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Research Article

Potato nitrogen acquisition behavior and productivity following legume

***[1]Elsaid Mohamed Elsaid and [2]Ricardo Henrique silva Santos**

[1]Horticulture Research Institute. 9 Gamaa st. Orman, Giza. Egypt
[2]Departamento de Fitotecnia, Universidade Federal de Viçosa, Viçosa. MG, Brazil

*Corresponding Author E-mail: saidsaid79@yahoo.com , Tel: (+2)010-03003303

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Abstract

Legumes` residues as alternatives to synthetic nitrogen fertilizers for sustained vegetable production, particularly in the tropics and subtropics, are increasing dramatically. However, quantitative information concerning plant growth parameters succeeding their incorporation remains destitute. Sun hemp residue N release, potato N recovery and productivity as well as how N release coincides with potato N uptake were investigated. Litter decay was estimated using *litter bags* and first order exponential function. Potato N acquisition, yield and NUE was quantified under different rates of residue-N (100, 200 and 400 kg ha^{-1}), in relation to mineral nitrogen (MN) and zero N treatment. Residue decay presented an accelerated rate, 0.0215 g N g^{-1} day^{-1}, with significant mineralized proportion of the initial nitrogen content after 6 weeks of incorporation. Potato foliage N accumulation exhibited quadratic patterns and peaked between 52.5 and 56.5 DAP. However, linear patterns were best fitted within potato tubers as well as whole plant, with superior estimates under sun hemp treatments. Additionally, yield was increased by increasing residue nitrogen rate. However, N productivity presented an inverse trend to nitrogen dose. The high negative correlation indicated that litter N mineralization matched potato N recovery leading to affordable N supply and economic yield.

Keywords: *Solanum tuberosum* L, *Crotalaria junceae* L., N accumulation, synchrony

INTRODUCTION

Potato (*Solanum tubersum* L.) growth patterns and nitrogen distribution among plant segments are important parameters to adjust proper management practices for improved nitrogen uptake, yield and tuber quality. Furthermore, nitrogen availability within soil influences its magnitude, plant uptake pattern, accumulation and partitioning. In this regard, different simulation models were developed to predict potato growth, tuber production and adjust rational fertilization programs under different nitrogen management practices.

Under mineral nitrogen fertilization, potato tends to accumulate dry matter within foliage four-folds, under high N rates (16 g plant^{-1}), greater than under low N rates (2.5 and 8 g plant^{-1}) after emergence and up to 80 days (*Biemond and Vos*, 1992). *Vos* (1999) found yield increases by increasing N rate. In addition, split N application did not affect yield at maturity but improved N utilization. Furthermore, increasing applied N before planting increased foliage dry matter and N content early after emergence within two different potato varieties.

Different investigations have estimated nitrogen accumulation within plant segments under mineral nitrogen fertilization. *Alva* et al.(2002) found that canopy N accumulation followed quadratic patterns and peaked at 90-100 DAP in two potato cultivars (Russet Burbank and Hilite Russet). However, *Zebarth* et al. (2004) found linear nitrogen accumulation to increased N supply with seasonal significant differences between cultivars. Under Brazilian conditions, *Fernandes* et al. (2010, 2011) found sigmoid patterns of N, dry matter and fresh tuber yield accumulation over time with relative variations of accumulation rates between cultivars, depending on maturity.

In the recent past, integrating green manures in farming systems for sustainability issues has been renewed.

Furthermore, potato yield increases after green manure incorporation has been reported. *Nyiraneza and Snapp* (2007) found that potato yield and N uptake, following winter rye, was greater by 20% than after fallow plots in the presence of mineral N supply. Meanwhile, in the absence of mineral fertilizer, rye cover crop increased tuber yield by 40 to 210% than in bare soil. *Sincik et al.* (2008) obtained higher yields following legume green manures and cover crops. Tuber yield raise was approximately 36% to 38% higher than following winter wheat in the absence of external N supply. *Campiglia et al*. (2009) found that potato fresh marketable yield following subclover and hairy vetch was similar to that obtained by mineral nitrogen fertilization (48.5 t ha^{-1}). The study demonstrated the potential of green manures to provide potato with adequate nitrogen supply and yield equal to that of mineral nitrogen. *Möller and Reents* (2009) reported potato higher fresh yield after legumes by 10 % than after non-legumes. Similarly, tuber N uptake was higher by 30%.

