NITROGEN DECISION SUPPORT SYSTEM (NDSS)

Collection and Evaluation of Literature on Crop Response to N Application:
The Case of Corn in South America

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The Nitrogen Decision Support System is one component of an Integrated Decision Support System (IntDSS), which is being designed to integrate and disseminate decision aid tools that will reduce acidity and nutrient limitations to food production and quality by facilitating diagnosis of soil constraints and selecting the appropriate management practices for location-specific conditions. The purpose of NDSS is to provide realistic fertilizer N recommendations for crops grown in different agro-ecological zones of the tropics. Such recommendations will be based on data for climate, soils, fertilizer, lime, use of legume green manure, animal manure, varieties, targeted yields, nutrient uptake, and apparent N recovery from inputs (see Decision Aids for Integrated Soil Nutrient Management for more details about this component).

An extensive literature review on crop response to applied N is in progress to collect, organize and process data to provide a strong database for development of the NDSS component. Since the purpose of this system is to provide recommendations on use of fertilizer N, we are gathering and interpreting information on crop response to applied fertilizer N and on non-fertilizer N sources available to support crop production.

Calculations of N needs for of a given crop are based on the following algorithm which is an expansion of the Stanford equation (16),

$$\underset{\underline{A}}{N_{fert}} = \underset{\underline{B}}{(Y_r * N_{cr})} - [\, \underset{\underline{C}}{N_{soil}} + \underset{\underline{D}}{(N_{green\ man.} * C_{gm})} + \underset{\underline{E}}{(N_{manure} * C_m)} \,] / \underset{\underline{F}}{E_f}$$

where:

N_{fert} = N fertilizer needed;
Y_r = Realistic dry matter yield, both vegetative and/or reproductive and/or total dry matter;
N_{cr} = Concentration of nitrogen (%N) in vegetative and/or reproductive and/or total dry matter;
N_{soil} = Nitrogen from soil organic matter and previous crop residue mineralization and from atmospheric deposition during growing season;
$N_{green\ man.}$ = Nitrogen mineralized from green manure in current growing season;
C_{gm} = Proportion of N mineralized from green manure that is absorbed by plant;
N_{manure} = Nitrogen mineralized from manure;
C_m= Proportion of nitrogen mineralized from manure that plant absorbs; and
E_f = Fertilizer efficiency.

For the purpose of illustration, data from South America is used to calculate the N needs for corn with the algorithm mentioned above. Information was gathered from studies conducted in the Cerrado [Grove et.al., 1980 (1); Bowen, 1987 (2); Carsky, 1989 (3); Burle et al., 1992 (4)] and Amazon sub-regions [Melgar, 1989 (5), Manaus, Brazil; Benitez, 1981 (6), Yurimaguas, Peru]. The former is located in the country of Brazil, and the latter includes the countries of Brazil and Peru. These studies were conducted between 1973 and 1991 with most occurring in the rainy season, with different levels of nitrogen and corn hybrids/varieties, and all utilizing a randomized complete block experimental design.

The Cerrado region in central Brazil covers about 180 million ha. It has an ustic soil moisture regime with well defined wet and dry seasons that correspond respectively to the summer and winter months. Vegetation is mainly composed by grasses and tortuous trees. Annual rainfall averages 1500 mm, of which 95 % falls between October and April. Deep Oxisols with high water permeability, low nutrient status, high Al saturation and high organic matter content are prominent.

The Amazon with a udic soil moisture regime comprises uplands and lowlands covered by tropical forest vegetation. Manaus is located in the Central Amazon in Brazil and has two soil ecosystems of major importance: upland landscapes called “terra firme” and flood plains called “varzea”. Annual rainfall averages 2461 mm, of which 80 % falls between October and May. Clayey Oxisols with high Al saturation, strong aggregation and high water permeability characterizes “terra firme” landscapes. Entisols, with silty textures, high fertility and low aggregation are most common in “varzea” landscapes. Yurimaguas is in the upper Amazon basin of Peru and has an annual rainfall of 2100 mm with occasional drought periods between June and August. The soils are well-drained Ultisols with low nutrient status, high Al saturation and low in organic matter content.

Procedure

Data was organized and processed as follows:

1. Grain yield, above ground N accumulation, applied N and apparent N recovery were sorted by sub-region within countries.
2. Four data sets resulted based on sub-region and landscape position; the first set included all studies conducted in the Cerrado sub-region; the three remaining data sets came from the Amazon sub-region. Data set 2 included only the study conducted on the “terra firme” landscape, data set 3 included the study on the “varzea” landscape, and data set 4 included the study conducted in Yurimaguas.
3. Plots for three relationships were obtained for each data set group: I) aboveground N accumulation vs. grain yield, ii) relative grain yield vs. applied N, and iii) apparent N recovery vs. applied N.
4. The above relationships were evaluated using the Mixed Models procedure of SAS, emphasizing the use of random coefficients. In cases where studies were conducted for two or more cropping seasons in the same location, each cropping season was treated as an individual experiment in the statistical analysis.

