American Journal of Plant Sciences, 2016, 7, 469-478
Published Online March 2016 in SciRes. http://www.scirp.org/journal/ajps
http://dx.doi.org/10.4236/ajps.2016.73041

Onion Response to Added N in Histosols of Contrasting C and N Contents

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Received 5 February 2016; accepted 13 March 2016; published 16 March 2016

Abstract

Adjusting the N fertilization to soil potentially mineralizable N in Histosols is required to secure high vegetable yields while mitigating nitrate contamination of surface waters. However, there is still no soil test N (STN) relating the response of Histosol-grown onion (*Allium cepa* L.) to added N. Compositional data analysis can integrate soil C and N composition into a STN index computed as Mahalanobis distance ($\mathcal{M}^2$) across isometric log ratios (*ilr*) of diagnosed and reference soil C and N compositions. Our objective was to calibrate onion response to added N against a compositional STN index for Histosols. Reference compositions were computed from high N-mineralizing Histosols reported in the literature. Soil analyses were total C and N, and a residual soil mass (F_v) was computed as 100%-%C-%N to close the compositional vector to 100%. The C, N, and F_v pro- portions were synthesized into two *ilrs*. We conducted thirteen onion N fertilization trials in Histosols of south-western Quebec showing contrasting C, N, and F_v proportions. Each crop received four N rates broadcast before seeding or split-applied. We derived two STN classes separating weakly to highly responsive crops about the $\mathcal{M}^2$ value of 5.5. Onion crops grown on soils showing $\mathcal{M}^2$ values >5.5 required more N and yielded less in control treatments compared with soils showing $\mathcal{M}^2$ values <5.5. Onions grown in low-($\mathcal{M}^2$ < 5.5) and high-($\mathcal{M}^2$ > 5.5) soils responded significantly ($P < 0.10$) to 60 and 180 kg N ha^{-1}, respectively. Using literature data and the results of this study, we elaborated a provisory N requirement model for Histosol-grown onions in Quebec.

Keywords

Compositional Data Analysis, Meta-Analysis, Onion, C/N Ratio, Soil Test N

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How to cite this paper: Quinche Gonzalez, M., Pellerin, A. and Parent, L. (2016) Onion Response to Added N in Histosols of Contrasting C and N Contents. *American Journal of Plant Sciences*, **7**, 469-478. http://dx.doi.org/10.4236/ajps.2016.73041

1. Introduction

Onions (*Allium cepa* L.) are grown on nearly 9000 ha of Histosols in Quebec, Ontario and New York state. Depending on the C/N ratio, organic N amounts varied from 5000 to 27,000 kg N ha^{-1} in the top 20 cm of Histosols [1]. Reference [2] showed that combined effects of fertilization, drainage and mineralization produced 40 to 50 times more NO_3-N in runoff water during the growing season under cultivated compared to uncultivated marsh in Ontario. Reference [3] reported N losses of 37 - 245 kg N $ha^{-1}\cdot yr^{-1}$ from Ontario Histosols with yearly concentrations varying between 15 and 43 mg NO_3-N L^{-1} in surface waters. After mineralization of organic N into nitrate, the net nitrate accumulation reached 850 kg NO_3-N ha^{-1} in New York Histosols [4] and 1400 kg NO_3-N ha^{-1} in the Florida Everglades [5]. About 60% of the nitrate production accumulated in the 0 - 40 cm layer [1]. Growers practice is to add fertilizer N as preventive measure against under-fertilization. When soil N supply capacity is high over-fertilization must contribute to nutrient waste and water contamination [6]-[8], especially for onion crops, due to low capacity of the root system to exploit soil N [9].

