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Slow-Release Fertilizers Its Hydrosolubility and Response in Potato Plant (*Solanum tuberosum* L.) cv. Gigant.

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Abstract

Nitrogen excessive use in agriculture had generated slow-release fertilizers, the objective was to determine quality, hidrosolubility, and response in potatoes. The assessment was made in a greenhouse in pots with two soil types: acid and calcareous. Three slow-release fertilizer from clay-urea-potassium type (AUK) was evaluated with three manufactured forms: (1) unless intercalation, (2) intercalation by dry milled, and (3) intercalation by absorption of the solution, and traditional fertilizers (T) with two doses: 70-400-100 and 140-400-200, and one blank without fertilization. Nine treatments in random design with four replications were generated. Quality with standardization norms, hidrosolubility with soil solution, and measure of $N\text{-}NO_3$, K and CE with specific electrode and response by inductive experimental and deductive conceptual methods was determined. Quality showed that AUK was in standard norms, except by the size that it difficult the use in conventional fertilizer equipment. The hidrosolubility showed that AUK3-140 had the most height values of $N\text{-}NO_3$ with 767 mg L^{-1} and K with 166 mg L^{-1}, also T-140 had the most height value of CE with 5.5 dS m^{-1}; in calcareous soil, the values were height than acid soil. In the inductive method, the height response of yield was in AUK1 with 88 kg N ha^{-1}, the lowest N dose in acid soil. In calcareous soils, only T and AUK3 showed a quadratic response with doses up to 195 kg N ha^{-1}. In the deductive method, AUK1-70 showed the best significant response ($P \leq 0.05$) in acid soil with 4.48 mg mg^{-1}, 161.9 mg mg^{-1} y 335.9 % of N uptake efficiency (EAN), N use efficiency (EUN), and N utilization efficiency (ERN), respectively. In calcareous soil, T-70 showed a significant difference in EUN, and the other efficiencies no-showed an overwhelming difference. Acid soil showed height values of efficiency and in both soils, the deductive method overestimates the efficiency values.

Keywords: fertilizers, quality, nitrate, potassium, salinity, evaluation methods.

1. Introduction

The need to apply inorganic fertilizers began in the nineteenth century when fertilization for crop production in Mexico was with organic residues and green manures mainly, but yields were less than 1.5 Mg ha^{-1}, from the 1950s the green revolution begins, with the use of improved seed and an increase in the use of agrochemicals and inorganic fertilizers with an increase in production more than double the national average (Núñez, 2001).

The increasing use of nitrogen fertilizers in agriculture raised crop yields, but also caused an increase in pollution, specifically by leaching nitrates into underground aquifers, reaching average levels of 37 mg L^{-1} of NO_3 for the agricultural region of the Comarca Lagunera (Castellanos and Peña-Cabriales, 1990), 50 mg L^{-1} in the crop potato region of Coahuila and Nuevo León (Covarrubias and Contreras, 1997) and 14.4 mg L^{-1}, in the state of Guanajuato (Castellanos *et al.*, 2001), all in Mexico.

Leaching is not the only form of pollution, but also gaseous losses by volatilization and denitrification that can reach up to 60% of the fertilizer nitrogen applied (Chen *et al.*, 2022). Yingying *et al.* (2022) report that urea and ammonium sulfate produced twice as much N_2O as anhydrous ammonia and unseeded fertilized soil. In general, pollution reports are only focused on NO_3, but NH_3, being in an alkaline pH of irrigation water or soil, can volatilize more than 50% into the atmosphere.

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The consumption of nitrogen fertilizer in grain production increased from 1960 to 2020, from 36 to 61% (IFA, 2022), due to the lack of food forcing an increase in yields per unit area. If 23 tons of grain per ton of fertilizer is produced today, by 2022 108 million tons of nitrogen fertilizer will be needed (Havlin *et al.*, 2017). An alternative to nitrogen fertilization with less risk of contamination is the use of fertilizers of low solubility and slow release, which, due to their greater absorption efficiency, reduce the amount that must be supplied to the plants, without them ceasing to be well nourished, because the nutritional supply is synchronized with the demand of the crop (Jiajun *et al.*, 2022), reducing leaching and volatilization losses. The European Committee for Standardization points out that a slow-release fertilizer is one that, at 25 °C, no more than 15% is released in 24 h, no more than 75% is released in 28 days and at least 75% is released between 1 and 28 days (Shaviv, 2000).

The objective of this study is to evaluate the quality, hydro solubility, and response in potato plants of three slow-release fertilizers that are in the experimental stage, synthesized at the Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV), Saltillo Unit.

2. Materials and methods

2.1 Description

The study was conducted at CINVESTAV, Irapuato Unit, under greenhouse conditions with a controlled atmosphere, in the spring-summer agricultural cycle.

