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Identifying NEMO

An application of crop modeling for strategic nitrogen recommendations adapted to given soil and climate

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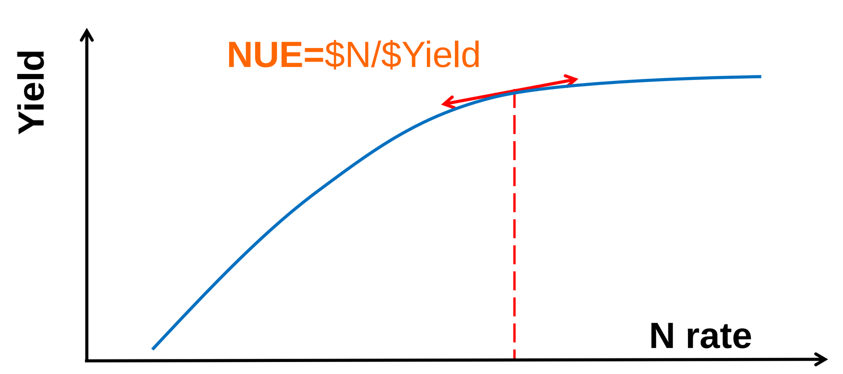
Introduction

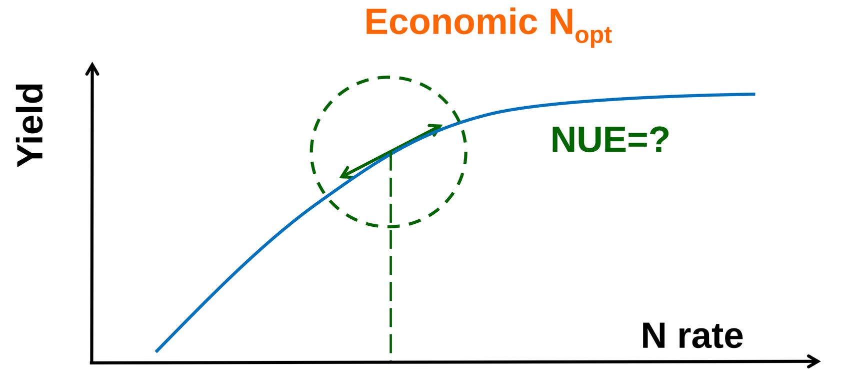
Identifying optimum rate of nitrogen (N_{opt}) application is essential for increasing agricultural production while limiting potential environmental contaminations caused by release of reactive N, especially for high demand N crops such as corn. However, N_{opt} varies by climate and soil. The central questions of N management is then: **What should be recommended N for given soil and climate?**

What is an optimum N rate?

Economic optimum N rate (N_{opt}) is an N rate at which the crop net return is maximized. At this rate the slope of yield function, known as N use efficiency (NUE), is equal to \$N/\$Yield.

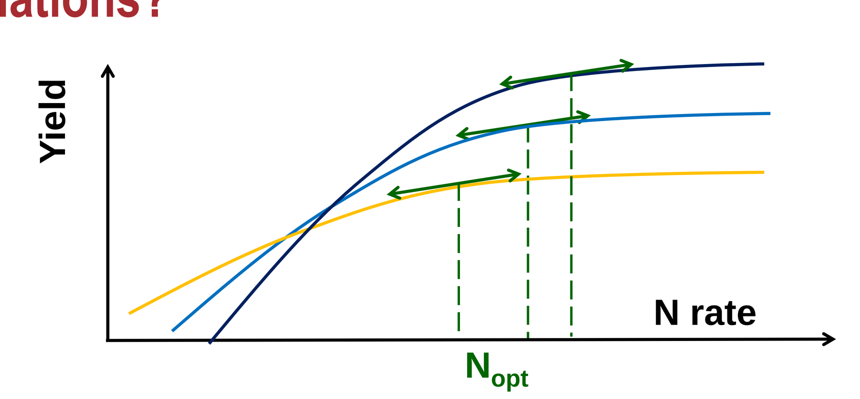


To account for environmental damage costs, we define an ecophysiological N_{opt}, which is a rate at which the N excess (i.e., the amount not taken up by plants) is minimized with little reduction in maximum achievable yield.