In general, N requirements increase with yield potential [10]-[12]. Reference [13] found no significant effect of adding 22.4 kg N ha^{-1} to onion crops at yield potential of 41 Mg ha^{-1} in Quebec Histosols. Reference [1] reported no significant onion response at yield potential of 55 Mg ha^{-1}. Reference [14] found that eliminating the N fertilization (56 - 112 kg N ha^{-1}) could be very risky for early planted onions in New York Histosols at yield levels of 42 - 80 Mg N ha^{-1}, because substantial quantities of mineral N were released later in the season. The discrepancy between the limited research results and growers' practice is indicative of a large spectrum of soil properties and management options. Although a pre-side-dress-nitrogen test (PSNT) has been proposed to adjust N fertilization in Histosols [15], there is still no soil test N (STN) to discriminate between responsive and non-responsive situations in Histosols with differential N mineralization potentials.

The N and C transformations in soils are closely related [16]. The C/N ratio thus allowed evaluating N mineralization or immobilization in Histosols [17]. Reference [18] suggested using a critical C/N ratio of 29 to separate the opposing processes of net mineralization and net immobilization in Histosols. In cultivated Quebec Histosols, C/N ratios were found to vary between 15 and 21, and were associated with the release of mineral N up to 620 kg N ha^{-1} in the upper 30 cm [19]. Reference [20] showed that N mineralization in Histosols depended not only on the C/N ratio but also on organic matter content. Reference [1] proposed using a compositional multi-ratio concept assuming that N mineralization was limited by C excess or C and N dilution in the residual soil mass computed as a filling value (F_v) between 100% and analytical results (%C and %N).

Compositional data analysis provides tools to handle data closed to 100% that are distorted by redundancy of information, sub-compositional incoherence and non-normal distribution [21]. The isometric log ratio (*ilr*) is the most appropriate data transformation technique to avoid misinterpreting the results of statistical analyses of compositional data [22] [23]. Because *ilrs* are orthogonal to each other, a Mahalanobis distance ($\mathcal{M}^2$) can be computed as STN index across C, N and F_v proportions to diagnose a given composition of Histosols against a reference one [24]. On the other hand, trials on N effect on crop yield can be synthesized using subgroup meta-analysis [25]-[27]. Allocating trials to STN subgroups and analyzing the effect size of N additions by meta-analysis could improve the accuracy of N fertilizer recommendations for onions grown in Histosols.

Our objective was to conduct a meta-analysis of multi-year and multi-site trials on yield response of dry onions to added N in Quebec Histosols using a compositional index as soil test N.

2. Material and Methods

2.1. Experimental Sites

The onion data set comprised 13 N fertilization trials conducted in Histosols of south-western Quebec, Quebec, Canada, between 2003 and 2006. Meteorological data were obtained from the Hemmingford station, Quebec (Latitude: 45˚4.200'N; Longitude: 73˚43.200'W; Altitude: 61 m). The length of the growing period averaged 120 d. The onion was irrigated during dry periods.

Plots were 3 to 8 rows in width and 6 to 8 m in length. Fertilizers were applied broadcast before sowing or in 2 split applications. There were four N rates up to 180 kg N ha^{-1} including a control treatment without N, allocated to three randomized blocks. Harvest date depended on the number of days required to meet commercial standards. Yields were measured in two central rows of 3 m in length. Plant density of cultivars Bastille, Fortress, Arsenal, Genesis, Frontier and Hamlet at harvest averaged 245,863, 325,650, 382,979, 449,173, 477,205 and 501,774 plants ha^{-1}, respectively. Bulbs were classified as follows (Ø = diameter): extra-large (Ø > 76.3 mm), large (Ø 57.3 - 76.3 mm), medium (Ø 44.5 - 57.3 mm), small (Ø 31.8 - 44.5 mm), and discarded (too small, evidence of rot).

2.2. Soil Analysis

Soil samples were collected in the spring before fertilizer application and composited by block (three sub-samples per sample). Soils were cleaned from roots and woody particles, air-dried to constant weight and sieved to < 2 mm before analysis. Soil pH was determined in a 0.01 M $CaCl_2$ using a 1:4 soil to solution volumetric ratio [28]. Total C and N were determined by combustion using CNS-Leco 2000 [29]. Organic matter content was estimated assuming 58% C content. Elements were extracted using the Mehlich-3 method [30] and quantified by ICP-OES.

