Applications of adaptable and quantitative soil quality assessment framework in land reclamation

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Introduction

- Ecosystem restoration includes reclamation of land **(soil, water, vegetation etc.)** to ensure sustainability of land use operations
- Soil is a critical component of ecosystem that influences overall ecosystem health
- **Soil quality** implies capability to perform **specific functions**
- Therefore, conservation and maintenance of soil quality influences the success of land reclamation operations

Soil quality assessment (SQA) in land reclamation

- **Soil quality assessment – recent advances**
  - Focus on quantifying and monitoring soil's functions
  - Use **multi-indicators framework** to integrate physical, chemical and biological functions
  - Use rating functions and quality scores to integrate multiple functions
- **Applications in land reclamation**
  - Soil conservation , profile reconstruction, reclamation (soil) cover design, temporal assessment of functionalities in reclamation covers, performance of vegetation, etc.

Land Reclamation: Alberta Oil Sands

Challenges - SQA

- **Use of generic criteria – address site specific issues**
  - Example , soil pH (6 – 8) is not the optimum range of pH for nutrient supply in a/b ecosites litters supporting the growth of jackpines
- **Current approach to SQA – qualitative/semi-quantitative, with emphasis on land capability and static indicators**
  - Need for quantitative approach that account for variability in baseline parameters
- **Lack of correlation between SQ indicators, quality rating and important soil/ecosystem functions such as plant productivity, nutrient supply potentials, etc.**