Nested models were run including the four data sets from both sub-regions to fit the best model. The criteria to keep a particular model for each relationship was obtained by a *likelihood ratio test* which is suitable for nested models. To carry out this test between two nested models the difference between the *-2 REML log likelihood* or *–2 log likelihood* terms from each model was obtained; if models have the same fixed effects the former term is used, otherwise the latter is used. The absolute value of this difference was compared with a Chi -square distribution with degrees of freedom equal to the difference in the number of parameters between the two models (Wolfinger, 1992). This test allowed us to conclude, for a particular relationship, whether the four data sets from both sub-regions had: (a) similar slopes but different intercepts, (b) similar intercept and slope or (c) similar intercept and different slope. When all data sets have similar intercepts and slopes for any relationship, all of them were represented by a common function.

5. Data on the use of green manure as a source of N for corn was available for data set 1, along with data for dry matter yield and N accumulation for tropical legumes for the four data sets described above and from experiments in Bolivia. In this case the relationships of interest were the dry matter N accumulation vs dry matter yield, and the apparent N recovery by corn vs. N applied to soil in green manure. The procedure followed for the relationships mentioned above was applied to these relationships.
6. Nitrogen from soil was calculated as the average N accumulated by the crop in the zero applied-N treatments for experiments in each data set.
7. Results obtained through these six steps allowed us to calculate the B, C, D, and F terms in the proposed algorithm. As no data was available for manure, the "E" term is ignored.

It is important to note that this procedure is relatively simple because data has been previously processed, and each study contained detailed information. In the IntDSS software, however, the user will be provided with different default values and pre-established approximations for cases where location-specific information is not available.

Results

Corn

Relationship 1: Aboveground N accumulation vs. grain yield - a full and two reduced models were tested and compared (Tables 1 and 2). Comparisons indicated that each data set needs to be represented by its own function. The "reduced 1" model was selected as the function to represent this relationship because data sets have similar slopes (Table 3) (Figure 1).

Table 1. Models for the aboveground N accumulation vs grain yield relationship, parameters and –2 log likelihood terms.

MODEL	PARAMETERS	-2 log LIKELIHOOD
Full: N accumulation = data set gyield gyield*data set	7	819.2011
Reduced 1: N accumulation = data set gyield	4	819.6674
Reduced 2: N accumulation = gyield	1	827.8178

Table 2. Model comparison for the aboveground N accumulation vs grain yield relationship, and data set grouping decision.

FULL vs RED. 1 MODEL	RED. 1 vs RED. 2 MODEL	DECISION
819.2011 – 819.6674 = $\lvert 0.4663 \rvert$ 7-4 = 3 $\chi^2_{df=3\ \alpha=0.05} = 7.81$ $\lvert 0.4663 \rvert < 7.81$ Models are similar	819.6674 – 827.8178 = $\lvert 8.1504 \rvert$ 4 – 1 = 3 $\chi^2_{df=3\ \alpha=0.05} = 7.81$ $\lvert 8.1504 \rvert > 7.81$ Models are different	Each data set needs to be represented by its own function. The full or reduced 1 model can be used. Since they have similar slopes, the reduced 1 model is selected.

Table 3. Functions to represent the aboveground N accumulation vs grain yield relationship for each data set.

Data set 1: Cerrado, Brazil	N accumulation = -8.91 + 0.0235 Grain yield
Data set 2: Amazon “Terra Firme”, Brazil	N accumulation = 11.33 + 0.0235 Grain yield
Data set 3: Amazon “Varzea”, Brazil	N accumulation = 5.13 + 0.0235 Grain yield
Data set 4: Amazon, Peru	N accumulation = -4.41 + 0.0235 Grain yield