2.3. Compositional Data Analysis

The compositional space *S* of C and N analyses was described as follows [21]:

$$S = c\left(\mathrm{C}, \mathrm{N}, F_v\right) = 100\% \tag{1}$$

where F_v was computed by difference between 100% and analytical results (%C, %N) and c indicates closure of the simplex to the unit of measurement (here, 100%). Compositional data are relative to each other and thus inter-related. As inferred from Equation (1), any change in a given concentration (by adding more N for example) must affect the proportion of other components. Due to redundancy among components, there are D-1 degrees of freedom in a D-parts composition [31]. The *ilr* allows reducing D parts to D-1 orthogonally arranged variables. The D-1 *ilr* coordinates are computed as follows [22]:

$$ilr_i = \sqrt{\frac{n_i^+ \times n_i^-}{n_i^+ + n_i^-}} \ln \frac{g\left(c_i^+\right)}{g\left(c_i^-\right)} \tag{2}$$

where *i* varies between 1 and D-1, n_i^+ and n_i^- are the numbers of components in group c_i^+ at numerator and group c_i^- at denominator, respectively, $g\left(c_i^+\right)$ is geometric mean across components in c_i^+ and $g\left(c_i^-\right)$ is geometric mean across components in c_i^-. We selected the following two isometric log contrasts or balances between C, N and F_v as follows: C (c_i^+) vs. N (c_i^-) representing the C/N ratio and the contrast between C and N (c_i^+) and F_v (c_i^-) representing the dilution of C and N in the residual soil mass. For example, a soil containing 46.61% C and 2.09% N returns the following *ilr* values:

$$ilr_{[\mathrm{N|C}]} = \sqrt{\frac{1 \times 1}{1+1}} \ln\left(\frac{\mathrm{C}}{\mathrm{N}}\right) = \sqrt{\frac{1}{2}} \ln\left(\frac{46.61}{2.09}\right) = 2.195 \tag{3}$$

$$ilr_{[F_v|\mathrm{C,N}]} = \sqrt{\frac{2 \times 1}{2+1}} \ln\left(\frac{\sqrt{\mathrm{C} \times \mathrm{N}}}{F_v}\right) = \sqrt{\frac{2}{3}} \ln\left(\frac{\sqrt{46.61 \times 2.09}}{100 - 46.61 - 2.09}\right) = -1.346 \tag{4}$$

Balance indices were computed as distances between a given composition and a reference one, as follows across results of Equations (3) and (4):

$$I_{[\mathrm{N|C}]} = \frac{ilr_{[\mathrm{N|C}]} - ilr^*_{[\mathrm{N|C}]}}{S^*_{ilr_{[\mathrm{N|C}]}}} = 1.711 \tag{5}$$

$$I_{[F_v|\mathrm{C,N}]} = \frac{ilr_{[F_v|\mathrm{C,N}]} - ilr^*_{[F_v|\mathrm{C,N}]}}{S^*_{ilr_{[F_v|\mathrm{C,N}]}}} = 0.234 \tag{6}$$

where ilr_x^* and $S^*_{ilr_x}$ are the mean and standard deviation of a reference soil subpopulation defined using independent data from highly mineralizing Histosols (>1 kg NO_3-N $ha^{-1} \cdot d^{-1}$) in USA and Europe [32]. Reference *ilr* values (mean ± standard deviation) were computed as 1.899 ± 0.173 for $ilr^*_{[\mathrm{N|C}]}$ and −1.391 ± 0.192 for $ilr^*_{[F_v|\mathrm{C,N}]}$ (**Table 1**). Because *ilrs* are orthogonal to each other, an STN index is computed as Mahalanobis distance ($\mathcal{M}^2$) across results of Equations (5) and (6) as follows:

Table 1. Compositional nutrient diagnosis norms for the three-component simplex (C, N, and F_v).