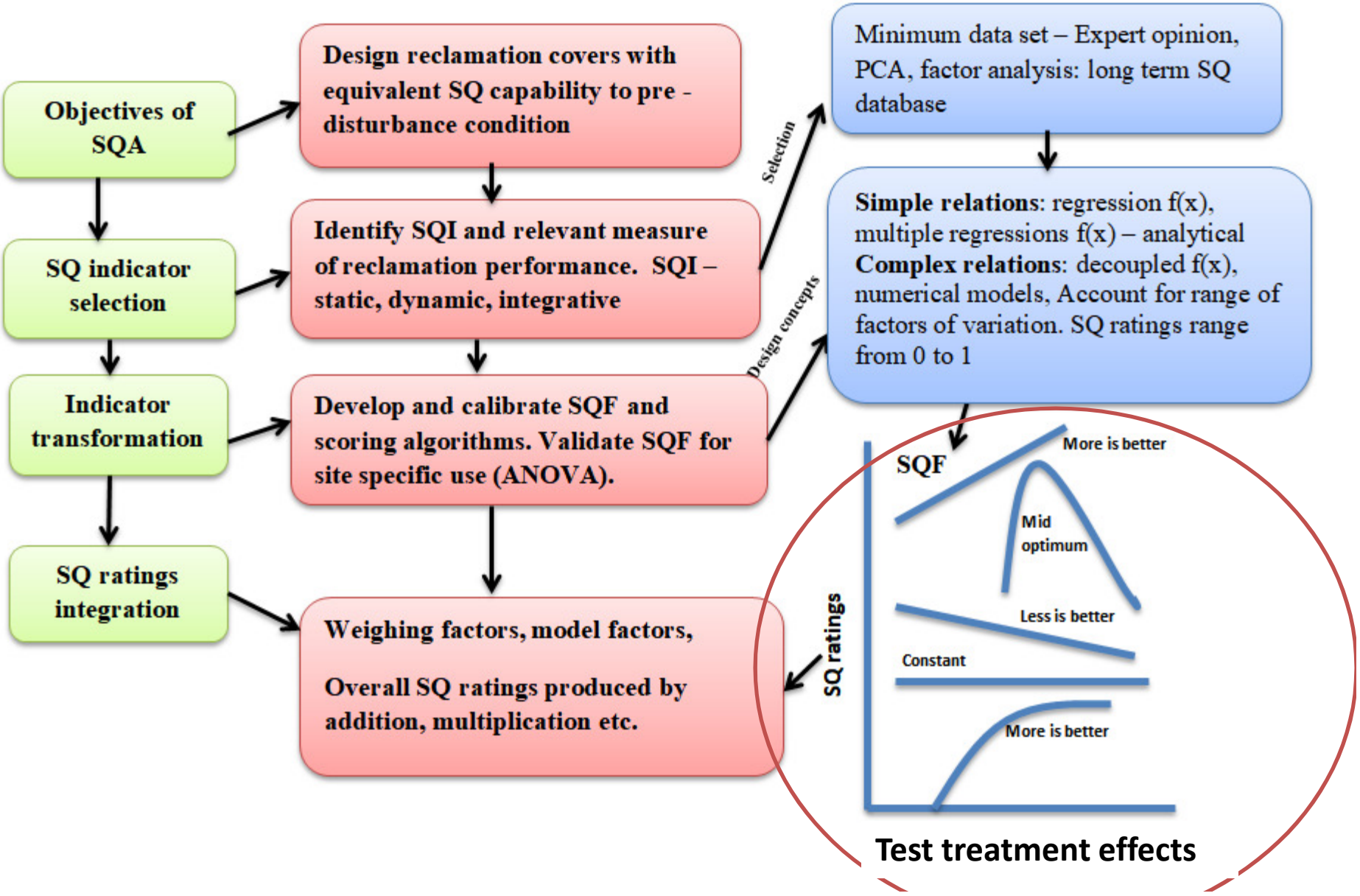
Research - Objective

- **Need to propose a quantitative soil quality assessment framework in land reclamation that** ;
  - Correlates with critical soil and ecosystem functionalities
  - Integrate multiple functions
  - Address site specific challenges
  - Suitable for monitoring long term quality improvement
- **Demonstrate the applicability and transferability of the such framework to similar soil types and process**

Design of proposed framework

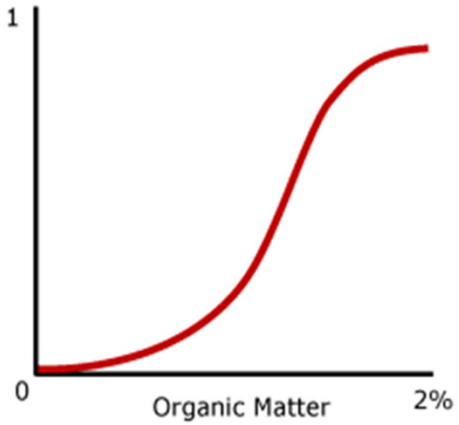
- Similar to SMAF (Andrews et al., 2004), CASH (Fine et al., 2016), etc.
- Emphasis on the applications of soil quality functions or ratings functions (Stott et al. 2004)
- Identify **predictive indicators** (SOC, pH, EC, texture….) and direct **measure of performance** (plant productivity, nutrient supply, biomass yeild, …)
- **Calibrate predictive indicators to measure of performance** using various numerical techniques : regression, multiple regression, process-based models, empirical models, etc.