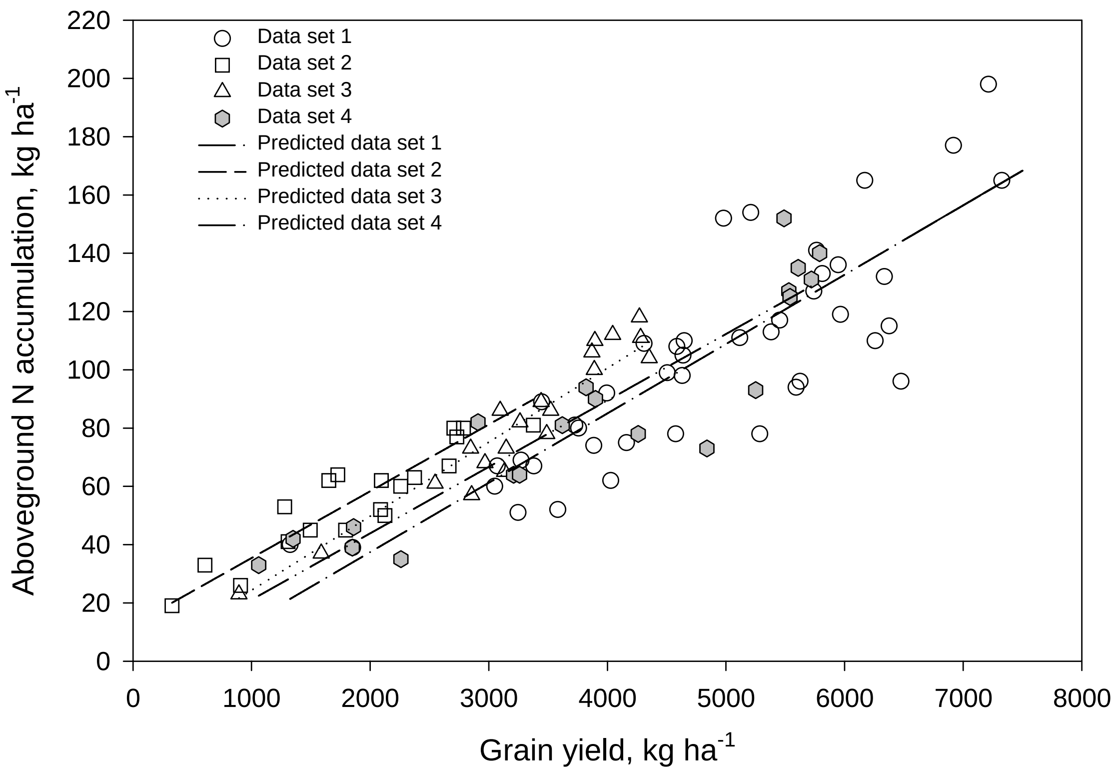

Figure 1. Relationship 1: aboveground N accumulation vs. corn grain yield. Data sets 1, 2, 3 and 4 are from the Cerrado and Amazon sub-regions of South America.

Relationship 2: Relative grain yield vs Applied N - three models were tested and compared using procedures similar to relationship 1 (Tables 4 and 5). Model comparisons suggested that each data set group need to be represented by its own function. Full and reduced 1 models were similar, meaning that the quadratic effect is statistically the same for all the functions. Nevertheless, the full model provided the best fit (Table 6) (Figures 2, 3, 4, 5), so, it was selected to obtain the functions.

Table 4. Models for the relative grain yield vs applied N relationship, parameters and –2 log likelihood terms.

MODEL	PARAMETERS	-2 log LIKELIHOOD
Full: Rel.grain yield = data set N N*data set N*N*data set	11	768.9435
Reduced 1: Rel. grain yield = data set N N*data set N*N	8	775.3677
Reduced 2: Rel. grain yield = data set N N*N	5	789.8554

Table 5. Model comparison for the relative grain yield vs applied N relationship, and data set grouping decision.

FULL vs RED. 1 MODEL	RED. 1 vs RED. 2 MODEL	DECISION
768.9435 – 775.3677 = $\lvert 6.4242 \rvert$ 11-8 = 3 $\chi^2_{df=3\ \alpha=0.05} = 7.81$ $\lvert 6.4242 \rvert < 7.81$ Models are similar	775.3677 – 789.8554 = $\lvert 14.4877 \rvert$ 8 – 5 = 3 $\chi^2_{df=3\ \alpha=0.05} = 7.81$ $\lvert 14.4877 \rvert > 7.81$ Models are different	Each data set group needs to be represented by its own function. The Full or reduced 1 model can be used, but the Full model provided the best fit.

Table 6. Functions to represent the relative grain yield vs applied N relationship for each data set.

Data set 1: Cerrado, Brazil	Rel. grain yield = 54.93 + 0.4829N – 0.00128 N^2
Data set 2: Amazon “Terra Firme”, Brazil	Rel. grain yield = 36.64 + 0.9220N – 0.00330 N^2
Data set 3: Amazon “Varzea”, Brazil	Rel. grain yield = 58.54 + 0.6686N – 0.00265 N^2
Data set 4: Amazon, Peru	Rel. grain yield = 35.95 + 0.7531N – 0.00213 N^2

Relationship 3: Apparent N recovery vs applied N - because of the nature of this relationship an intercept was not desired, thus the structure of the full model was different from prior relationships investigated. A full and a reduced model were tested and compared (Tables 7, 8). Results showed that the four data set have similar slope and intercept (Figure 6). Thus the reduced model was selected and one function was derived to represent the four data sets (Table 9).