Treatments were formed from fertilizer sources and fertilization doses. The fertilizer sources were three slow-release fertilizers (FLL) with nitrogen and potassium in three forms of processing: (1) Clay-Urea-Potassium (AUK1) with no effect on intercalation, (2) AUK2 by intercalation by dry grinding and (3) AUK3 by intercalation by absorption of the solution. The FLL were synthesized in the ceramics and metallurgy laboratory of the Saltillo Unit of CINVESTAV and are in the experimental stage, in addition to traditional fertilization (T) based on N-P_20_5 and K_20 with ammonium nitrate (NA), diammonium phosphate (DAP), triple calcium superphosphate (SFT) and potassium sulfate (SP), these treatments were evaluated in two doses. The fertilization doses were: 140-400-200 (140) and 70-400-100 (70), to have eight treatments; in addition to control (00-400-00) without fertilization of N and K to have nine treatments.

2.2 Soil Characteristics

The treatments were evaluated in two soils, with an experimental design that was completely randomized with nine treatments and four repetitions for a total of 36 experimental units in each type of soil; the soil types of potato-producing regions in Mexico were two: calcareous and acidic; and whose characteristics are shown in Table 1.

Table 1. Characteristics of the two types of soil used in the study.

Characteristics	Acidic Soil	Calcareous Soil
Locality	Metepec, Edo. de Mex.	Navidad, Galeana, N.L.
Latitude	19° 14' 35" N	25° 04' 33" N
Longitude	99° 33' 41" O	100° 36' 00" O
Elevation (msnm)	2590	1895
Texture	Loam	Silt Loam
Inorganic Nitrogen (mg kg^{-1})	45.8	16.9
Phosphorus (mg kg^{-1})	254[1]	3[2]
Interchangeable potassium ($cmol_c$ kg^{-1})	45.3	5.7
Interchangeable calcium ($cmol_c$ kg^{-1})	125	677
Interchangeable magnesium ($cmol_c$ kg^{-1})	26.3	2.45
Iron extracted by DTPA (mg kg^{-1})	89	1.3
Zinc extracted by DTPA (mg kg^{-1})	3.47	1.71
Manganese extracted by DTPA (mg kg^{-1})	43.4	2.61
Copper extracted by DTPA (mg kg^{-1})	1.38	0.12
Organic Matter (%)	2.77	1.46
pH (relation 1:2 soil:water)	5.7	7.6
Electrical conductivity of saturation extract (dS m^{-1})	0.73	2.24

[1] Bray [2] Olsen

The acidic soil is an Andosol of medium texture and bulk density of 1.36 Mg m^{-3}, of fertile condition with a medium organic matter content and without salinity problems. The calcareous soil is a Planosol of medium texture and bulk density of 1.16 Mg m^{-3}, of poor fertility condition, low content of organic matter, and slightly saline.

The Gigant cultivar was used from a mini tuber, it was planted in pots of 10 L with 6 kg of soil with drip irrigation. The fertilizer was applied at the time of planting and the weight of the soil was considered to calculate the doses in grams per pot, which were for T in the dose 140-400-200 (1,547, 1.24, and 1.03 g pot^{-1}) as NA, DAP, SFT and SP; and the dose 70-400-100 (0.771, 1.748 and 0.517 g pot^{-1}) in calcareous soils; in acidic soils was the dose 140-400-200 (1.319, 1.059 and 0.882 g pot^{-1}) and the dose 70-400-100 (0.657, 1.491 and 0.441 g pot^{-1}); with the same sources.

In the FLL, for the dose 140-400-200 applied 3,979, 2,249, and 4,232 g pot^{-1} was with the sources AUK, SFT and K_2SO_4 and for the dose 70-400-100 it was 1,989, 2,249, and, 2,114 g pot^{-1} in the calcareous soil; in acidic soil for dose 140-400-200 of 3,394, 1,918 and 3.61 g pot^{-1} and for dose 70-400-100 of 1,697, 1,918 and 1,803 g pot^{-1}, with the same sources, the doses were considered the weight of the soil and tripled this amount (Harraq et al., 2022) for greenhouse experiments and considering 6 kg of soil per pot. The irrigation was programmed with tensiometers when the soil moisture level reached 33 kPa; the rest of the management was adequate for potato cultivation, according to the technology generated by the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), (Parga et al., 2005).

2.2 Response variables

The quality of FLLs was determined according to the standards described by the European standardization committee (Shaviv, 2000); the water solubility was determined every 15 days in the soil solution by soil tensiometer, after irrigation when the soil moisture level was at 20 kPa, the suction of the solution was made with soil solution access tube.

In the soil solution about 10 mL was obtained and salinity was determined as electrical conductivity (EC) in dS m^{-1}, nitrates ($N\text{-}NO_3$) in mg L^{-1} and potassium (K) in mg L^{-1} by the selective ion method (Horiba Ltd,); readings were taken at 10 s after placing the solution on the sensor (Alcantar *et al.*, 2016).