Proposed framework for soil quality assessment

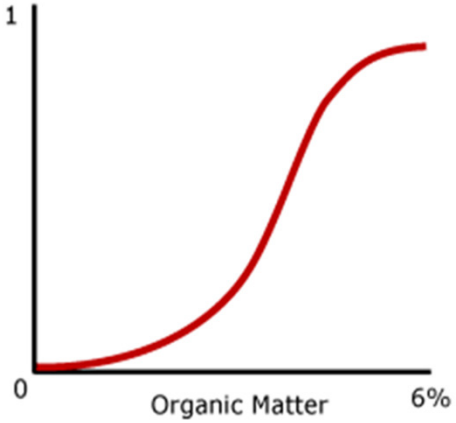


Soil quality function / rating functions

Ultisol



Mollisols



Applications in land reclamation

Calibrate predictive indicator – measures of performance

Define boundary condition and functional soil quality zone

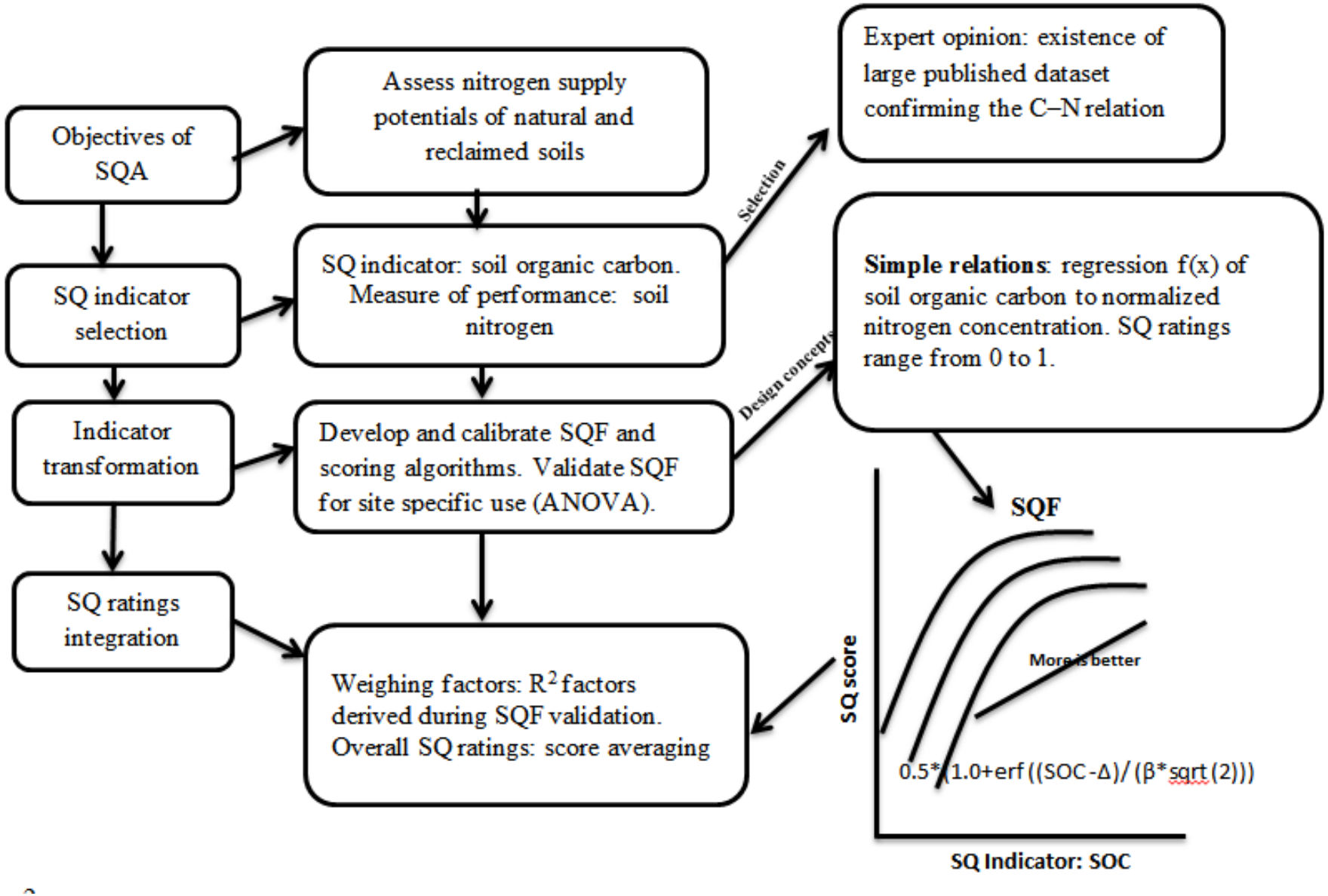
Quality ratings can be integrated using statistical tests

Validated SQF – project ecosystem performance

Derive optimized range of soil quality indicator – site specific criteria

http://soilquality.org/tools/interpret_indicators.html

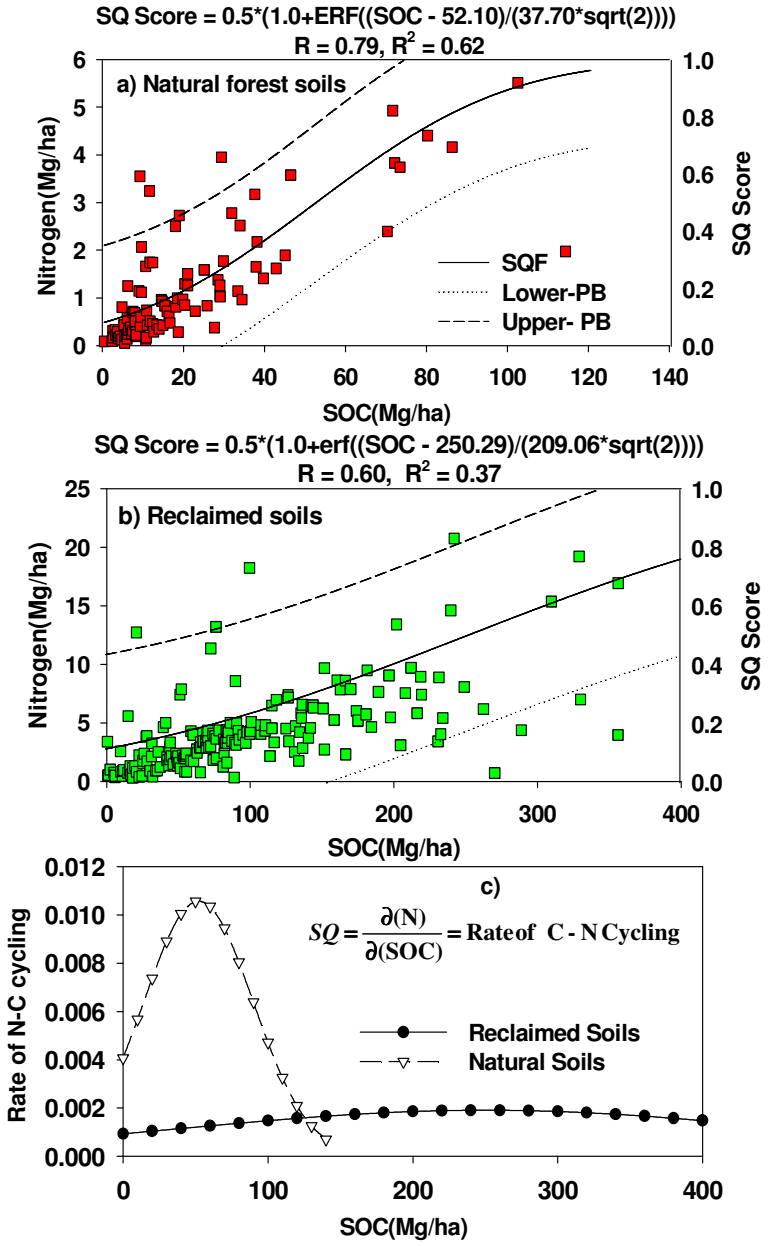
Application I : Assess nutrient supply potentials in reclamation covers