Regarding potato growth patterns under organic managements, *Macqueen*, (2007) carried out an investigation in 12 sites to estimate dry matter production and N uptake, and fresh tuber yield accumulation in order to optimize fertilization programs. The results showed different foliage N accumulation patterns (linear, quadratic, cubic and sigmoid). However, N accumulation in tubers presented a linear model in all farms with different estimated rates (1.6 – 2 kg ha^{-1} day^{-1}). The differences between farms were regarded to management and fertilization history, which influenced nitrogen availability. Additionally, maturity age of the potato varieties resulted in relative differences in growth parameters and N uptake pattern. Investigations dealt with potato yield improvement following organic fertilizers have attributed yield augment to non-nitrogen effects. Meanwhile, reports concerning growth patterns are still limited.

It is evident that potato N accumulation under organic N fertilization, particularly green manuring is marginally studied. The current study aimed to estimate potato nitrogen uptake patterns and test the synchrony between N mineralization of the green manure sunhemp (*Crotalaria juncea* L.) as well as potato yield and sunhemp N productivity.

MATERIALS AND METHODS

The experiment was conducted from May 21st to September 27th 2012, in the Horta Nova experimental farm of Universidade Federal de Viçosa, MG, Brazil. The farm is located at 693 m altitude, 20°45` S latitude and 42°51′W longitude. The region is characterized by dry moderate to cold winter and rainy hot summer. Meteorological data (**Table 1**) during the experiment was obtained from a nearby weather station.

Table 1. Mean daily air and night temperatures and precipitation rate during potato plantation from May to September 2012

Variable	May	June	July	August	September
Mean daily temperature (^{0}C)	23.6	24.0	24.8	25.2	27.8
Mean night temperature (^{0}C)	14.3	14.0	10.9	12.0	13.6
Precipitation (mm)	3.04	0	0	0	1.56

Two sequential corn plantations were planted prior to potato experiment to reduce soil mineral N content. After the second corn harvest, soil samples were collected from the top soil surface (0-30 cm), homogenized and mixed in a composite sample. Then, a representative sample was collected and submitted to mechanical and chemical analysis (Table 2).

Table 2. Initial characteristics of the experimental soil before sunhemp incorporation and potato plantation

Property	Unit	Value	Method
OM	dag kg^{-1}	3.0	Walkely-Black =org C×1.724
pH (in water1:2.5)		5.3	
P	mg dm^{-3}	37.7	Mehlich-1 extractor
K	mg dm^{-3}	45.0	Mehlich-1 extractor
Ca^{2+}	$cmol_c$ dm^{-3}	3.0	KCL-1mol L^{-1} extractor
Mg^{2+}	$cmol_c$ dm^{-3}	0.5	KCL-1mol L^{-1} extractor
Al^{3+}	$cmol_c$ dm^{-3}	0.0	KCL-1mol L^{-1} extractor
Effective CTC	$cmol_c$ dm^{-3}	3.66	
CTC in pH 7.0	$cmol_c$ dm^{-3}	8.61	
V	%	43.0	
Rem-P	mg L^{-1}	37.3	
Texture		Sandy clay	EMBRAPA, 2006

Green manure production, chemical characterization and nitrogen mineralization

Sunhemp (GM) seeds were sown on February 10th, in an adjacent area to potato experiment. Seeds were sown manually with 0.5 m row spacing and density of 40 per meter linear. Plants did not receive any fertilizers before sowing and during growing season. At full blooming (65 Day after Planting - DAP), the green manure was harvested manually, chopped and air dried at room temperature then stored until incorporation. Prior to incorporation, the dry biomass was homogenized, and sampled for dry matter and total nitrogen determination. Samples were oven dried in a forced air oven at 60 ^{0}C until constant weight. Thereafter, samples were ground to pass through a 2 mm sieve. Total nitrogen content was determined in micro-Kjledahl (*Miyazawa et al.* 2009). Sunhemp dry mass presented 87.5 % dry matter and 2.37% N-total content.