Table 7. Models for the apparent N recovery vs. Applied N relationship, parameters and –2 log likelihood terms.

MODEL	PARAMETERS	-2 log LIKELIHOOD
Full: Apparent N recovery = N (data set)	4	660.2826
Reduced: Apparent N recovery = N	1	662.0195

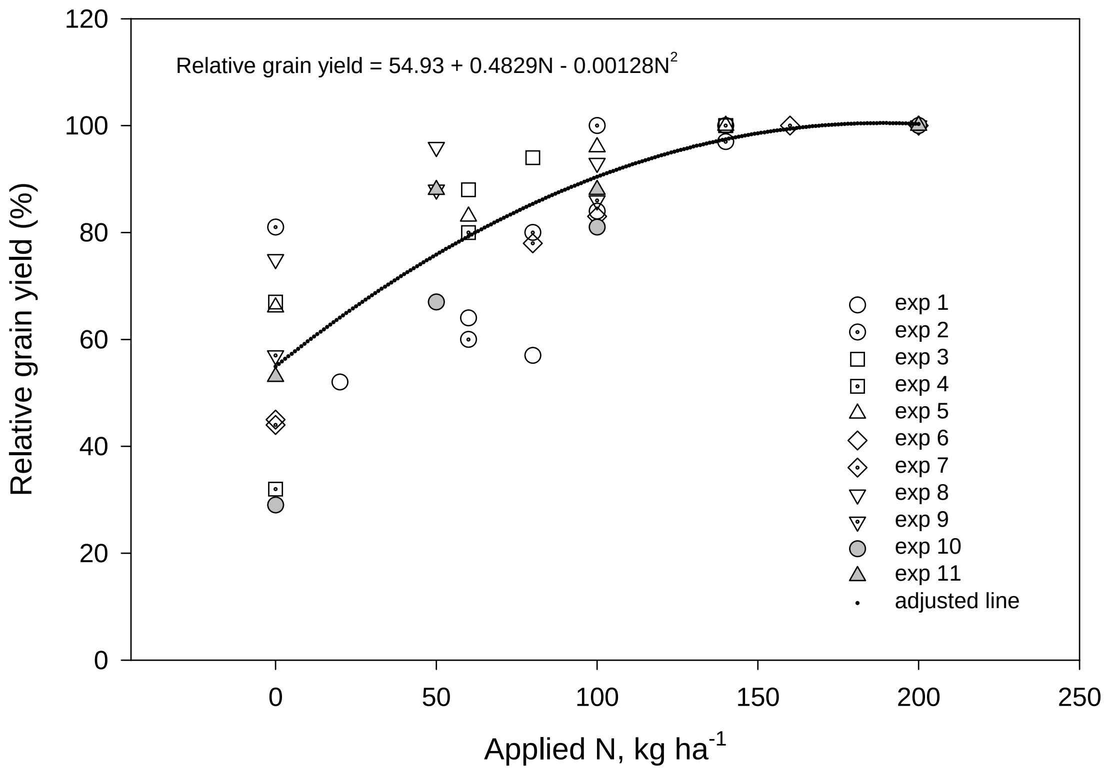

Figure 2. Relationship 2: relative grain yield vs. applied N for data set 1 (Cerrado sub-region of South America).

Table 8. Model comparison for the apparent N recovery vs applied N relationship, and data set grouping decision.

FULL vs REDUCED MODEL	DECISION
660.2826 – 662.0195 = $\lvert 1.7369 \rvert$ 4-1 = 3 $\chi^2_{df=3\ \alpha=0.05} = 7.81$ $\lvert 1.7369 \rvert < 7.81$ Models are similar	The four data set groups statistically had the same intercept and slope for this relationship, therefore the reduced model was selected to be the representative function for this relationship.