Materials and methods

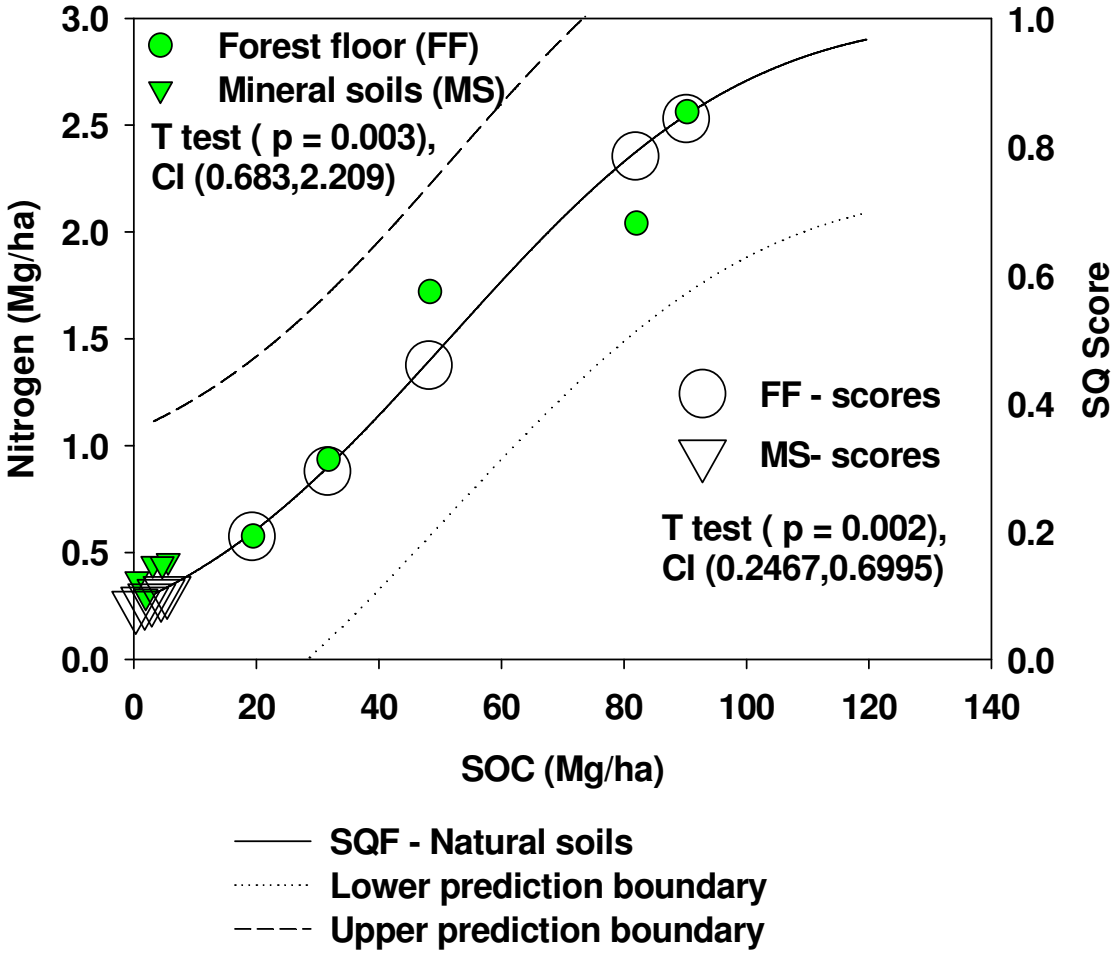
- Data sources : Development, calibration and analysis of SQF using 10 years soil database (CEMA, SVG).
  - **Database compiled using Day, J.H., 1983. The Canada Soil Information System (CanSIS). Manual for describing soils in the field, 1982 Revised. Research Branch, Agriculture Canada, Ottawa. *In:* L.A. Douglas and M.L. Thompson (Editors), Soil Micromorphology and Soil Classification. Special Ecological Land Classification Series, No. 24.**
- Validation and application datasets : Yan et al., 2012; Macyk et al., 2005
- Statistical Analysis : MINITAB using ANOVA
- Selection of best fit and differential analysis : Curve-expert with 200 built in and custom functions
- Focus on predicting N supply potential based on SOC(Mg/ha) composition