How is N_{opt} affected by climate variations?

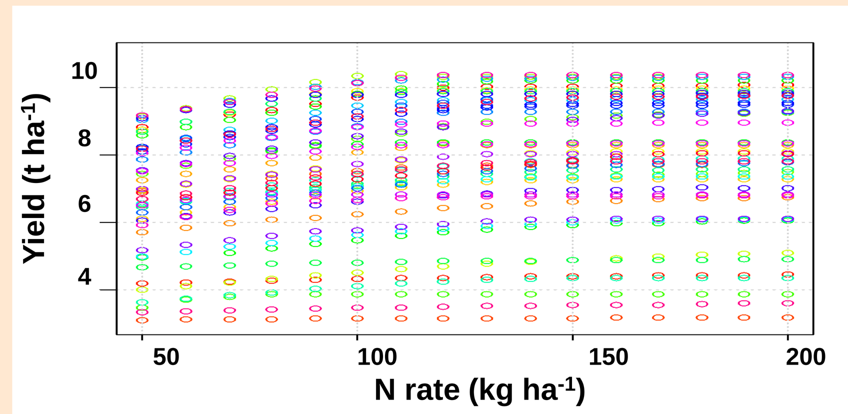
Regardless of how N_{opt} is defined, the N_{opt} values will be different from one year to another because of different climatic conditions. Therefore, a unique optimum NUE (slope) results in different N_{opt} values for different years.



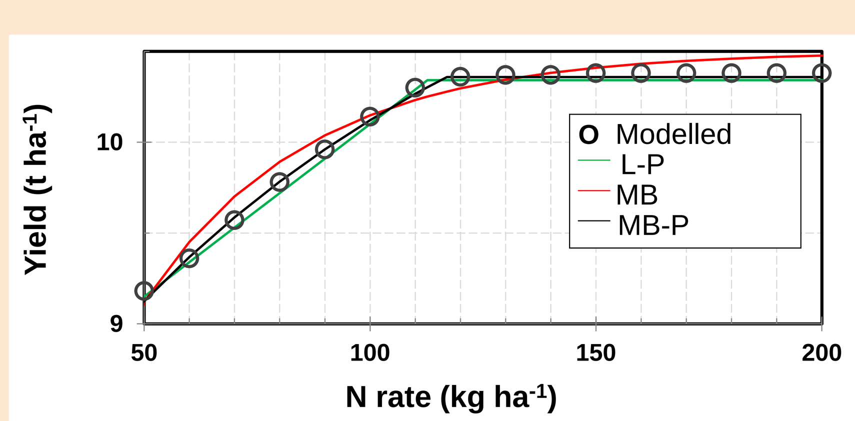
Identifying NEMO (N Ecophysiologically Modelled Optimum)

We used a newly developed model-based approach, called Identifying NEMO, to identify ecophysiological NUE_{opt} and corresponding N_{opt} values for given climate and soil (Mesbah et al. 2017). This approach has the following steps:

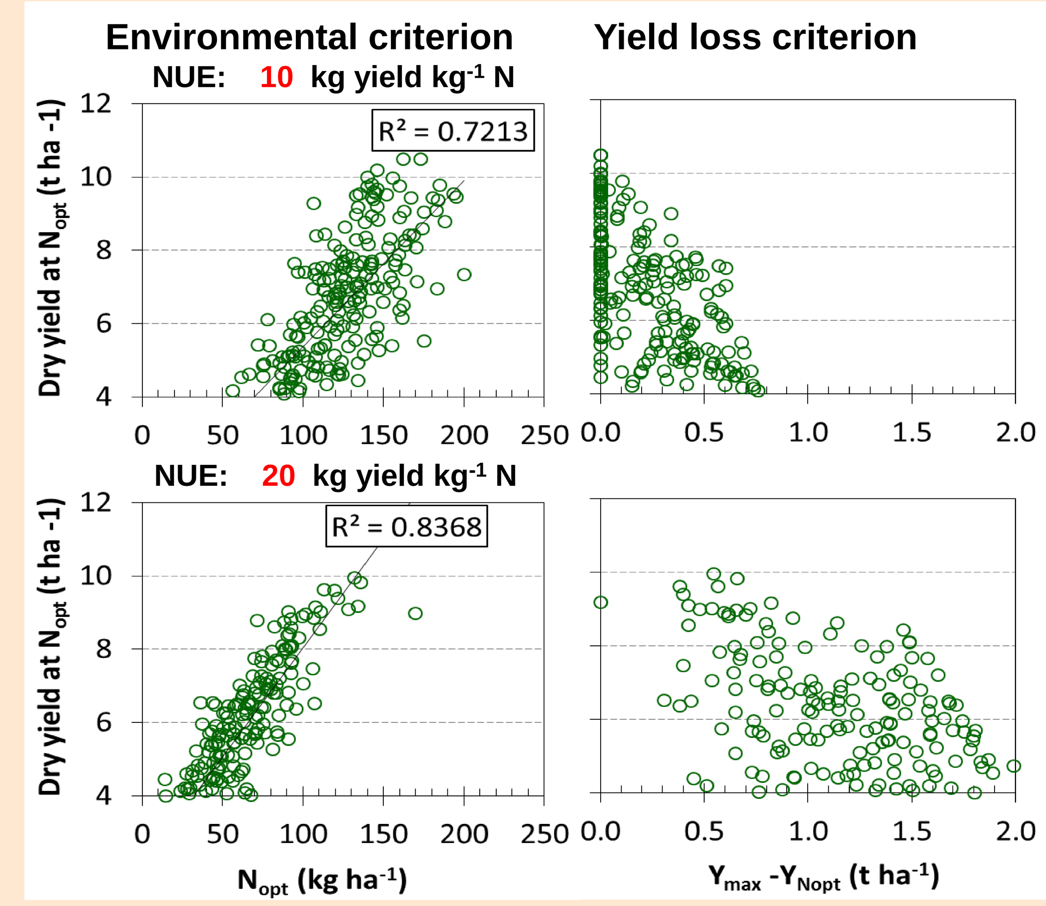
1. A crop model is adapted to the region of interest and modeling is performed to capture the yield response to small N increments of 10 kg ha^{-1}. Each color represents a different growing season.



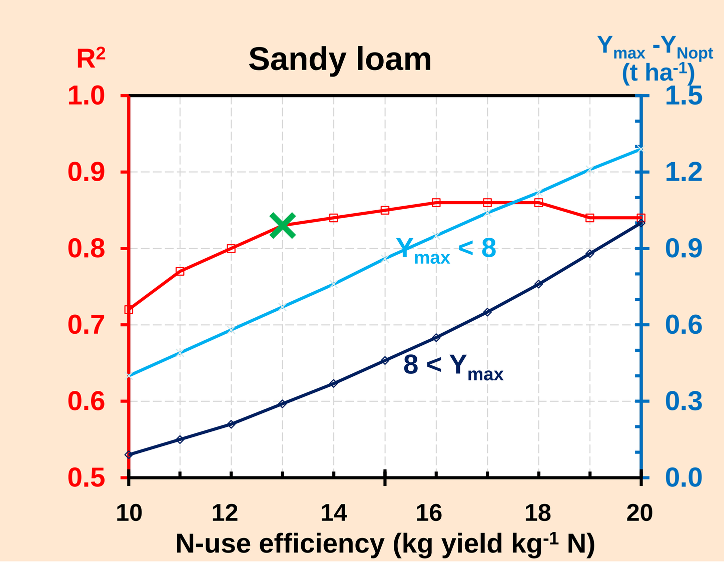
2. A new yield function, Mitscherlich Baule-plateau (MB-P), was fitted to the modelled data from each growing season separately. This function was able to better mimic the modeled data compared to two commonly used yield functions: linear-plateau (L-P) and MB (Mesbah et al. 2017).