The crop response to the treatments under study was evaluated with the sampling of biomass production (MF) and dry matter (DM) production, extracting the whole plant at physiological maturity, the root and tuber were washed to remove the soil, the aerial part of the plant was distributed as foliage, the root as the underground part and the tuber as production, each part was weighed to obtain the MF and placed in perforated tin paper bags to be dried in an oven at 70 ° C for 72 h to obtain the DM.

The crop response was determined as a response surface analyzing MF and DM with the experimental inductive model that consists of determining a quadratic model $Y = a + bx + cx^2$ where Y is the response of crop and x the levels of N, with the GLM and RSREG declaration of the SAS 9.4 program and selected the best model with an error term of $P \leq 0.05$ in the ANOVA and the highest coefficient of determination R^2, and obtaining the 1st derivative of Y with respect to x, to obtain the optimal physiological dose when the slope is zero (Navidi, 2011).

The experimental inductive model was compared with the conceptual deductive method that consists of determining the absorption efficiency of N (EAN) as the relationship between the N content in the plant measured as total N by the Kjeldahl method, between the amount of fertilizer applied as N; the efficiency in use of N (EUtN) which is the relationship between DM and N content in the plant; efficiency in the use of N (EUN) as the ratio of DM between the amount of fertilizer applied as N and efficiency in the recovery of N (ERN) measured as N in the fertilized plant minus N in the plant without fertilization between the amount of fertilizer applied as N (Divya *et al.*, 2021).

Statistical analysis of treatments was performed with an error term with a probability of $P \leq 0.05$ and the difference between treatments with Tukey (SAS 9.4, 2022).

3. Results and Discussion

3.1 Quality

The quality of the FFL is described in Table 2, where the presentation of N with 9.1 % and none of the three sources of FLL presents it, AUK1 was lower by 0.14 %, AUK2 by 0.42%, and AUK3 was higher by 0.65%. The concentration of K as K_2O with 9.8% with AUK1 was 1.06% lower, AUK2 was 0.51% lower and AUK3 was 0.13% higher.

Table 2. Characterization of slow-release fertilizers

Characteristic				
Presentation:	9.1 - 00 - 8.2	as N - P - K	or 9.1 – 00 - 9.8	as N - P_2O_5 - K_2O
	Fuente	N (%)	K (%)	K_2O (%)
Concentration:	AUK1	8.96 ab	7.71 b	8.74 b
	AUK2	8.68 b	7.23 b	9.29 b
	AUK3	9.75 a	8.24 a	9.93 a
	a = Tukey 0.05			
Composition:	$CO(NH_4)_2$ +	KCl + $CaSiO_3$		
Properties:	AUK1	AUK2	AUK3	
Type:	Clay with no effect on intercalation	Clay with intercalation by dry grinding	Clay with intercalation by absorption of solution	
Colour:	Pale Pink	Clear Coffee	Clear Coffee	
Form:	Cylindrical	Cylindrical	Cylindrical	
Humidity:	0.5 a 1.1 %			
Size:	2.3 x 0.45 cm.			
Hygroscopicity:	Minimum			
Chemical analysis: *	AUK1	AUK2	AUK3	
pH	7.86	7.9	7.91	
EC (dS m^{-1})	6.4	5.8	18.2	
$N-NO_3$ (mg L^{-1})	5400	6700	18000	
K (mg L^{-1})	590	560	200	

* Solution to the 5 % at 25 °C.

3.2 Water solubility

The water solubility of the sources and doses in both soils is shown in Table 3. The concentration of $N-NO_3$ for sources in calcareous soil is significantly different ($P \leq 0.01$) and indicates that AUK3-140 exceeds all treatments and the control by 388%.

Table 3. Components of water solubility of traditional fertilizers and slow release under three doses in two types of soil with potato plants.

TREATMENT		----------- Calcareous soil----------			------------- Acid soil -------------		
		$N-NO_3$ §	K	E. C.	$N-NO_3$	K	E. C.
Source	Doses	(mg L^{-1})	(mg L^{-1})	(dS m^{-1})	(mg L^{-1})	(mg L^{-1})	(dS m^{-1})
Traditional	140-400-200	489 bc†	31 b	5.5 a	196 c	46 bc	3.3 b
	70-400-100	409 bcd	18 b	4.7 abc	183 c	25 cd	3.2 b
AUK1	140-400-200	267 cde	40 b	4.9 abc	296 bc	30 cd	4.7 a
	70-400-100	233 de	34 b	4.7 abc	259 bc	13 d	4.4 a
AUK2	140-400-200	421 bcd	29 b	5.3 ab	296 bc	82 a	4.3 a
	70-400-100	280 bcde	15 b	4.6 abc	241 bc	28 cd	2.7 b
AUK3	140-400-200	767 a	166 a	4.3 bc	591 a	70 ab	4.3 a
	70-400-100	517 b	134 a	4.2 c	390 b	34 cd	4.1 a
Control	0	157 e	13 b	4.4 bc	159 c	12 d	1.5 c

† Means of treatments followed by the same letters are statistically similar with Tukey ($p \leq 0.05$).