Comparison: Natural and reclaimed soils



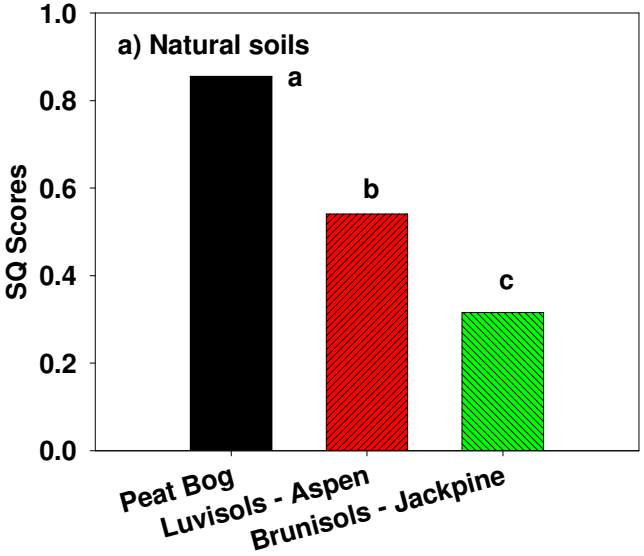
- Differences in SOC composition, but similarity in trends of SOC – N relation
  - Similarity in fundamental processes (mineralization)
- Maximum rate of N supply
  - Natural soil = 0.01
  - Reclaimed soil = 0.002
  - 5 orders of difference in rates of N cycling between natural and reclaimed soils