A litter bag experiment was set up, to determine mass breakdown and nitrogen mineralization, simultaneously with the GM incorporation until potato harvest. Fifteen grams of the air-dried biomass (14 g DW) were placed in Nylon bags (2 mm mesh size and 25×25 cm) and buried to the depth of 10-15 cm, adjacent to potato experiment. Sampling was conducted at 0, 7, 14, 21, 35, 49, 70, 91 and 112 days after incorporation, whereas three random bags were retrieved. The remaining GM mass was cleaned from soil particles then dried and subjected to total nitrogen content determination in micro-Kjeldahl. The remaining dry matter (DM) and nitrogen was calculated as follow;

XR (%) = (Xt/Xo) × 100;

The XR is the percent DM weight or nitrogen remaining; Xt is the DM weight or the nitrogen content at each sampling time and Xo is the DM weight or nitrogen amount at the decomposition start.

Dry matter and nitrogen mineralization kinetics were fitted into the first-order single exponential model (*Wieder and Lang*, 1982): $Mt = M_0 e^{-kt}$, where; Mt is the remaining dry matter or nitrogen amount after a time period "t", in days, M_0 is the total dry matter or nitrogen at the beginning of the experiment, "k" is the decomposition rate constant.

Potato treatments and experimental layout

Five treatments whereas 3 green manure (GM) treatments, equivalent to 100, 200 and 400 kg N ha^{-1}. The two other treatments were a zero N treatment (N0) and recommended mineral nitrogen (MN 250 kg ha^{-1}). Treatments were arranged in a complete randomized block design (RCBD) with 4 replicates. Sunhemp dry mass corresponding to N doses was incorporated one week before planting potato. Meanwhile, mineral nitrogen was supplied in the form of ammonium sulfate (21% N) whereas 70% spread in the furrows before planting, and 30% as side dressing at 22 day after emergence (*Fontes,* 2005).

Before planting, soil was tilled and disc harrowed. One meter interspacing between blocks and 0.5 m distance between each experimental plot were left to avoid green manure translocation during incorporation. The experimental plot had 9.4 m^2 (3.75×2.5 m) and contained 50 plants. The outer two rows were considered as border and were excluded from data collection.

Soil was amended with the following mineral fertilizers; simple super phosphate, potassium chloride and magnesium sulphate (420, 220 and 200 kg ha^{-1}, respectively). In addition, micro-nutrients (boron, copper and zinc as 10 kg ha^{-1} of each and 250 g ha^{-1} molybdenum) were blended and applied inside the furrows.

Homogeneous potato seeds 'Ágata', with a mean weight of 25g were pre-germinated at room temperature and indirect sunlight. When the sprouts reached around 3cm length, tubers were hand planted (0.25 m apart) and covered with 10 cm of soil. In addition, agronomic practices such as irrigation and control of pests and diseases were implemented following the regional recommendations.

Potato sampling and nitrogen uptake determination

Nitrogen uptake was quantified over the growing season in the above and underground plant parts, excluding roots, beginning at an early stage of tuber set (35 DAP) until senescence (80 DAP) with an interval of 15 days following the method described by *Sullivan* et al., (2008). Calculations were based on plant population of 50,000.00 plant ha^{-1}. At each sampling date, two plants from the inner rows surrounded by competitive plants were harvested, excluding roots, and segmented into foliage and tubers. Foliage was cleaned and dried in air forced oven at 60 ^{o}C until constant weight and then dry weight was recorded. Tubers were weighed and a sample of five tubers was collected, washed by tap water followed by distilled water and left to dry. Tubers were cut into cubes of approximately 1 cm^3 and mixed. A sub-sample of 200 g was dried at 60^{o}C until constant weight. Plant samples were ground to pass through a 2 mm sieve, and N-total content (%) was determined in micro-Kjledahl. N uptake was calculated by the following equation; N uptake (kg ha^{-1}) = dry biomass (kg ha^{-1}) x N%