Soil identification	C	N	F_v	C:N ratio	$[F_v\|C.\ N]$	[N|C]
	g·kg^{-1}					
Zegvelderbrock	352	40.0	608	8.8	−1.334	1.538
Hula	311	30.6	658	10.2	−1.559	1.640
Terra Ceia	433	21.4	546	20.2	−1.416	2.127
Lauderhill	432	23.8	544	18.2	−1.372	2.050
Pahokee	429	23.0	548	18.7	−1.394	2.069
Monteverde	366	25.5	609	14.4	−1.503	1.884
Lauderhill muck	435	36.8	528	11.8	−1.167	1.746
Brighton	385	31.5	584	12.2	−1.361	1.770
Pahokee muck	469	38.1	493	12.3	−1.065	1.775
Aitkin	352	19.0	629	18.5	−1.666	2.064
1b	530	34.4	436	15.4	−0.956	1.934
2a	376	30.2	594	12.5	−1.403	1.783
2b	467	32.0	501	14.6	−1.152	1.895
3	348	27.9	624	12.5	−1.507	1.784
4	310	28.2	662	11.0	−1.598	1.695
6	356	19.0	625	18.7	−1.656	2.072
11	454	26.1	520	17.4	−1.277	2.020
29	413	24.5	562	16.9	−1.405	1.998
20	375	21.5	604	17.4	−1.557	2.021
13	416	20.9	563	19.9	−1.468	2.115
Mean					−1.391	1.899
Standard deviation					0.192	0.173

$$\mathcal{M}^2 = I^2_{[\mathrm{N}|\mathrm{C}]} + I^2_{[F_v|\mathrm{C,N}]} = 2.982 \tag{7}$$

To separate low-from high-N mineralizing Histosols, we selected the critical $\mathcal{M}^2$ value of 5.5, computed as half the maximum $\mathcal{M}^2$ value of 11 for net nitrification [32]. Net N immobilization was assumed to occur for $\mathcal{M}^2$ values >11, high-N net mineralization for $\mathcal{M}^2$ values <5.5, and low-N mineralization for intermediate $\mathcal{M}^2$ values (>5.5 and <11). Approximately halving or doubling a critical value is suggested to build soil fertility classes in view of interpreting soil test results to make fertilizer recommendations [33].

2.4. Statistical Analysis

Analysis of variance of marketable yields was conducted using the MIXED procedure using SAS version 9.2 for Windows [34]. Meta-analyses were conducted using Excel and formulas for random mixed models in [35]. The response ratio (*RR*) was computed as follows:

$$RR = \ln\left(\frac{\bar{X}_1}{\bar{X}_2}\right) \tag{8}$$

The variance of *RR* was computed as follows [35]:

$$V_{\ln RR} = S^2_{pooled}\left(\frac{1}{n_1\left(\bar{X}_1\right)^2} + \frac{1}{n_2\left(\bar{X}_2\right)^2}\right) \tag{9}$$

where

$$S_{pooled} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \tag{10}$$

where

$$S_1 = S_2 = \sqrt{MSE + \sigma} \tag{11}$$

where

$$\sigma = \left(SE^2 \times MSE\right) - n \tag{12}$$

where S_{pooled} is the pooled within group standard deviation, n_1 and n_2 are the numbers of observations in treatment and control, respectively (here, $n = n_1 = n_2$), $\bar{X}_1$ and $\bar{X}_2$ are treatment and control means, respectively, and S_1 and S_2 are standard deviations for treatment and control, respectively, computed as the square root of error mean square (MSE) plus the term variance for the block effect (σ) which takes into account the standard error (SE) (Gaétan Daigle, professional statistician, University Laval, personal communication). Size effect in meta-analysis was declared significant at $P < 0.10$ for possible inclusion into the response model.