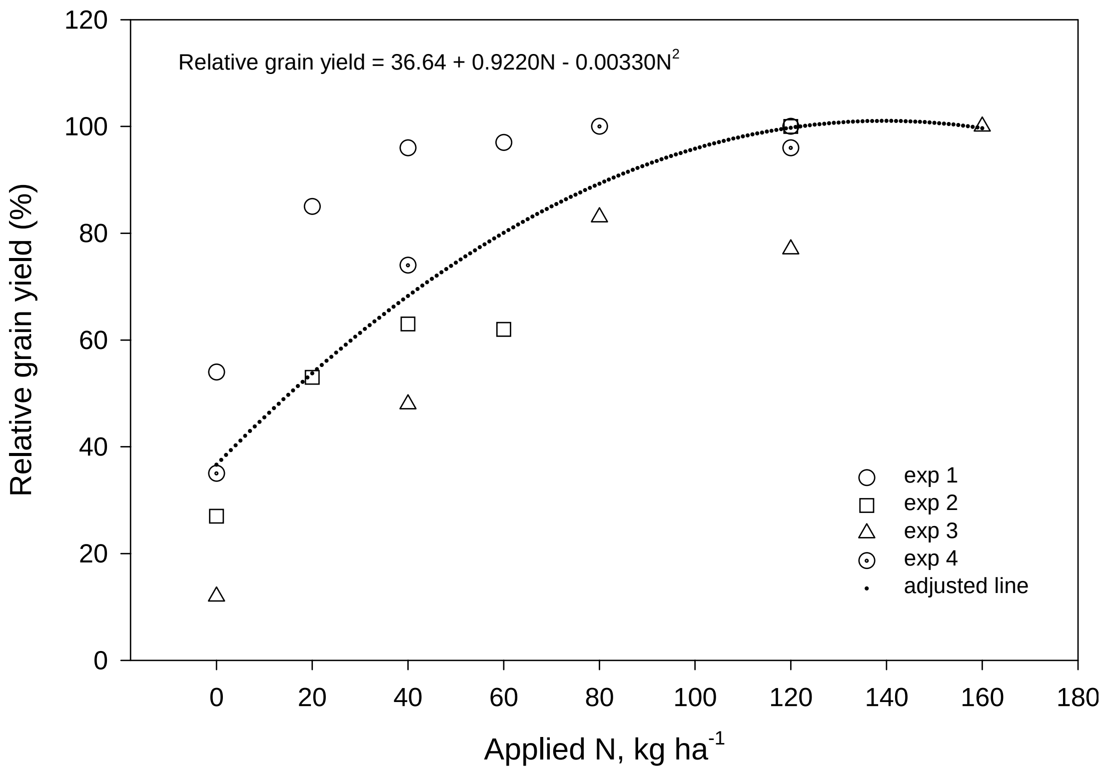

Figure 3. Relationship 2: relative grain yield vs. applied N for data set 2 ("terra firme" near Manaus, Brazil in the Amazon sub-region).

Table 9. Function representing the apparent N recovery vs applied N relationship for all data sets.

Data set 1: Cerrado, Brazil Data set 2: Amazon "Terra Firme", Brazil Data set 3: Amazon "Varzea", Brazil Data set 4: Amazon, Peru	Apparent N recovery = 0.40 N