Sum of mean foliage and tubers dry matter and nitrogen were expressed in kg per hectare basis to represent the total amount per hectare. Additionally, nitrogen recovery (NR kg ha^{-1}) was obtained, within the last sampling date, by summing foliage and tubers N-content to represent N-total per plant and then expressed in a per hectare basis.

At harvest (103 DAP), 10 plants from the central rows were harvested for yield determination. Tubers were left , 2 hours after dig out, for curing then graded according to Brazilian Ministry of Agriculture standards (Ministério da Agricultura, Agropecuária e Abastecimento, 1995). Commercial yield included grades 1, 2 and 3 (diameter > 3.3 cm).

Moreover, total yield included commercial yield and class 4 which included tubers with a diameter less than 3.3 cm and tubers with any commercial disorders (i.e., greenish, rotten and infected by insects or diseased). Nitrogen use efficiency (NUE, kg tuber kg^{-1}N) for the total and commercial yield was calculated by dividing total and marketable yield by the applied nitrogen.

Statistical analysis

Data were subjected to analysis of variance ($P<0.05$), using SAEG software (V, 9.1, 2007. Nitrogen accumulation was obtained by regression analysis whereas treatments were fixed, and time was considered as a dependent factor. Regression models were selected according to coefficient significance, determination coefficient and biological behavior of each variable. Additionally, within variables rather than N uptake means were compared by Tukey test ($p\geq0.5$). Synchrony between N mineralization and potato N uptake, in the whole plant, was tested by Pearson`s correlation using 16 data sets within potato sampling dates.

RESULTS AND DISCUSSIONS

Green manure decomposition and nitrogen mineralization

Dry matter decomposition and nitrogen mineralization of sunhemp (Figure 1) presented high decomposition rates, 0.0168 and 0.0215 g g^{-1} day^{-1}, respectively. Moreover, nitrogen mineralization was higher than dry matter decomposition. These fast breakdown and mineralization rates can be attributed to sunhemp tissue high quality, particularly the low C/N ratio, since it was harvested in an early stage. *Chaves* et al. (2004) reported that C/N ratio was the best predictor for N mineralization potential form incorporated organic residues. Furthermore, N mineralization rate after clover and Lucerne green manures (12 and 10 C/N ratio) incorporation was higher than after vetch and oat mixture (31 C/N ratio). Additionally, high quality residues which contain easily degradable components tend to increase soil microbial biomass and activity leading to net N mineralization (*Stark* et al. 2007).

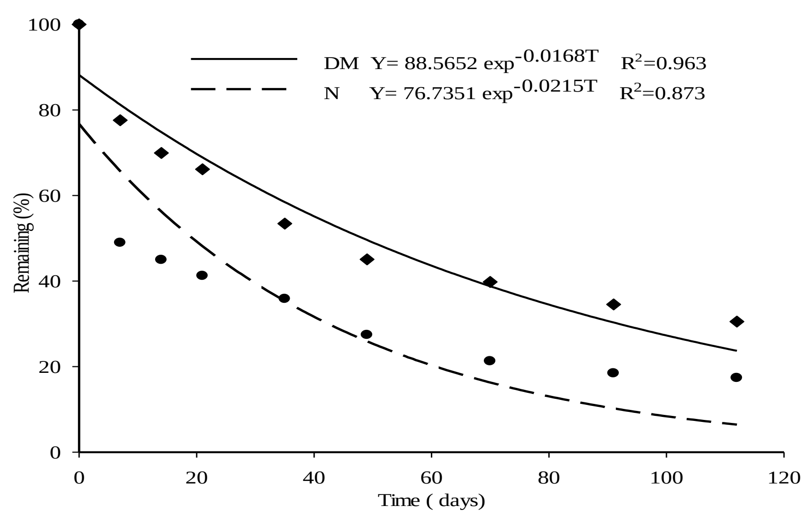

Figure 1. Dry matter decomposition and nitrogen mineralization of sunhemp form biomass incorporation until potato harvest