The AUK3-140 treatment (3.97 g pot^{-1}) presented the highest concentration with 767 mg L^{-1} and is statistically higher at 250 mg L^{-1} compared to AUK3-70 (1.99 g pot^{-1}), this treatment is significantly similar to T-140, T-70, AUK2-140, and AUK2-70; where the latter is equal to AUK1-140, AUK1-70 and the control without fertilization.

In the acidic soil, there was a highly significant difference ($P \leq 0.01$), where the AUK3-140 treatment (3.39 g pot^{-1}), has the highest concentration with 591 mg L^{-1} and was significantly higher in 201 mg L^{-1} with AUK3-70 and the control in 271 %; AUK3-70 treatment is statistically similar to the other treatments.

The concentration of K in calcareous soils indicates a significant difference between treatments ($P \leq 0.01$), AUK3-140 obtained the highest concentration with 166 mg L^{-1} and is higher than the control by more than one thousand percent. The AUK3-140 treatment is statistically similar to AUK3-70 and these are significantly superior to the other treatments.

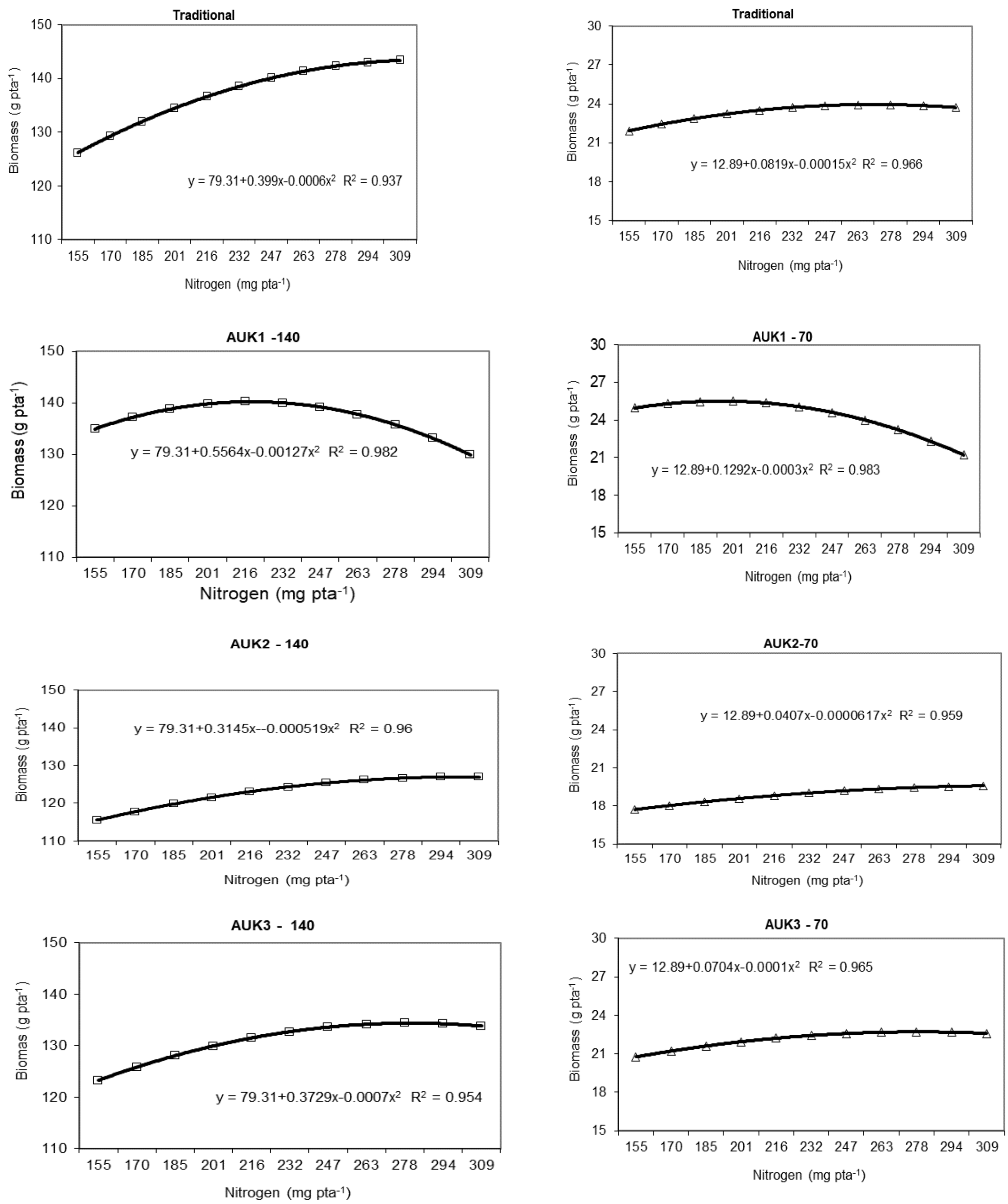


Figure 1. The nitrogen response function in two doses in potato plants established in acidic soil.