3. Results and Discussion

3.1. Climate

Rainfall from May to August was higher in 2003 and 2006 compared to 2004 and 2005 (**Figure 1**). Climate was driest in 2005, especially in May and August. Irrigation was applied at need. However, the effect of climate on the response ratio could not be tested due to the limited number of N trials. Hence, STN was the only factor retained to build subgroups of onion response to added N.

3.2. Soil Properties

The soils covered a large spectrum of C and N concentration values and other properties (**Table 2**). Total soil C varied from 222.7 to 507.4 g C kg^{-1} while total N ranged between 11.6 and 25.3 g N kg^{-1} compared to 310 to 530 g C kg^{-1} and 19.0 to 40.0 g N kg^{-1} in [32] (**Table 1**). Organic matter varied between 12.9% and 29.4% and the soil C/N ratio between 18.9 and 29.3. Soil pH ($CaCl_2$) varied from 4.5 to 6.7 therefore pH_{H2O}varied from 4.7

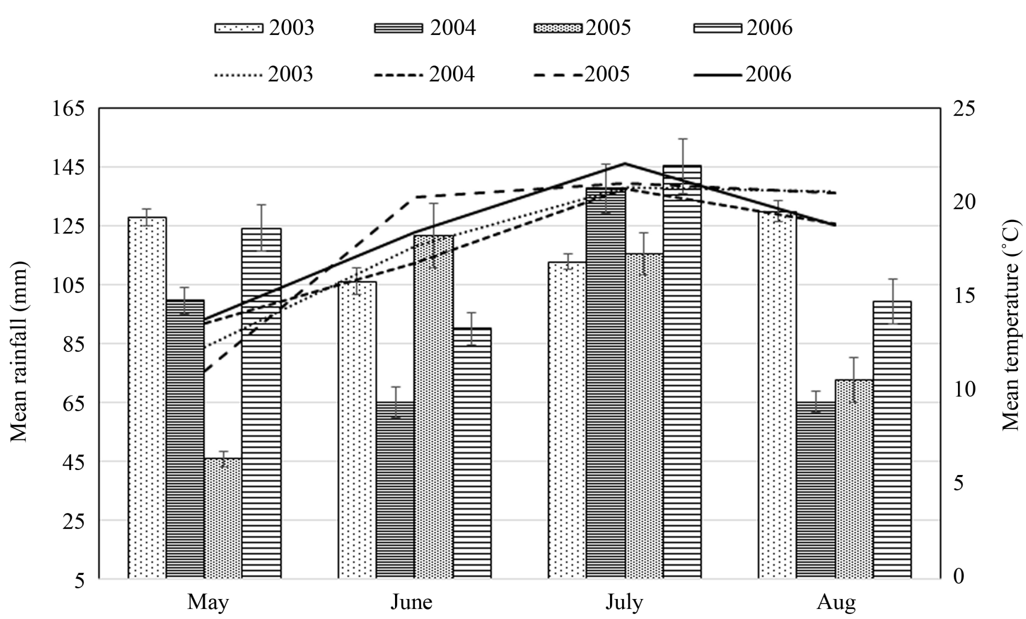

Figure 1. Climatic conditions at the Hemmingford (Quebec) meteorological station near experimental sites (Columns represent rainfall and lines represent temperature). Source: Hemmingford station, Quebec (Latitude: 45˚4.200'N; Longitude: 73˚43.200'W; Altitude: 61 m).

Table 2. Soil properties and soil test N at the 13 onion experimental sites.