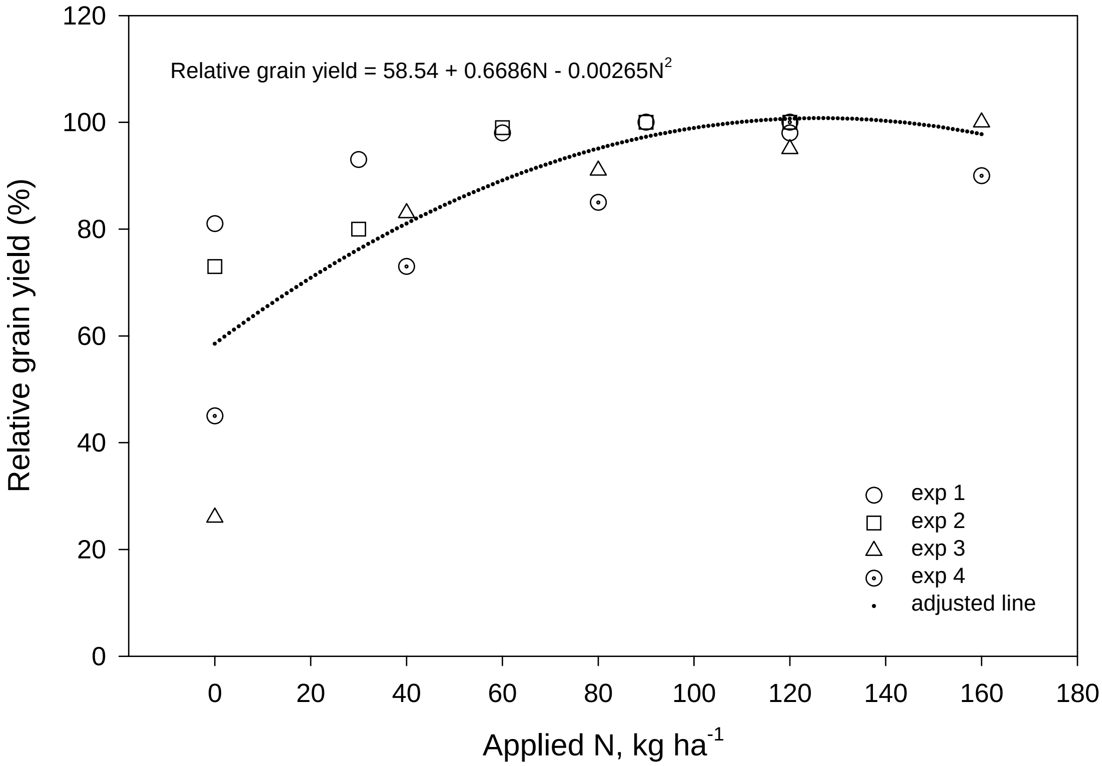

Figure 4. Relationship 2: relative grain yield vs. applied N for data set 3 (“varzea” ecosystem near Manaus, Brazil in the Amazon sub-region).

Soil Nitrogen

Aboveground N accumulation by crops from the non-N fertilized plots was averaged from each data set as the best estimate of native soil N supplied to corn (Table 10).

Table 10. Mean values of native soil N supplied to corn for each data set.

SUB-REGION			
CERRADO	**AMAZON**		
DATA SET 1	**DATA SET 2**	**DATA SET 3**	**DATA SET 4**
-------------------- soil N, kg ha^{-1} --------------------			
69	31	55	39

Green manure.

Relationship 1: dry matter N accumulation vs dry matter yield - most of data came from the same studies mentioned above, but other studies and countries in the same region of South America were also included (Luna-Orea and Wagger, 1995; Barber and Navarro, 1994; Quintana, 1987; Becker et al., 1990; Alegre et al., 1988; Smyth et al., 1991; Horta de Sa and Vargas, 1997; Arya et al., 1988; Sociedade Brasileira de Ciencia do Solo, 1996). Because of the nature of the data (legume species with one observation) a sole model was used to describe this linear relationship (Table 11) (Figure 7).

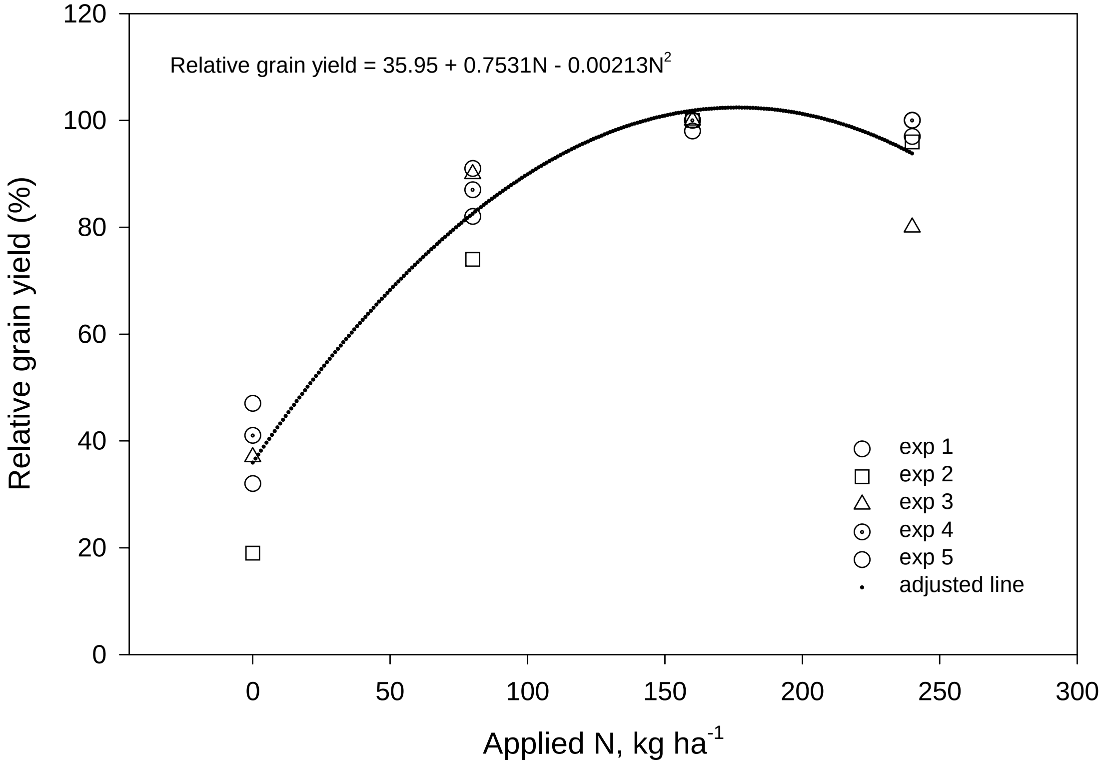

Figure 5. Relationship 2: relative corn grain yield vs. applied N for data set 4 (Yurimaguas, Peru in the Amazon sub-region).