K levels in acidic soil showed a significant difference ($P \leq 0.01$) in treatments, AUK2-140 presented the highest concentration with 82 mg L^{-1} and was 583 % higher than the control and significantly similar to AUK3-140, which is similar to T-140 and which turn is similar with treatments T-70, AUK1-140, AUK2-70 and AUK3-70; AUK1-70 treatment is similar to the control treatment.

K levels with 20 to 60 mg L^{-1} are adequate under the above conditions, only AUK2 at doses 200 kg ha^{-1} is higher than the level and AUK1 at doses 100 kg $ha^{-1.}$

In the concentration of salts in calcareous soils was found a significant difference ($P \leq 0.01$) in the treatments, T-140 obtained the highest concentration of 5.5 dS m^{-1}, which is higher by 30% to AUK3-70 that presented the lowest value, the other treatments are statistically similar.

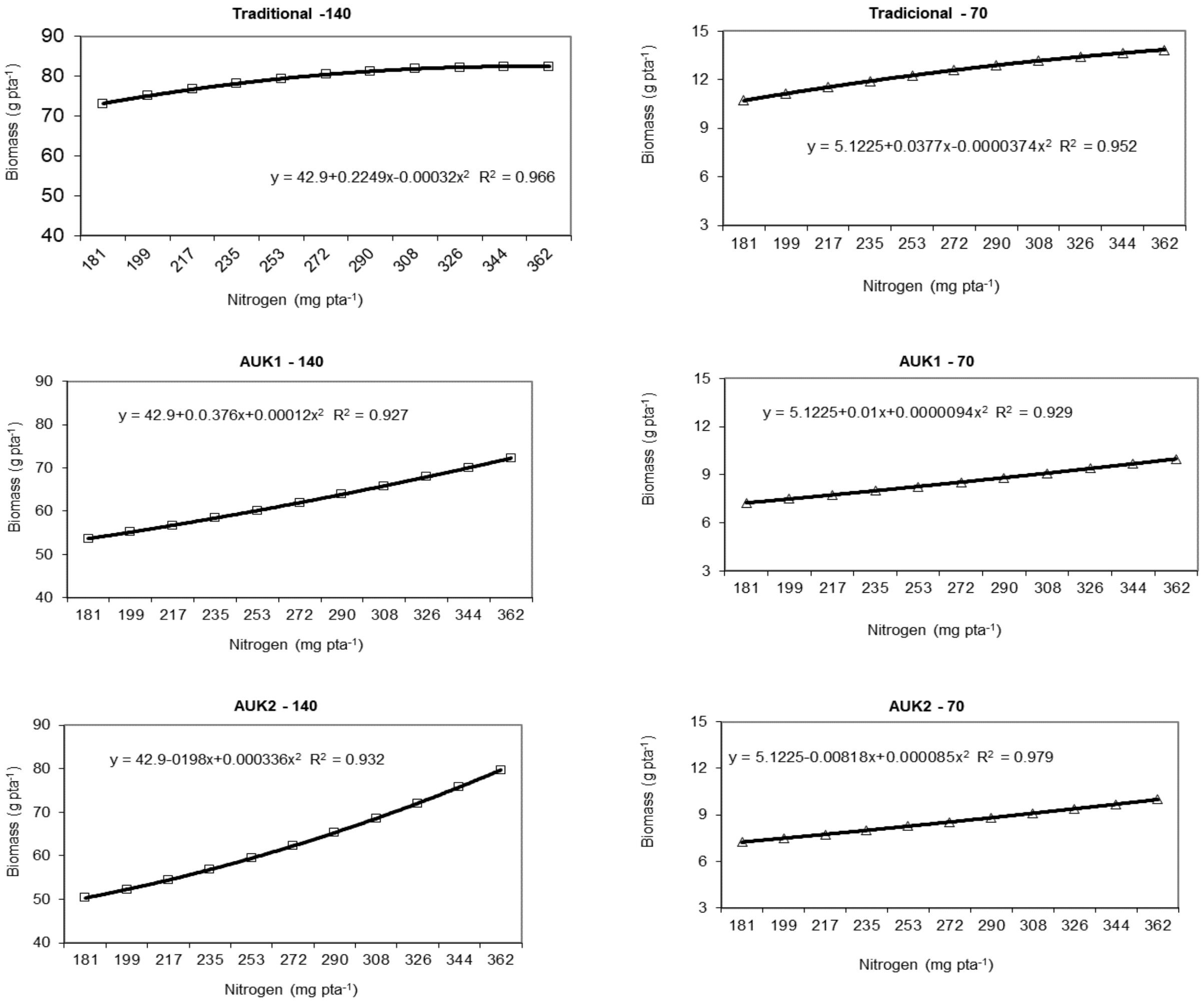
In acidic soils, a significant difference ($P \leq 0.01$) was found in the treatments, where AUK1-140 presented the highest concentration of salts with 4.7 dS m-1 and is 213 % higher than the control; AUK1-140 is statistically similar to AUK1-70, AUK2-140, AUK3-140, and AUK3-70. The T-140, T-70, and AUK2-70 treatments are statistically similar, but lower than the previous treatments and superior to the control.