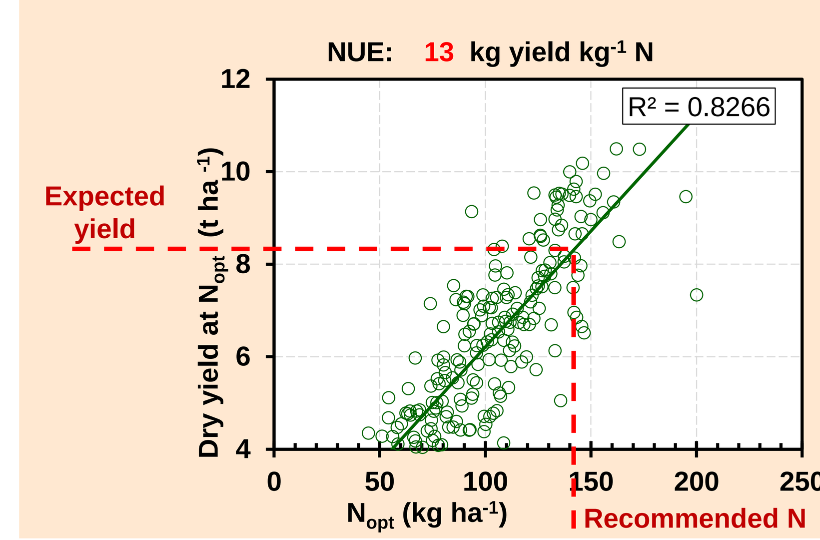
3. For a given soil and various growing seasons, the MB-P fitted functions were used to identify the optimum NUE (NUE_{opt}). The NUE_{opt} is identified by two criteria: 1) the reduction in yield compared to maximum achievable yield as an economic consideration, and 2) the linearity (R^2) of the relationship between yield and N_{opt}, which is used as a criterion to account for environmental impacts.