A hug nitrogen mineralization proportion was observed, particularly in the first few days, whereas approximately 70 % of the initial N content was mineralized during the first six weeks after incorporation. These results are in accordance with that obtained by *Perin* et al. (2006), *Odhiambo* (2010) and *Araujo* (2012) for the same green manure in comparable conditions.

Foliage nitrogen accumulation

Nitrogen accumulation within potato foliage under all treatments presented quadratic functions with different peaks (Figure 2). Whereas, maximum accumulated N for sunhemp treatments and MN was observed between 52.5 and 56.5 DAP. The elevated GM doses (200 and 400 kg N ha^{-1}) increased N accumulation (35.73and 39.13 kg ha^{-1}, respectively) which was more than the remaining GM dose (100 kg N ha^{-1} dose) as well as mineral N dose (25.51 and 26.22 kg ha^{-1}, respectively) and exceeded N0 treatment (15 kg ha^{-1}). The obtained models in the current experiment are different from that reported by *Kleinkopf* et al. (1981) *Alva* et al. (2002), *Macqueen* (2007) and *Fernandes* et al. (2011) since they mentioned sigmoid functions for nitrogen accumulation with delayed peaks before senescence. These differences can be seen as site-specific and variety differences as mentioned by *Zebarth* et al. (2005). He found different accumulation patterns between Shepody and Russet Burbank grown under the same conditions. Taking into account the results obtained *Fernandes* et al. (2010), comparable results for MN fertilization was attained.

The fast decline of foliage N before senescence is a result of nitrogen translocation from foliage to tubers (*Zebarth* et al. 2004a). Furthermore, it can be seen as accelerated and regarded as a stimulus effect of the experimental conditions to augment nitrogen compounds translocation to tubers consequently early defoliation under green manuring.