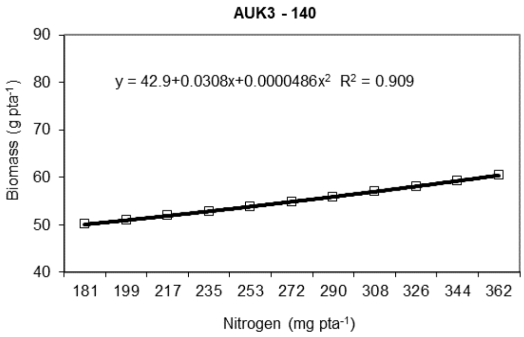
3.3 Experimental inductive method

The response in the production of MF and DM in the potato plant in acidic soil is shown (Figure 1), all responses are quadratic, significant ($P \leq 0.05$), and with R^2 greater than 0.93. In MF the lowest physiological optimal dose (DOF) to obtain the maximum yield of the potato crop corresponded to the source AUK1 with 218 mg pta^{-1}, followed by AUK3, AUK2, and T, with 280, 302, and 321 mg pta^{-1} respectively.

In the case of MS, AUK1 also has the lowest DOF with 195 mg pta^{-1} (88 kg N ha^{-1}) and exceeds T, AUK3, and AUK2 that presented values of 269, 279 and 329 mg pta^{-1} in the same order as can be seen the value of 329 mg pta^{-1} of AUK2 in DM represents 149 kg N ha^{-1} that exceeds all levels of DOF.

The response in potato cultivation in calcareous soil is shown in Figure 2, the behavior in the response is quadratic, significant ($P \leq 0.05$), and with R^2 greater than 0.79; DOF was obtained only in T with MF and DM, and AUK3 in DM the maximum performance was presented with 351, 503 and 986 mg pta^{-1} (136, 195 and 381 kg N ha^{-1}) respectively.





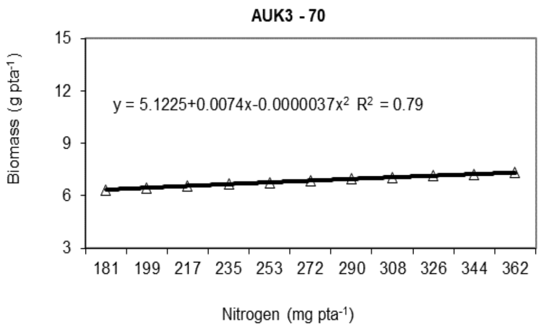


Figure 2. The nitrogen response function of fertilizer sources in potato plants established in calcareous soil

In AUK2 in both MF and MS answers were found at least; for AUK1 in MF and DM, and AUK3 in MF, it was not possible to have the DOF, the lack of response may be due to the availability of N in the soil was not enough to supply the demand of the crop in the early stages, where at 60 DDE the demand already exceeded 70% of the total.

3.4 Conceptual deductive method

Table 4 shows the results of the deductive method for acid soil, there was a significant difference ($P < 0.05$) in all the variables that make up the deductive method.

In MS the AUK1-70 treatment with 24,940 mg pta^{-1} had the highest production compared to the other treatments and exceeds the control by 93%, it is also statistically similar to T-140, which in turn, is statistically similar to AUK3-140 and T-70.

Table 4. The efficiency of N by potato cultivation developed in acidic soil.

Source	N applied mg pta^{-1}	Dry Matter mg pta-1	Total N %	N total yield mg N pta^{-1}	E Ut N mg mg^{-1}	E A N mg mg^{-1}	E U N mg mg^{-1}	E R N %
T-140	309	23718 ab†	2.93 a	694 a	34.5 b	2.25 de	76.8 d	168.9 c
T-70	154	21905 bc	2.15 b	472 b	46.6 a	3.07 cd	142.2 b	194.6 bc
AUK1-140	309	21218 cd	3.34 a	707 a	30.1 b	2.29 de	68.7 de	173.0 c
AUK1-70	154	24940 a	2.76 ab	690 a	36.9 b	4.48 a	161.9 a	335.9 a
AUK2-140	309	19583 d	3.29 a	641 a	30.9 b	2.08 e	63.4 e	151.8 c
AUK2-70	154	17700 e	2.74 ab	484 b	36.5 b	3.15 bc	114.9 c	202.6 bc
AUK3-140	309	22585 bc	3.21 a	727 a	31.2 b	2.35 cde	73.1 d	179.5 c
AUK3-70	154	20738 cd	2.94 a	610 ab	34.3 b	3.96 ab	134.7 b	284.2 ab
Control	0	12893 f	1.33 c	172 c				

EUtN = Efficiency in the utilization of N
EAN= Absorption efficiency de N
EUN = Efficiency in the use of N
ERN = Recovery efficiency de N
† Means of treatments followed by the same letters are statistically similar with Tukey ($p \leq 0.05$).