Table 11. Functions to describe dry matter N accumulation vs dry matter yield, and apparent N recovery by corn vs applied N in green manure.

RELATIONSHIP	FUNCTION
Dry matter N accumulation vs dry matter yield	Dry mat. N acc. = 8.63 + 0.0216 dry matter
Apparent N recovery by corn vs applied N in green manure	Apparent N recovery = 0.39N

Relationship 2: apparent N recovery by corn vs. Applied N in green manure - as mentioned before only data from data set 1 was available to describe this relationship. Like relationship 1 a unique model was developed to represent this relationship (Table 11) (Figure 8).

Practical Application

At this point the functions generated for South America can be used to calculate the N needs for a particular target yield. For instance, if a farmer in the Cerrado sub-region wants to get 5000 kg ha^{-1} yield and plans to use a green manure crop that will produce 1000 kg dry matter ha^{-1}, how much N needs to be applied as a commercial fertilizer?

1. The function generated for the aboveground N accumulation vs. grain yield relationship for data set 1, corresponding to the Cerrado sub-region, (Table 3) is used to calculate the **B** term in the proposed algorithm:
   N accumulation = -8.91 + 0.0235 grain yield

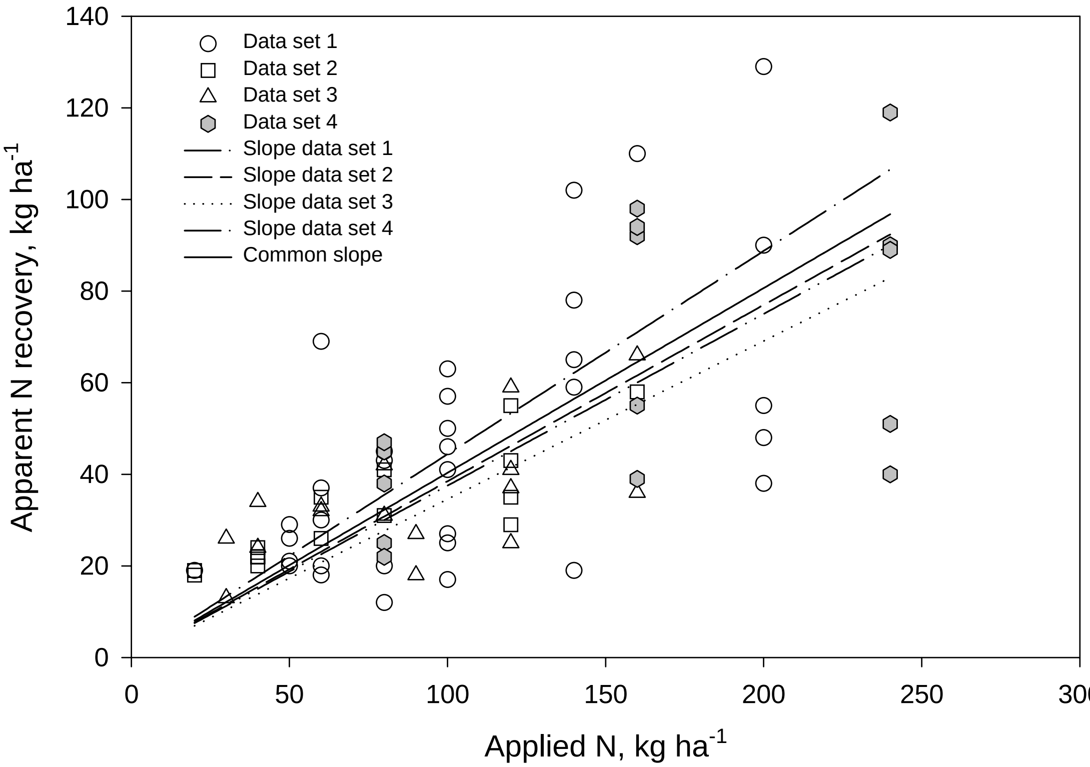

Figure 6. Relationship 3: apparent N recovery for corn vs. applied N for four data sets from the Cerrado and Amazon sub-regions of South America.