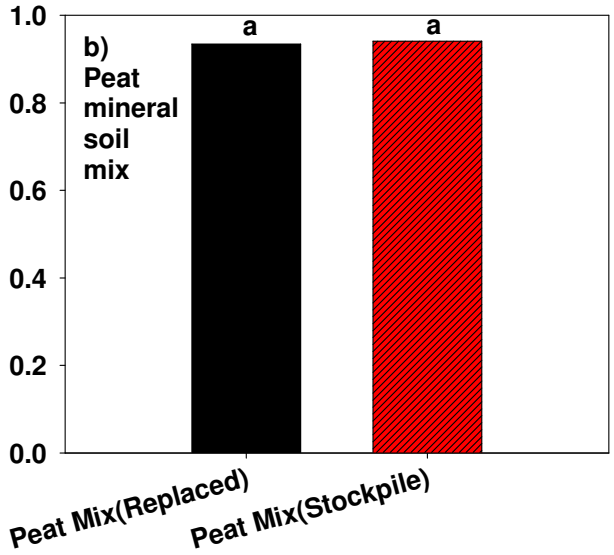
Validation of SQF for site specific use

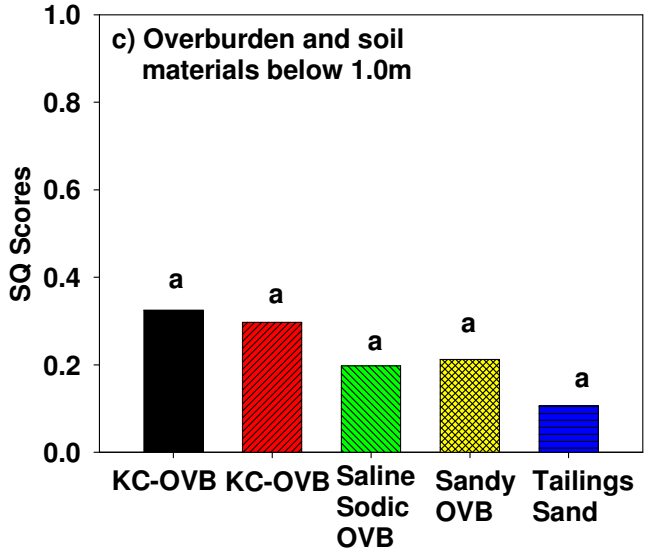


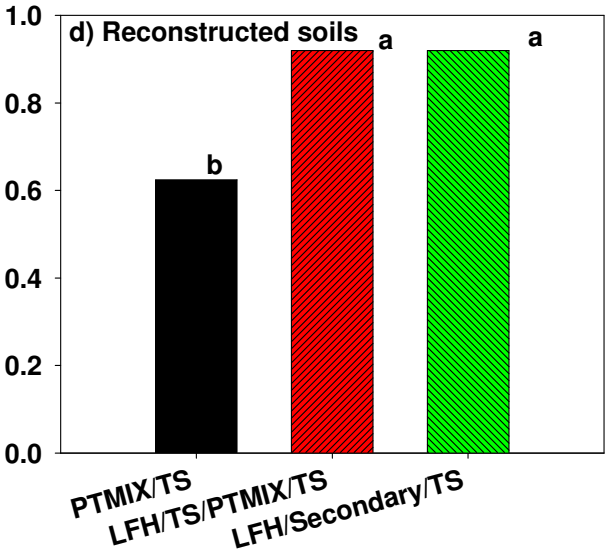
- Test SQF capability to distinguish between forest floor (FF) and minerals soils (MS)'s potential to supply N
- SQ scores produced by the SQF repeat similar significant differences ($p < 0.05$) in N supply potentials between MS and FF as reported by Yan et al., 2012

Application of SQF - Assess potentials to supply N (Macyk et al., 2015)