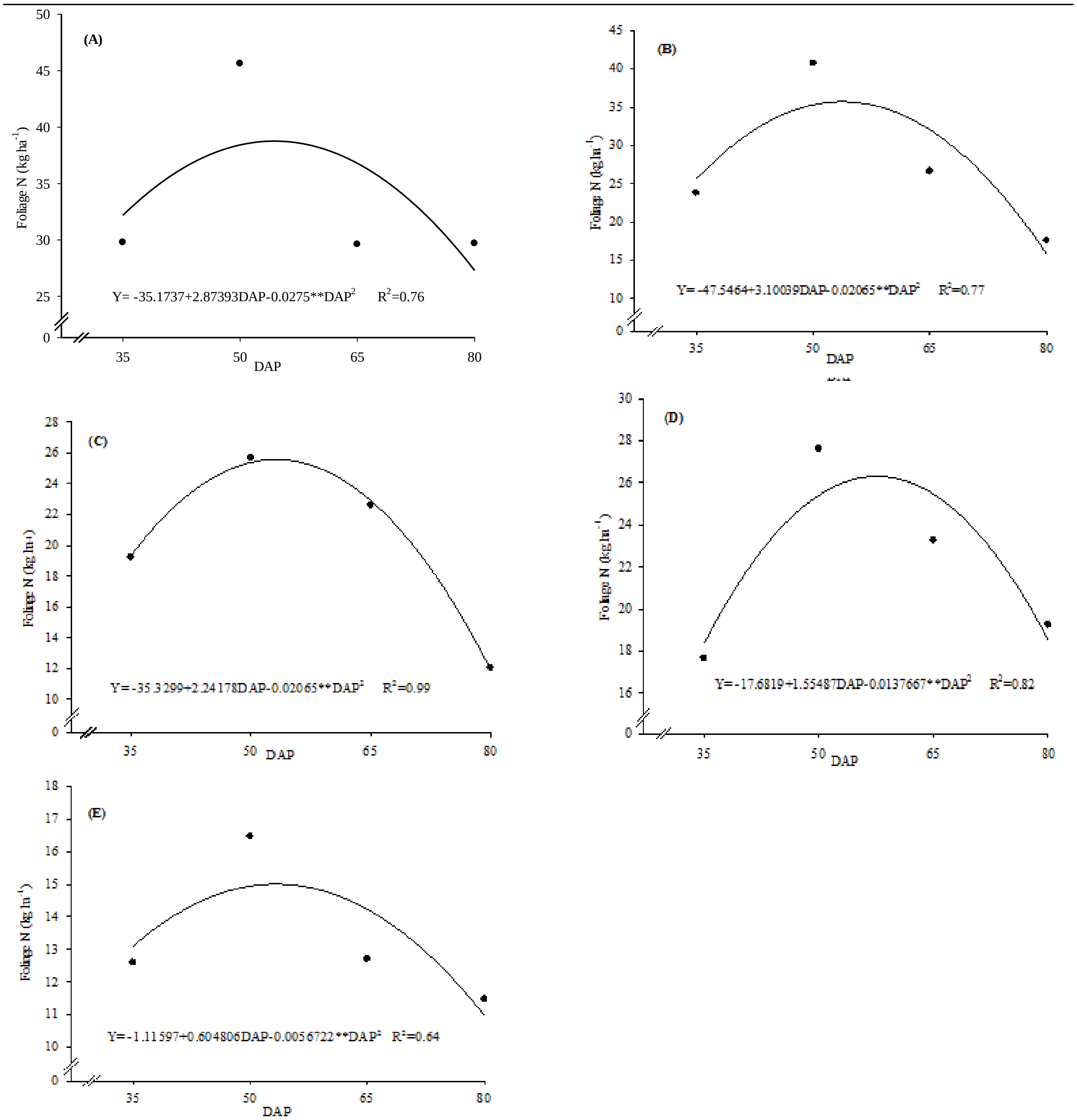

Figure 2. Foliage N accumulation (kg ha^{-1}) as a function of days after planting (DAP) under different fertilization treatments. (A): green manure (400 kg ha^{-1}), (B): green manure (200 kg ha^{-1}), (C): green manure (100 kg ha^{-1}), (D): mineral nitrogen (250 kg ha^{-1}) and (E): zero nitrogen

Tuber nitrogen accumulation

Tuber N accumulation presented linear patterns for all treatments (figure 3). GM100 and GM200 presented lower estimated rates (1.16 and 1.09 kg ha^{-1} day^{-1}, respectively) than MN treatment (1.31kg ha^{-1}day^{-1}). Meanwhile, the extreme estimated rates were recorded under the GM400 and N0 treatments (1.42 and 0.59 kg ha^{-1} day^{-1}, respectively). *Macqueen*, (2007) reported similar N accumulation rates (1.2 to 2 kg ha^{-1} day^{-1}) for different potato varieties grown in different organically managed sites. The tiny difference can be regarded as variety-specific characteristic whereas the used variety in our experiment is not for processing and has a medium maturity age. On the other hand, *Fernandes* et al. (2010, 2011) reported sigmoid functions for nitrogen accumulation for the same variety under Brazilian conditions. However, the obtained data did not fit into that model and this difference in plant performance could be attributed to management or site influence.