Soil property	Unit	Mean value	Range
Total C	$g \cdot kg^{-1}$	444.9	222.7 - 507.4
Total N	$g \cdot kg^{-1}$	19.6	11.6 - 25.3
C/N ratio	-	23.2	18.9 - 29.3
Organic matter	%	26.1	12.9 - 29.4
pH $CaCl_2$	-	5.3	4.5 - 6.7
Mahalanobis distance	-	6.9	1.1 - 19.6
	Mehlich-3 extraction		
P	$mg \cdot kg^{-1}$	326.6	49.3 - 630.0
100P/(Al + 5Fe)	%	14.0	2.8 - 25.6
K	$mg \cdot kg^{-1}$	526.2	144.9 - 1025.2
Ca	$mg \cdot kg^{-1}$	11,595.1	6344.3 – 17,217.9
Mg	$mg \cdot kg^{-1}$	1743.8	1019.7 - 3810.5
S	$mg \cdot kg^{-1}$	0.5	0.3 - 1.1
Cu	$mg \cdot kg^{-1}$	23.3	5.1 - 37.9
Mn	$mg \cdot kg^{-1}$	60.0	27.4 - 80.7
Zn	$mg \cdot kg^{-1}$	13.9	6.9 - 40.8
Fe	$mg \cdot kg^{-1}$	775.0	354.0 - 1417.7
Al	$mg \cdot kg^{-1}$	154.7	0.0 - 1118.1

to 7.1 using the conversion equation of [28], within ranges reported by [28] and [32] for Quebec Histosols. The $\mathcal{M}^2$ values ranged between 1.1 and 19.6, hence reaching beyond the limit of 11 for net N immobilization suggested by [32].

3.3. Crop Response to Added N within Pre-Determined Soil N Fertility Classes

There were 9 sites in the $\mathcal{M}^2 < 5.5$ STN group and 4 sites in the $\mathcal{M}^2 > 5.5$ group (**Table 3**). Onion response to added N was smaller in the $\mathcal{M}^2 < 5.5$ compared to the $\mathcal{M}^2 > 5.5$ group. In the $\mathcal{M}^2 < 5.5$, onion response to N was significant at the 0.10 level adding 60 kg N ha^{-1}. The onion crop in the $\mathcal{M}^2 > 5.5$ group was responsive to added N at the 0.10 level of significance adding 180 kg N ha^{-1}. The $\mathcal{M}^2$ scanned a much larger range up to nearly 20 in the $\mathcal{M}^2 > 5.5$ STN group (**Table 2**) but the latter group could not be further partitioned due to the small number of observations.

Although references [13] and [14] provided no soil analyses enabling to relate STN to added N, additions of 0 to 56 kg N ha^{-1} without significant yield response supported our results if such trials had been conducted on Histosols showing $\mathcal{M}^2 < 5.5$. Indeed, reference [13] conducted their trials on a "well-drained and well-decomposed muck" at the Agriculture and Agrifood Canada experimental farm (Ste-Clotilde, Quebec) where STN as $\mathcal{M}^2$ was found to be 2.5 in 2004 and 2.6 in 2005 in our study. The trials of reference [14] have been conducted on 2-m deep Elba "muck" soil containing 80% organic matter. A Cornell University survey report [36] indicated that recommended N should not exceed 56 kg N ha^{-1} in "Elba" deep mucks containing ≈80% organic matter while discharging up to 37 NO_3-N L^{-1} into waterways, an extremely high value.

On the other hand, in a Nova Scotia experiment on the Caribou bog where N was applied at rates of 0, 90, 180 and 270 kg N ha^{-1}, reference [37] found that maximum onion yield of 50.5 Mg ha^{-1} was obtained with 180 kg N ha^{-1} for a ripening acid sphagnum peat soil cultivated five years after reclamation. In comparison, a maximum yield of 37.2 Mg ha^{-1} was obtained with 270 kg N ha^{-1} on a newly broken Histosol of similar origin. Although reference [37] did not provide soil C and N analyses, a former soil survey of the pristine Caribou bog [38] where their trial was conducted indicated that the upper soil layer made of the brownish fibrous mossy peat contained

0.91% of total N and 46% of total C (*i.e.*, organic matter content = 79.3%), returning a $\mathcal{M}^2$ value of 28.5, far beyond the upper limit of the model in **Figure 2**. Onion response was consistent with the peat ripening process where N concentration increases in the upper layer [39] resulting in lower $\mathcal{M}^2$ values, hence less N requirement.