4. Using the two criteria (R^2 and Y_{max}-Y_{nopt}), the optimum NUE is selected.

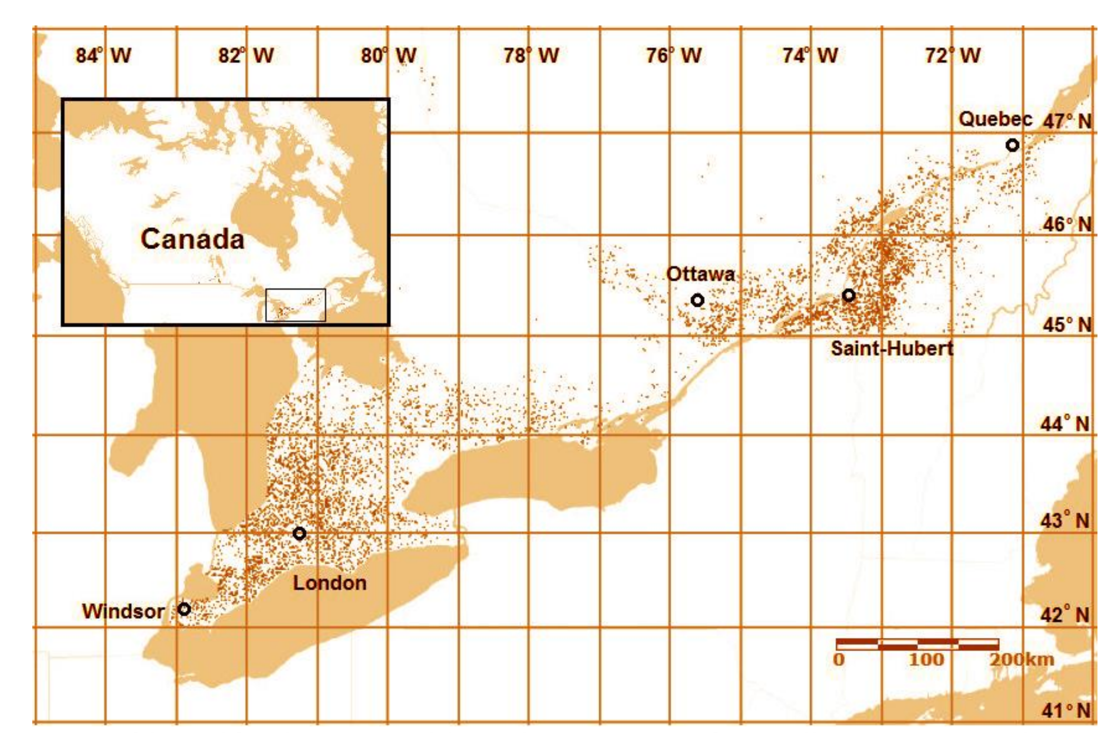


5. The fitted line for selected NUE is used to identify the recommended N rate for expected yield.



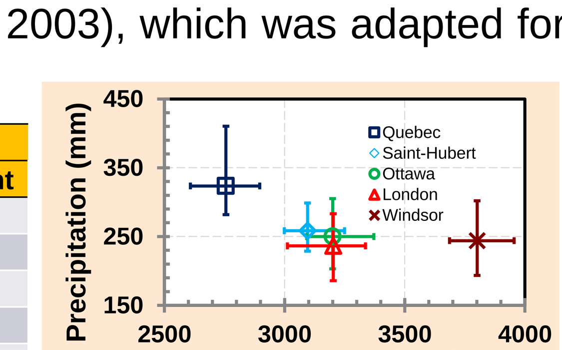
Results and discussions

Identifying NEMO was examined via a case study for 48 to 61 years of daily climate data and 3 contrasting soils in 5 regions along the Mixedwood Plains ecozone of Eastern Canada (42.3°N 83°W–46.8°N 71°W), where more than 90% of Canadian corn is produced. The economic NUE_{opt} at this region was 10 kg yield kg^{-1} N (Nyiraneza et al. 2010), and was selected as the lower bound for NUE evaluation, and the upper bound was set at double of the lower bound, i.e., 20 kg yield kg^{-1}N. The simulations were performed using the STICS crop model (Brisson et al. 2003), which was adapted for corn cultivar in Eastern Canada (Jégo et al. 2011).