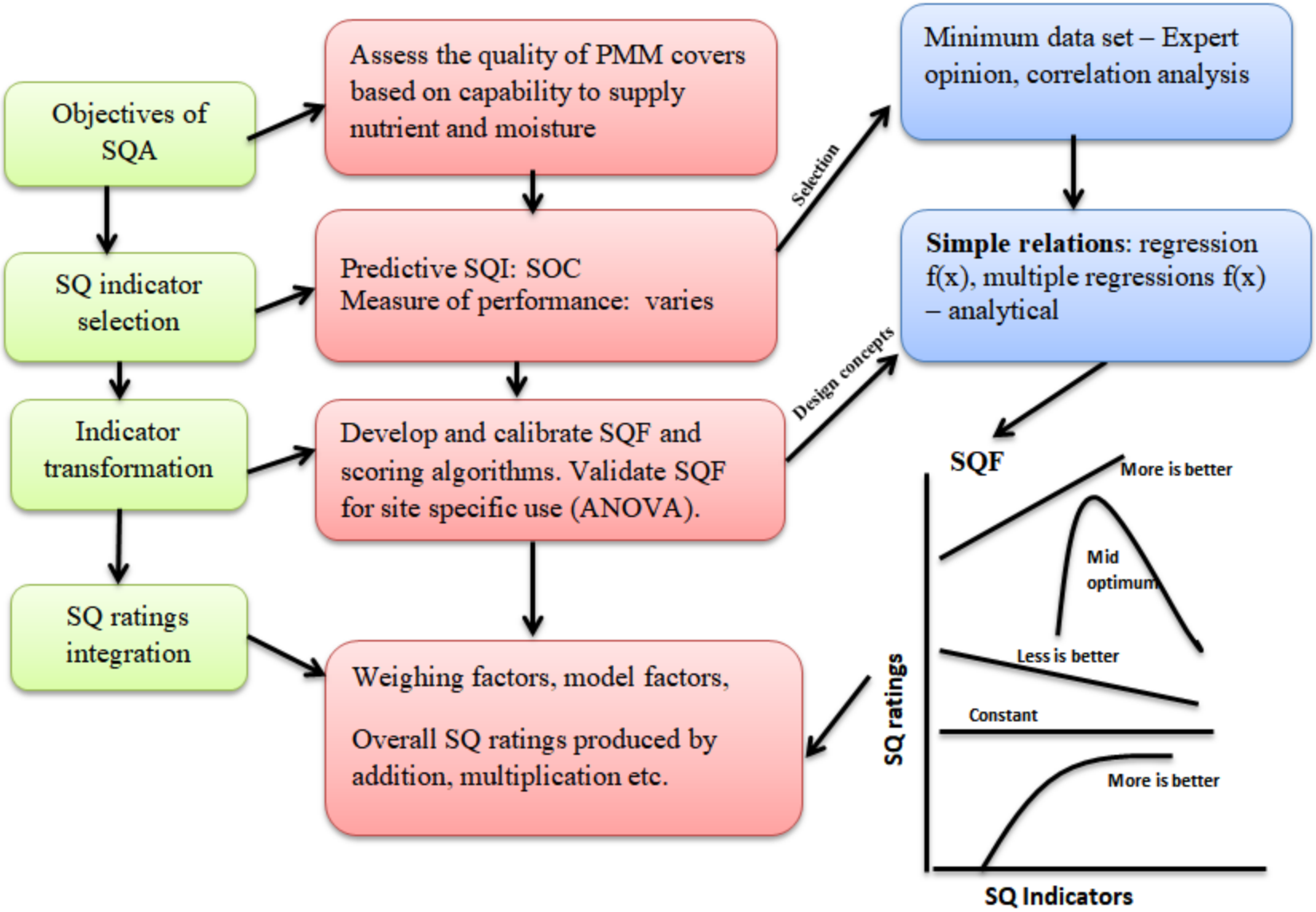




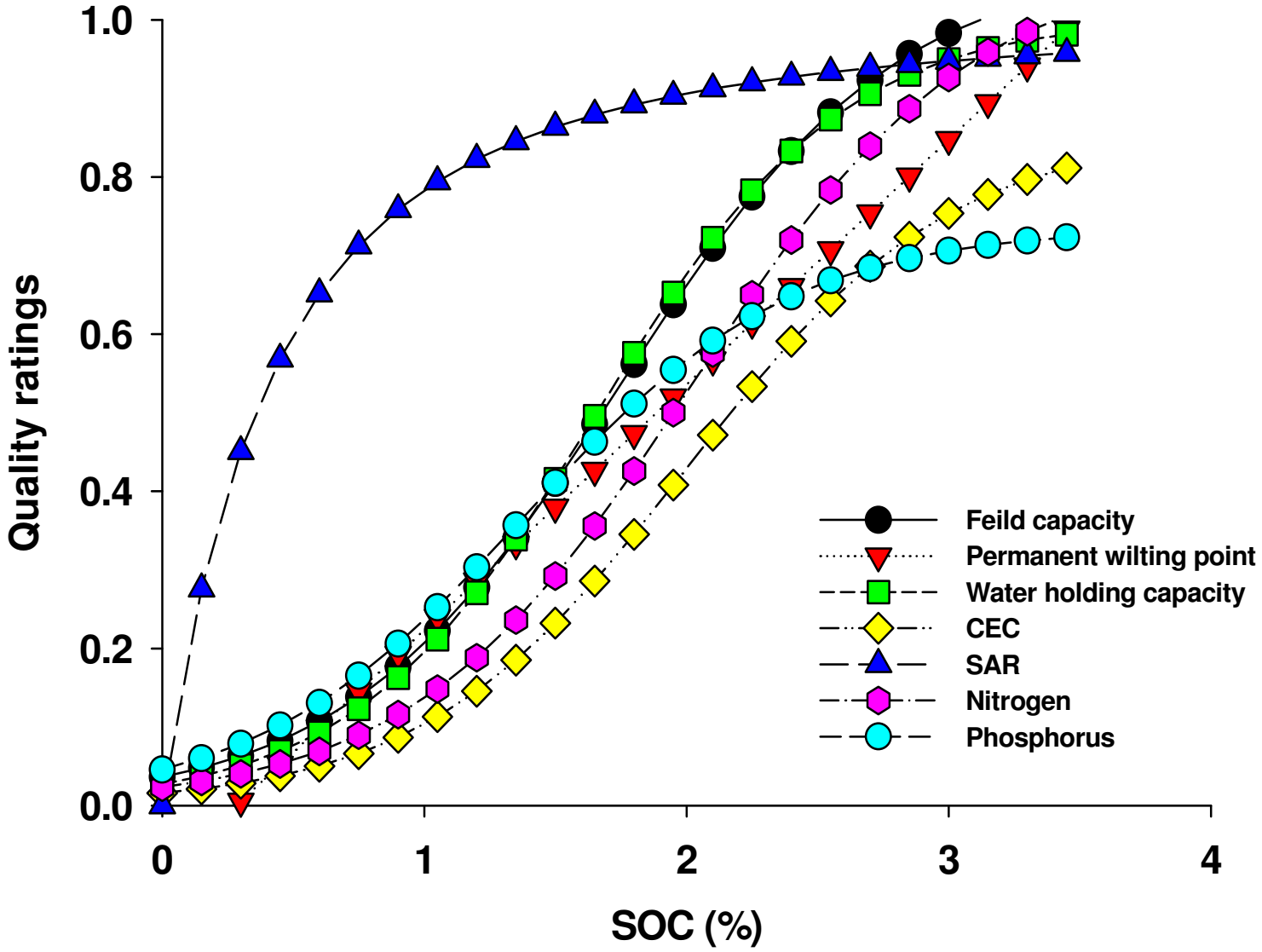




Application II : Assess quality of peat mineral mix covers



SQF for rating of PMM covers



Soil quality functions for rating PMM covers

Soil function	SQI	SQF (y = ratings, 0,1)	x = SOC(%)			
			a	b	c	r^2
Retain moisture for plant's use	Field capacity	y = a/(1+exp(-(x-c)/b)	1.073	0.523	1.750	0.96
	Permanent wilting point	y = a+b*x	-8.828	3.120		0.77
	Water holding capacity	y = a/(1+exp(-(x-c)/b)	1.003	0.464	1.661	0.93
Exchange cation	CEC	y = a/(1+exp(-(x-c)/b)	0.857	0.503	1.998	0.88
Salinization	SAR	y = 1-(1/(1+a*x)^b)	1.233	1.903		0.23
Supply essential nutrient	Nitrogen	y = a/(1+exp(-(x-c)/b)	1.074	2.023	0.531	0.97
	Phosphorus	y = a/(1+exp(-(x-c)/b)	0.735	0.509	1.380	0.76