Reference [39] reported that Histosols showing C/N ratio of 29 could release 77 - 98 kg N ha^{-1} yr^{-1}; more ripened soils showing C/N ratios of 23 - 24, 170 - 493 kg N ha^{-1} yr^{-1} while muck soils with C/N ratio of 18 could release 99 - 186 kg N ha^{-1} yr^{-1}. The pattern of soil N mineralization capacity thus appeared to be quadratic. Indeed, total N and the C/N ratio could be effective STNs where F_v content varies little such as in high-C peat materials [1] [17] [18]. Otherwise, $\mathcal{M}^2$ is a more suitable STN where Histosol compositions vary more widely within the limits of soil properties outlined in **Table 1**.

3.4. Provisory Onion N Recommendation Model

Significant ($P < 0.10$) trends of crop response to added N for treatments showing the highest RR (**Table 3**) in

Table 3. Response to added N (60 - 180 kg N ha^{-1}) of onion grown in two fertility classes in Quebec organic soils. N.B. # is number of trials per group, STN is soil test N, N is total N, C/N is the C/N ratio, BRR is the back-transformation of ln (response ratio) into relative yield (treatment/control) and CI is confidence interval about RR.

Mahalanobis distance	#	STN group mean	N	C/N	N rate	$Yield_t$	$Yield_0$	BRR
			g·kg^{-1}		kg N ha^{-1}	Mg ha^{-1}		
<5.5 group	9	3.16	21.7	21.8	60	56.7	52.9	1.13^a
		3.35	21.5	22.2	120	58.9	53.9	1.11^a
		3.35	21.5	22.2	180	58.7	53.9	1.11^a
>5.5 group	4	10.30	15.5	25.8	60	38.0	33.4	1.23^{ns}
		10.55	15.6	25.3	120	40.1	30.1	1.30^{ns}
		10.55	15.6	25.3	180	38.8	30.1	1.36^a

^{ns}, ^{a}: not significant and significantly different from BRR = 1 at the 0.10 level according to t test, respectively. $Yield_t$ and $Yield_0$: yields of treatment with added N and control (zero N), respectively.

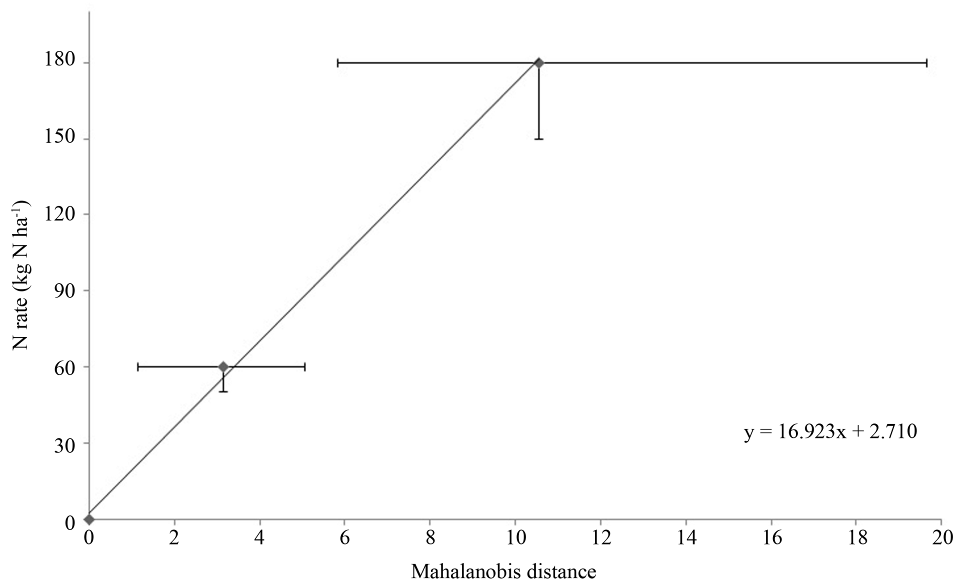

Figure 2. Relationship between onion N requirements and STN fertility classes. The soil N fertility classes are indicated as Mahalanobis distance <5.5 and >5.5. The ranges represent the smallest and the highest Mahalanobis distance values in each STN class.

each STN class were selected to build a provisory N requirement model, *i.e*. 60 and 180 kg N ha^{-1} for the $\mathcal{M}^2$ values of 3.16 (1.14 to 5.08) for the high-N mineralizing STN group and 10.55 (5.83 to 19.65) for the low-N mineralizing STN group, respectively.

