aspect that affects NUE, i.e., fertilizer inhibitors, such as NI and UI. Urea + NI + UI treatment enumerated the highest NUE value (0.492 and 0.425 in 2018 and 2019, respectively).

In Phillips et al.'s (2005) study, the use of 84 nitrogen ha^{-1} rate of NUE ranged from 28.4% to 23.6% in the first year. Other results by Phillips et al. (2005) and Fernandes et al. (2018) marked a decrease in NUE when increasing the rate during the two experimental years. On the other hand, Hill et al. (1990) present information on increasing NUE by raising the nitrogen rate. Specifically, NUE was noticed around 55% for cultivars with high nitrogen uptake levels (Hill et al., 1990). In relation to our results, NUE index for urea + NI + UI treatment is 49.2% in 2018 and 4.25% in 2019. Also, there are cultivars that do not significant affected by nitrogen rate so NUE (Martí and Mills, 2002).

Figure 2 depicts the correlation among fertilizers, marketable yield Kg · ha^{-1} and yield Kg · ha^{-1}, where it was noticed that when yield (Kg · ha^{-1}) rose the marketable yield also increased. The marketable yield (Kg · ha^{-1}) and yield (Kg · ha^{-1}) are increased by adding inhibitors in fertilizers. Comparing these two yields we noted that the marketable yield was influenced more by inhibitors in fertilizer than yield ($R^2 = 0.75$ and $R^2 = 0.54$, respectively).

Figure 3 presents the linear relationship between NUE, NAE nitrogen indicators and fertilizers with inhibitors. It was noted that the difference between NUE and NAE under urea fertilization in sweet potato

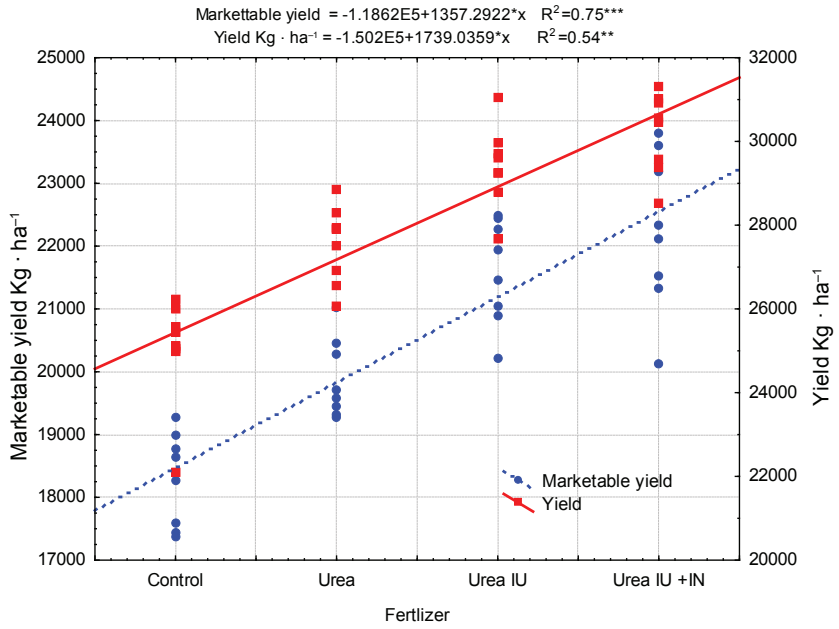


Figure 2. Correlation between different fertilizer, marketable yield and yield.

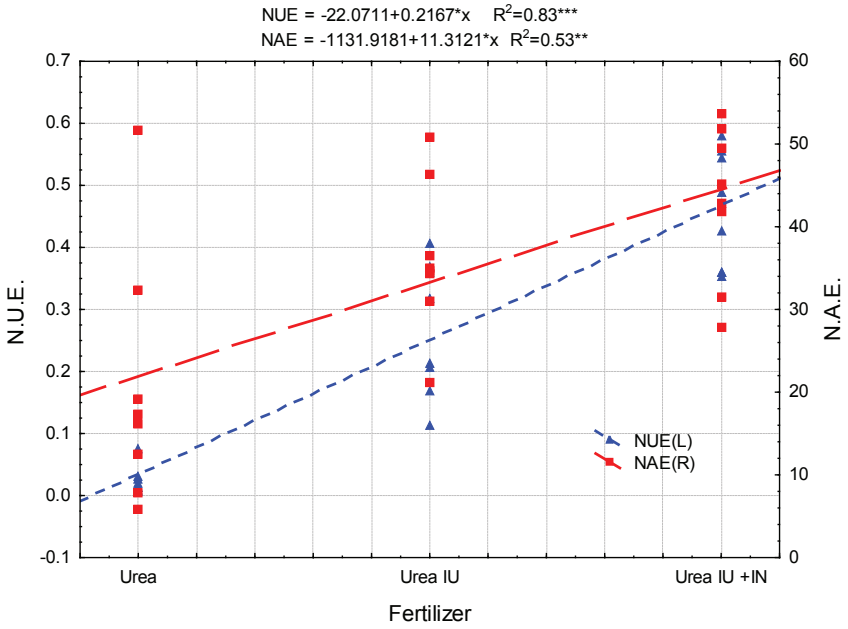


Figure 3. Correlation between different fertilizers, NUE and NAE.