The deductive method comprises the total N content, where T, AUK1, AUK2 AUK3 at dose 140 and AUK3-70, are significantly similar ($P \leq 0.05$) and statistically exceed the control; in the total N yield where T, AUK1, AUK2, AUK3 at dose 140 and AUK1-70 are significantly similar ($P \leq 0.05$) and statistically exceed the rest of treatments.

In EUtN, the T-70 treatment presents the highest value with 46.6 mg mg^{-1} and statistically exceeds the rest of the treatments; in EAN the AUK1-70 treatment presented the greatest absorption, but statistically similar to AUK3-70, this indicates that the lower doses are more effective with FLL in acidic soils, a situation observed in EUN where AUK1-70 is significantly higher (161.9 mg mg^{-1}) to the rest of the treatments and is also significantly higher in ERN, as well as AUK3-70, these results show that AUK1-70 is the best treatment in conductive and deductive methods in acidic soil.

In the calcareous soil, there were significant differences in all variables (Table 5), in DM the sources AUK2 and T at dose 140 are significantly higher ($P \leq 0.05$) than the rest of the treatments.

Table 5. The efficiency of N by potato cultivation developed in a calcareous soil.

Source	N applied mg pta^{-1}	Dry Matter mg pta-1	Total N %	N total yield mg N pta^{-1}	E Ut N mg mg^{-1}	E A N mg mg^{-1}	E U N mg mg^{-1}	E R N %
T-140	362	13855 a†	2.56 ab	355 ab	39.2 ab	0.98 ab	38.3 b	85.8 abc
T-70	181	10715 b	1.97 b	212 c	51.9 a	1.17 a	59.2 a	92.5 ab
AUK1-140	362	9985 b	3.05 a	305 b	32.9 b	0.84 ab	27.6 cd	72.0 abc
AUK1-70	181	7518 c	2.40 ab	181 c	42.1 ab	1.00 ab	41.5 b	75.7 abc
AUK2-140	362	13335 a	3.04 a	404 a	33.4 b	1.12 a	36.8 b	99.4 a
AUK2-70	181	6435 cd	2.25 b	147 c	45.2 ab	0.81 ab	35.6 b	56.7 bc
AUK3-140	362	7320 c	3.08 a	225 c	32.7 b	0.62 b	20.2 d	50.0 c
AUK3-70	181	6345 cd	2.62 ab	167 c	38.8 b	0.92 ab	35.1 bc	67.7 abc
Control	0	5123 d	0.87 c	44 d				

EUtN = Efficiency in utilization of N
EAN= Absorption efficiency de N
EUN = Efficiency in the use of N
ERN = Recovery efficiency de N
† Means of treatments followed by the same letters are statistically similar with Tukey ($p \leq 0.05$).

Dose 140 had the highest total N content in treatments statistically exceeding dose 70, a situation that was not observed in total N performance where AUK2-140 had the highest with 404 mg N pta^{-1}, and exceeded the control by 360 mg N pta^{-1}, but similar to T-140, and this, in turn, is similar to AUK1-140, but the above are significantly different ($P < 0.05$) to the other treatments.

In EUtN, the T-70 source presented the highest use of N, but there is no significant difference with AUK1-70, AUK2-70, and T-140, the rest of the treatments are statistically different from T-70, but similar to the previous ones, so the difference is not contrasting. For the absorption of N measured as EAN, T-70 and AUK2-140 showed the highest significant efficiency, but they are statistically similar to the rest of the treatments, with the same trend that EutN presented. The T-70 treatment presented the highest EUN with 59.2 mg N mg^{-1} and AUK2-140 the highest ERN with 99.4%, both significantly higher than the rest of the treatments, but the treatments tend to be statistically equal, so the difference is not conclusive.

4. Discussion

4.1 Quality

The composition of the FLL is a clay of the bentonite type, urea, and potassium chloride, in the properties of the type indicate that the intercalation by absorption of the solution presented greater concentration in the three sources, the color and cylindrical shape of the sources are similar, and their size indicates a greater volume of the particles compared to traditional fertilizers, therefore, it can affect its application in current agricultural fertilizers (Parga *et al.*, 2005).

The chemical analysis of the solubilized sources in 5% deionized water indicates an alkaline pH and high concentration of salts for the AUK3 source, the levels of nitrates and potassium measured with the selective ion showed the AUK3 source, with the highest concentration of nitrates, but lower potassium, reverse situation for the other sources (Jungsinyatam *et al.*, 2022).