Although there were only two soil fertility classes based on $\mathcal{M}^2$, the relationship between onion N requirements and STN was modelled under the following assumptions 1) N requirements → 0 kg N ha^{-1} where $\mathcal{M}^2$ values → 0 because there was no response to added N in the trials of references [1] and [13] (hence the probability of no response to added N is real); 2) onion responded significantly to 60 kg N ha^{-1} where $\mathcal{M}^2$ averaged 3.16, a value close to 56 kg N ha^{-1} obtained by [14] for high-N mineralizing soils; 3) onion responded significantly to 180 kg N ha^{-1} where $\mathcal{M}^2$ averaged 10.55. Onion response to added N appeared to be linearly related to $\mathcal{M}^2$ as STN index as shown in **Figure 2**. No R^2 value is presented because the meta-regression uses group means rather than individual data points. Variation about each group mean are indicated by confidence intervals (P = 0.05). The apparent close fit between $\mathcal{M}^2$ and the N rate indicated that $\mathcal{M}^2$ could be an appropriate STN index to adjust N fertilization to the Histosol capacity to supply N to the crop. There is some evidence for N requirements beyond 180 kg N ha^{-1} in a sphagnum bog of unknown composition [37]. The present empirical model that relies on a Quebec data set and meta-analysis should not be extrapolated to situations beyond the limits of application without additional experimentation where both soil test and crop response are reported. More robust and site-specific N recommendation interpolating models could be developed for the onion crop in Histosols through research collaboration to enhance the size of data set that include climatic data and soil classification.

Bulb quality could also be considered in N management because onion flavor [40] [41] and susceptibility to diseases [9] and bulb rot [42] may be affected by N excess. Moreover, an oversupply of nitrogen during the growing period may promote excessive top growth resulting in bulb expansion and splitting, while late-season applications may promote top growth, delay maturity, and favor diseases [36]. Because rapid growth rate of seeded onion may not occur until 5 - 6 weeks after emergence, a PSNT test [15] may be further investigated as complementary diagnostic tool to allow seasonal adjustment of N fertilization to soil N supply capacity as defined by STN and to N leaching through rainfall and irrigation.

4. Conclusion

A compositional STN index that integrates C, N and F_v into a Mahalanobis distance was calibrated against N requirements of onions grown on Histosols. The N requirements of onions appeared to be linearly related to the Mahalanobis distance $\mathcal{M}^2$ up to a value of 11. Onion crops grown in Histosols showing $\mathcal{M}^2$ values >5.5 required more N and yielded less in the control N treatment compared onions grown in Histosols with $\mathcal{M}^2$ values <5.5. A provisory N requirement model was elaborated based on $\mathcal{M}^2$ values measured in the thirteen Quebec trials and on assumptions where no soil analysis was reported in the literature. Although strong response trends were found in this research work, onion N requirements could be further validated by including more sites showing low, intermediate and high $\mathcal{M}^2$ values under a larger spectrum of climate and soil conditions.

Acknowledgements

We thank the Conseil de Recherche en Pêche et Agroalimentaire du Québec, the Conseil pour le développement de l'agriculture du Québec (CDAQ), Phytodata Inc. (Sherrington, QC), the Fonds de recherche du Québec-Nature et Technologies (FRQNT), Biopterre Inc., the Natural Sciences and Engineering Research Council of Canada (NSERC-OG-2254), and the participating vegetable growers for financial support.

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