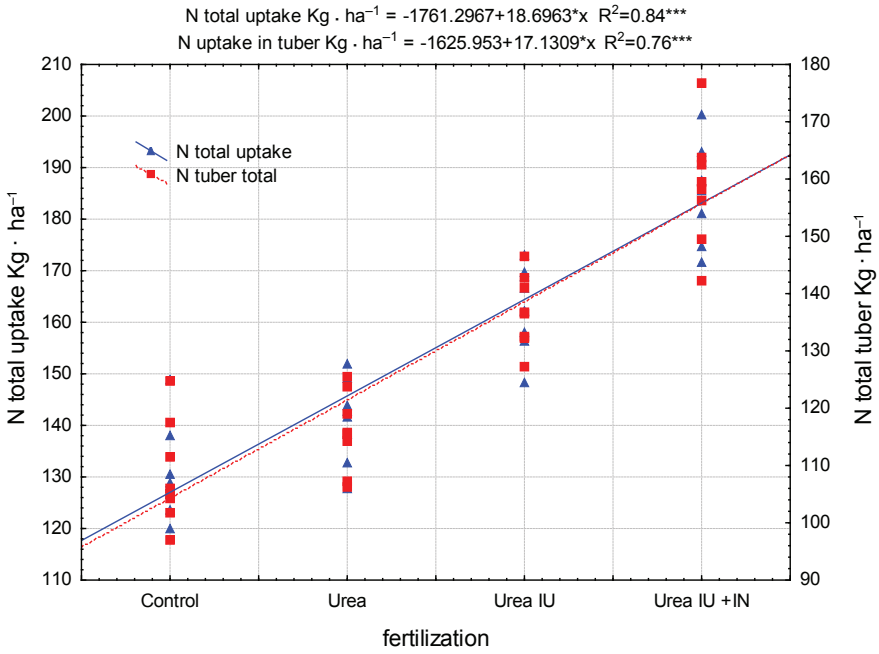


Figure 4. Correlation between different fertilizer, nitrogen total uptake and nitrogen total tuber.

crop was high. However, using the inhibitors NI + UI this difference is reduced and eventually the two aforementioned markers are almost identical. In other words, we observed that in sweet potato cultivation, the use of inhibitors results in greater nitrogen utilisation, which is enough to affect the agricultural efficiency.

Figure 4 illustrates the upward trend of total nitrogen uptake (Kg · ha^{-1}) and nitrogen uptake in tuber (Kg · ha^{-1}) from control, which marked the lowest amount of nitrogen uptake under urea + NI + UI treatment, which had the highest amount. Concluding, inhibitors boost not only the total nitrogen uptake of the plant but also the tuber nitrogen uptake.

The significant increase observed in DM of the upper part of sweet potato increased the nitrogen uptake in tuber (165 Kg · ha^{-1}) in the year 2018 and 153 Kg · ha^{-1} in the year 2019 when inhibitors NI and UI were added into nitrogen fertilizer (p = 0.11, Table 3).

Reviewing the data, yield (Kg · ha^{-1}) marked a significant correlation with NUE (p = 0.00), NHI (p = 0.014) and NAE (p = 0.00) inhibitors. We observed that total nitrogen uptake correlates responses to yield (p = 0.00, Table 3).

From the whole analysis, it is observed that only inhibitors mark a significant effect on yields of sweet potato and not the year.

CONCLUSION

This study has identified that using fertilizers with inhibitors will result in increasing the nitrogen exploitation for the growth and yield of sweet potato. The comparative data among several urea combinations enumerates urea + NI + UI treatment as the fertilizer causing higher yields. Urea with double inhibitors treatment resulted in better plant growth and nitrogen indices such as NUE, compared to urea treatment.

In particular, nitrogen indices were more efficient in urea + NI + UI treatment and more specifically NUE and NAE marked a better performance, thus resulting in higher yields. UI treatment showed the immediate best results in sweet potato cultivation. It is emphasised that all the above apply to the first and the second year when the experiments were conducted.

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AUTHORS CONTRIBUTIONS

All authors contributed equally to this work.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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