4.2 Water solubility

The levels of N-NO^3 found in the treatments in calcareous soils are higher than those of acidic soil, in addition, all treatments of sources in the dose of 140 kg N ha^{-1} is greater than the dose of 70 kg N ha^{-1} evaluated; a concentration of 280 mg L^{-1} of N-NO_3 in the soil solution 50 days after emergence (dae) is adequate in the period of greater absorption of N by the potato crop, the concentration is reduced 160 mg L^{-1} to 120 dae because the absorption of the crop is lower and the residual N in the soil is high (Soratto *et al.*, 2022; Arteaga *et al.*, 2022), other authors indicate a concentration of 50 to 70 mg L^{-1} in N-NO_3 lower than the previous ones but adequate during the beginning of the second stage of growth of most crops (Yadav *et al.*, 2022; Xing *et al.*, 2022).

The proportion of N-NO_3 and K changes during crop development depending on the uptake of these and the interactions between the elements that make up the nutrient solution in the soil (Sha *et al.*, 2021), an adequate K content in the solution is 200 to 400 mg L^{-1} (Zhang *et al.*, 2022).

The ratio of N-NO_3 and K changes during crop development depending on the uptake of these and the interactions between the elements that make up the nutrient solution in the soil (Sha *et al.*, 2021), an adequate K content in the solution is 200 to 400 mg L^{-1} (Zhang *et al.*, 2022).

The maximum salinity level in the soil solution for potato cultivation is 1.7 dS m^{-1} and presents a yield reduction of 12% for each unit of increase, these values are obtained from the soil saturation extract (Ahmed *et al.*, 2020). A nutrient solution must have a value of 3.5 dS m^{-1} and less than 200 mM of NaCl (Judesse *et al.*, 2022) and in calcareous soil, all treatments have a value higher than this, so a reduction in yield is expected, instead in acidic soils only AUK1 and AUK3 in its two doses and AUK2 in the dose of 140, are above the limit.

4.3 Experimental inductive method

The production of MF and DM in potato cultivation in calcareous soil is lower compared to acidic soil, the lack of a maximum response in the sources of FLLs is because N is urea and its negative effect may be for the following reasons (Vos, 2009; Havlin *et al.*, 2017 and Yu *et al.*, 2022):

- Urea increases alkalinity in the calcareous soil because urea when passing from amide to ammonium carbonate alkalizes the medium.
- The presence of urease in calcareous soils is low due to the smaller population of microorganisms that contain it.
- Higher concentration of free NH_3 in an alkaline medium that inhibits enzymatic activity in the rhizosphere.
- In an alkaline pH (>7.5) urease inhibition occurs because the pH in the immediate vicinity of the FLL urea source can reach values of 9.0.

4.4 Conceptual deductive method

The EUtN values observed in the two soils (30.1 to 51.9 mg DM mg^{-1} N) are within the ranges observed in potato cultivation developed in potato (Koch *et al.*, 2020), in addition, the highest value of EAN (4.48 mg mg^{-1} in AUK1-70) are values that overestimate the EAN, which for potato cultivation, that is between 0.05 and 0.67 mg mg^{-1}, however, the values of EUN that varies from 20.2 to 161.9 mg mg^{-1}, are higher with respect to values of 2 to 28 mg mg^{-1} obtained with 225 kg N ha^{-1} in potato, the highest values are observed in acidic soils; and the ERN obtained (from 50 to 335.9%) is high compared to the fertilized crop with 225 kg N ha^{-1} (Naumann *et al.,* 2020), which indicates an overestimation in the recovery of the doses.

The above concepts indicate that the efficiency of nitrogen fertilization is lower in calcareous soils than acidic soils, AUK1-70 in acidic soils has the best response to N, and in calcareous soils, the T source has the greatest response and may be due to its greater release in the early stages (Zhang *et al.*, 2022), but AUK3 has the highest concentration of NO_3 in the soil and the highest EAN and ERN, which requires a greater precision of analysis in calcareous soils.

5. Conclusions

In quality, slow-release fertilizers are within standardization, only their greater volume of particles compared to traditional fertilizers can affect their application in current agricultural fertilizers. N-NO_3 and K are released in greater proportion in less time. The water solubility showed that the source AUK3 presented the highest values of N-NO_3, K and EC, and they were higher in the calcareous soil. The highest yield response corresponded to the AUK1 source with the lowest dose of N in acidic soils. In calcareous soils, no quadratic response was obtained in all treatments. In the efficiency of N, AUK1-70 showed the highest or one of the highest efficiencies of this element in acidic soil. In the calcareous soil, no consistency was achieved in the treatments for the efficiency of N in the crop. These slow-release fertilizers are experimental and require an analysis such as the one performed to demonstrate their quality and efficiency.

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