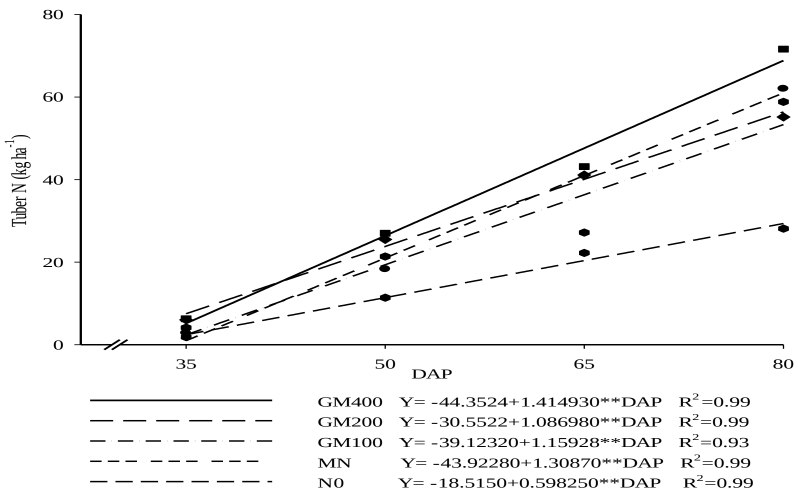

Figure 3. Tuber N accumulation (kg ha^{-1}) as a function of days after planting (DAP) under different fertilization treatments

Nitrogen accumulation within entire plant

Whole plant N uptake presented linear regression functions for all treatments (Figure 4) with different estimated rates. The superior N uptake rate was recorded under mineral N fertilization (1.28kgha^{-1} day^{-1}). However, GM treatments presented uptake rates between 0.87 to 1.12 kg ha^{-1} day^{-1}. Furthermore, the lowest estimated rate was for N0 treatment (0.55kgha^{-1} day^{-1}). Comparable linear N uptake models were mentioned by *Macqueen*, (2007) for different potato varieties that were grown under organic management which could be seen as similar management conditions. On the other hand *Alva* et al. (2002) and *Kleinkopf* et al. (1981) reported sigmoid N uptake models. In addition, cubic and quadratic models were reported by Lauer (1984). This difference could be possibly attributed to lack of more sampling early in the season and not continuing until the plants were mature.

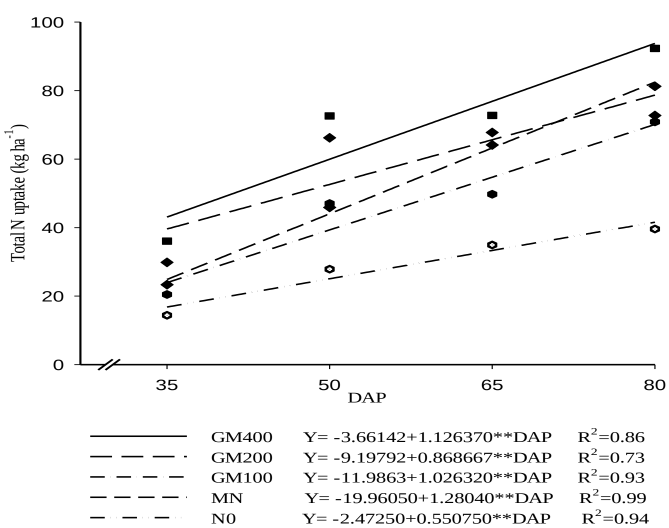

Figure 4. Potato total N uptake as a function of days after planting (DAP) under different N fertilization treatments

Relationship between N mineralization and potato acquisition

Correlation between sunhemp mineralization and potato nitrogen uptake presented high negative and significant correlation ($p<0.001$) coefficients. Pearson`s coefficients (r^2) were 0.959, 0.879 and 0.923 for the sunhemp nitrogen doses, GM100, GM200 and GM400, respectively. Considering *Hendrix* et al., (1990) theoretical hypothesis of nitrogen release scenarios following different litter incorporation, sunhemp incorporation (high quality litter) in this experiment presented the ideal case to afford plant N requirements within both time and quantity scales. So that, it can be assumed that there was a synchrony between N mineralization and potato uptake.