Validation of soil quality function

- **Use 3 independent data sources – similar sites and objectives**

(McGill et. al. 1980; Logan, 1978)

	Nitrogen (%)		CEC(cmol/kg)	
Material Type	Mean	Rating	Mean	Rating
Peat	0.980 a	1.000 a	183 a	1.00 a
Sandy Brunisols (B_m)	0.022 b	0.516 b	1.20 b	0.18 b
Tailings	0.008 b	0.508 b	1.18 b	0.18 b

- **SQF effectively differentiated nitrogen supply and cation exchange capabilities of reclamation materials**

Validation of soil quality function

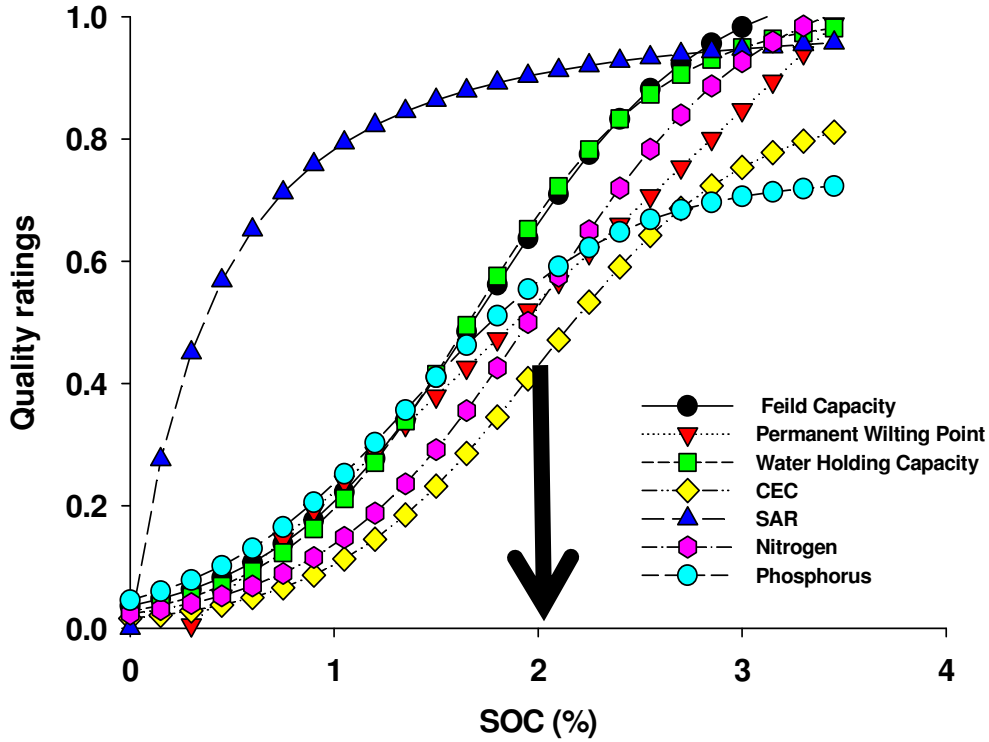
Moskal et al., 1999

Peat mineral ratio	Field capacity (g/100g)		Permanent wilting point (g/100g)		Av. water holding capacity (g/100g)	
	Means	Rating	Means	Rating	Means	Rating
3:1	39.7 a	1.0 a	20.1 a	1.0 a	19.6 a	1.0 a
1:1	19.9 b	0.7 b	6.7 b	0.5 b	13.2 ab	0.7 b
1:3	13.4 bc	0.3 c	6.3 b	0.3 c	7.1 bc	0.3 c
0:1	8.20 c	0.1 d	3.7 b	0.0 d	4.6 c	0.1 d

- Ratings represents about 80% of the effect of PMM on moisture retention

Application – Long term quality monitoring in reclaimed soils

- Macyk et. al., 2004 : Observed about 1-2 % decline in carbon level of peat mineral mix in 10-15 years study (Alberta Research Council)



- Confirms the need for continuous nutrient and soil moisture management of reclaimed soils

Conclusions

- **Proposed framework** :
  - Support the need for consistency in soil quality assessment
  - Applicable to various land use, ecosystems (upland or wetland)
  - Allow for quantitative definition of baseline capability or functionalities
- **Rating functions are adaptable and transferable** :
  - Ability to repeat specific treatment effect at independent site
- **Further applications : EIA, site specific criteria, remediation**, **etc.**

Acknowledgement

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