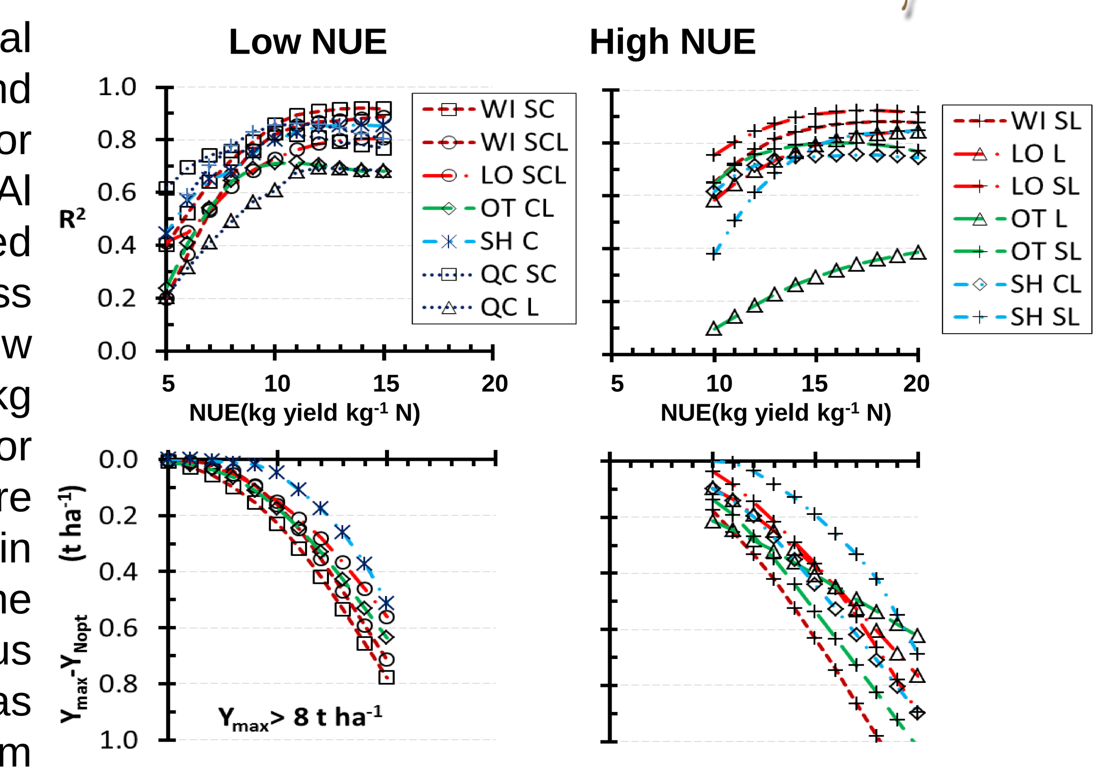


Corn cultivated lands extracted from the 2013 Annual Canadian Space-Based Crop Inventory (AAFC).

Region	# of years	Soil texture		
		Most dominant	2nd most dominant	3rd most dominant
Windsor	54	Silty clay loam	Sandy loam	Silty clay
London	48	Loam	Silty clay loam	Sandy loam
Ottawa	61	Sandy loam	Clay loam	Loam
Saint-Hubert	51	Clay	Sandy loam	Clay loam
Quebec	59	Sandy loam	Silty clay loam	Loam



Looking at the environmental criterion for all regions and soils, two different behavior was observed (Mesbah et. Al 2018). R^2 either reached plateau at an NUE of less than 11 kg yield kg^{-1} N (Low NUE), or greater than 11 kg yield kg^{-1} N (High NUE). For the low NUE group, there was no environmental gain in going beyond the economic NUE_{opt} and thus 10 kg yield kg^{-1} N was selected as the optimum value. For the high NUE group, the NUE were selected based on the two criteria with a threshold of 0.5 t ha^{-1} for the yield reduction.



WI: Windsor
LO: London
OT: Ottawa
SH: Saint-Hubert
QC: Quebec
C: Clay
CL: Clay loam
SC: Silty clay
SCL: Silty clay loam
L: Loam
SL: Sandy loam

NUE_{opt} (kg yield kg^{-1} N) (High NUE / Low NUE)

	C	CL	SC	SCL	L	SL
WI			10	10		13
LO				10	16	15
OT		10			17	11
SH	10	11				13
QC			10		10	10

We found that N recommendations vary by climate and soil. For example, to achieve a yield of 8 t ha^{-1} in sandy loam soil, N recommendation varies form 119 to 209 kg N ha^{-1}.

Our results also indicated that available water capacity (AWC) is an important factor affecting N recommendation (N_{rec}). While the highest yield expectations are in regions and soils with highest AWC (e.g., LO-SCL), the ratio of chance of expected yield to N_{rec} is highest for soils with intermediate AWC (e.g., LO-L).

Recommended N (N_{rec}) for an expected yield (Y_{exp}) of 8 t ha^{-1} (kg N ha^{-1})

CHU	Precipitation
3801	244
3203	236
3200	250
3096	259
2756	324

	C	CL	SC	SCL	L	SL
WI			157	139		125
LO				115	79	119
OT		137			80	143
SH	199	121				154
QC			225		155	209

Probability of Y > 8 t ha^{-1} (%)

	C	CL	SC	SCL	L	SL
WI			69	60		40
LO				71	54	42
OT		41			44	11
SH	27	52				17
QC			0		0	0

Volumetric available water capacity (%)

	C	CL	SC	SCL	L	SL
WI			16.8	16.4		9.9
LO				16.8	14.3	11.6
OT		13.4			13.7	11.9
SH	15.2	13.4				11.1
QC			15.7		14.3	12.1

$P(Y>8)/N_{rec}$ (%)

	C	CL	SC	SCL	L	SL
WI			44	43		32
LO				62	68	35
OT		30			55	8
SH	14	43				11
QC			0		0	0

In conclusions

- The ecophysiological optimum N rates vary by soil texture and climate, and N recommendations must be region and soil specific.
- Soils with intermediate AWC were best to cultivate corn with lowest N recommendations and highest chance of achieving high yield.
- These recommendations are 20-40 kg ha^{-1} less than recommended values in Ontario and Quebec.
- Identifying NEMO can be implemented for other regions and crops. To ease its application, an R-shiny package was developed, and currently is in testing stage.

References

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