Yield components

Yield components of sunhemp treatments were similar to mineral nitrogen fertilization (Table 3). The highest marketable and total yield was recorded under GM400 followed by GM200 which was superior to MN treatment. The treatment GM100 resulted in similar yield to MN treatment ($p\geq0.05$). Furthermore, N0 treatment presented the lowest marketable and total yield. Yield of sunhemp nitrogen doses, 100, 200 and 400 was greater by 3.89, 15.4 and 31.2 % and by 4.65, 13.65 and 29.72 % than MN treatment for marketable and total yield, respectively. *Campiglia* et al. (2009) reported potato yield of 48.5 t ha^{-1} after subclover and hairy vetch incorporation, which was similar to mineral nitrogen fertilization. In addition, different experiments showed yield increases when legumes preceded potato with additional mineral N supply. *Carter* et al., (2003) reported yield increase by 7.5% when green manure preceded potato compared to mineral nitrogen alone. *Sincik* et al. (2008) reported 12.7 % and 15 % more tuber yield when potato was cropped after incorporation of common vetch and faba bean than when cropped with mineral N fertilizer alone. Yield increase after green manuring was attributed to, besides nitrogen effect, improved water retention, cation exchange capacity and water infiltration, stimulated soil microbial activity and reduced crop pathogens which provide better conditions for crop growth and higher yields (*Bath*, 2000; *Rodrigues* et al., 2006; *Carter* et al., 2003; *Curless* et al., 2004).

Table 3. Marketable yield (MY), total yield (TY), and nitrogen use efficiency (NUE) on potato plants under different N treatments

Treatment	MY (kg ha^{-1})	TY (kg ha^{-1})	NUE (kg tuber kg^{-1} N)
GM400	41615.0	42887.25	107.22
GM200	36617.5	37575	187.88
GM100	32952.5	34602.5	346.03
MN	31717.5	33062.5	132.25
N0	25522.5	26555	-
LSD ($p\leq0.05$)	3722.57	3691.8	-
CV (%)	4.9	4.69	-

GM; green manure, MN; recommended mineral N fertilization, N0; zero N treatment and numerical values refer to N dose (kg ha^{-1})

Nitrogen use efficiency (NUE) presented an inverse response to N doses (Table 3). The lower the N dose is the higher the NUE. The GM200 dose increased nitrogen productivity and was higher than MN fertilizer. Meanwhile, a decline in NUE was recorded under GM400 and was smaller than MN. These results are in accordance with the trend mentioned by *Darwish* et al. (2006), *Kumar* et al. (2007), *Goffart* et al.(2008), *Fontes* et al. (2010) and *Irena* et al. (2011). The decline of NUE was attributed to the low ability of potatoes to assimilate soil mineral nitrogen. Comparison of NUE for sunhemp treatments with MN treatment showed superiority to mineral nitrogen. This high efficiency can be attributed to the non-nitrogen benefits of sunhemp incorporation which afford convenient soil conditions to potato N acquisition as mentioned by *Bath* (2000) and *Campiglia* et al. (2009). In addition, *Fontes* et al. (2010) reported values of 115 and 99 (kg tubers kg^{-1} N) as nitrogen productivity per each applied nitrogen unit (in the same region and variety) for total and marketable yield, respectively when 300 kg N ha^{-1} was supplied. In our study, the mean values for NUE of sunhemp nitrogen doses are in that range suggesting that green manure use provides a high NUE in potato.

CONCLUSION

Incorporating sunhemp as green manure prior to potato presented high N mineralization rate and guaranteed adequate nitrogen supply during its peak growth stage. Potato nitrogen acquisition presented similar models to that of mineral nitrogen fertilization with superior accumulation and earlier peaks of uptake which reflects quite shorter life cycle. Moreover, synchrony between nitrogen mineralization and uptake reveals suitability of sunhemp to substitute synthetic nitrogen fertilization. Moreover, Potato presented higher yields and improved nitrogen productivity under green manuring. Thus, economic yields with less nitrogen supply could be attained. Thus, green manures seemed to be more sustainable from economic and environmental point of view. It is evident that more research using different green manure varieties with different chemical composition and ages as well as different potato varieties are required to have better insights regarding potato growth physiology. In addition, investigate nitrogen dynamics within soil and soil organic matter in order to ensure sustainable use of green manures.

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