N accumulation = -8.91 + 0.0235 (**5 000** kg ha^{-1})
= 108.59 kg ha^{-1}= **(Y_r*N_{cr})**

2. The soil N value that corresponds to the sub-region of Cerrado (the **C** term of the algorithm) can be derived from Table 10:
   N_{soil} = 69 kg ha^{-1}
3. The function for the dry matter N accumulation vs. dry matter yield relationship for green manure (Table 11) is used to calculate the N in the 1000 kg of green manure residue:
   Dry matter N accumulation = 8.63 + 0.0216 Dry Matter
   = 8.63 + 0.0216 (**1000** kg ha^{-1})
   = 30.23 kg ha^{-1}
4. The function for the relationship of apparent N recovery by corn vs. applied N in green manure (Table 11) is used to obtain the amount of the applied N (30.23 kg ha^{-1}) in the green manure that is mineralized and recovered by corn, thus representing the **D** term in the algorithm:
   Apparent N recovery by corn = 0.39 N
   = 0.39 (30.23 kg ha^{-1})
   = 11.79 kg ha^{-1} = **$N_{green\ manure}$ *C_{gm}**

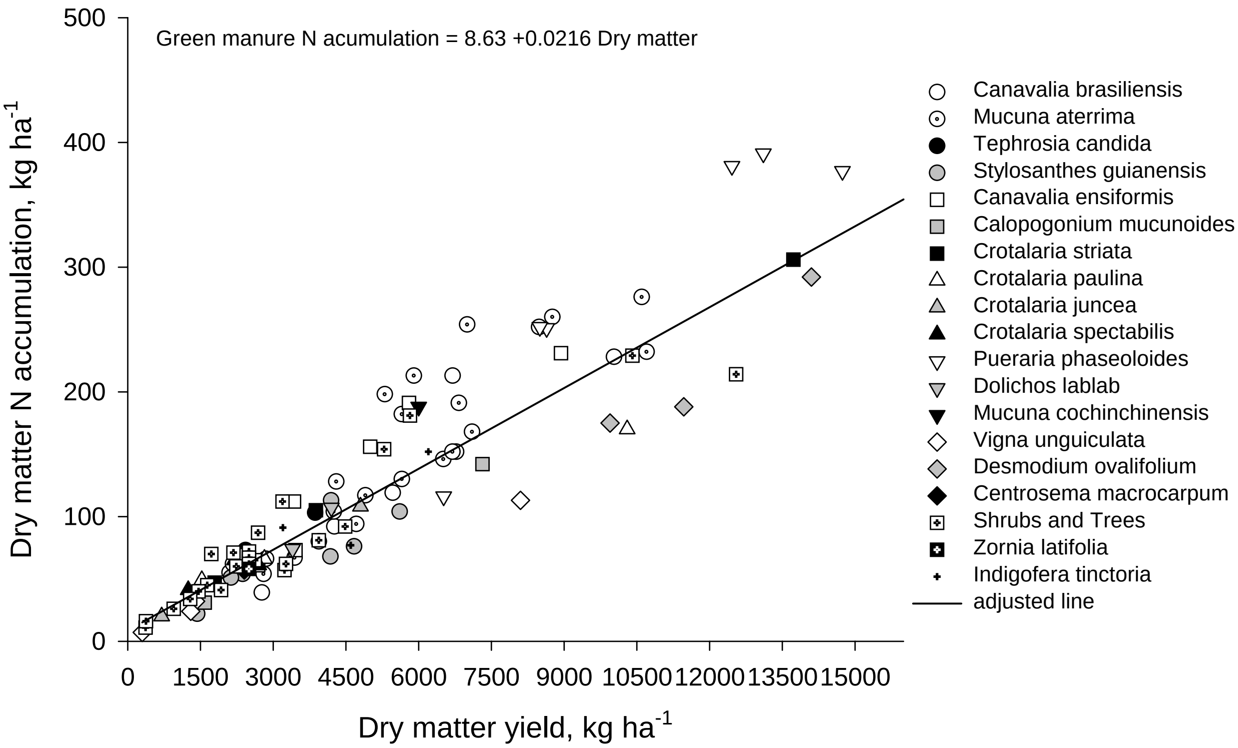

Figure 7. Green manure relationship 1: dry matter N accumulation vs. dry matter yield for tropical grain, forage, shrub and leguminous tree species grown in the Cerrado and Amazon sub-regions of South America.

5. The coefficient 0.40 from the function obtained for the apparent N recovery vs. applied N relationship for corn is used to represent your **F** term in the algorithm:
   Apparent N recovery = 0.40 N; 0.40=$\mathbf{E_f}$
6. The values obtained in steps 1-5 can be substituted into the algorithm to calculate the fertilizer N needs for the 5 000 kg ha^{-1} of corn grain crop to which 1000 kg of green manure is applied:
   N_{fert} = [108.59 – (69 kg N ha^{-1} + 11.79 kg N ha^{-1})] 0.40^{-1} = 69.5 kg N ha^{-1}

This means that 70 kg N ha^{-1} of commercial fertilizer should be applied to obtain a 5 000 kg ha^{-1} corn grain crop. This procedure will be applied to other crops considered in the IntDSS.

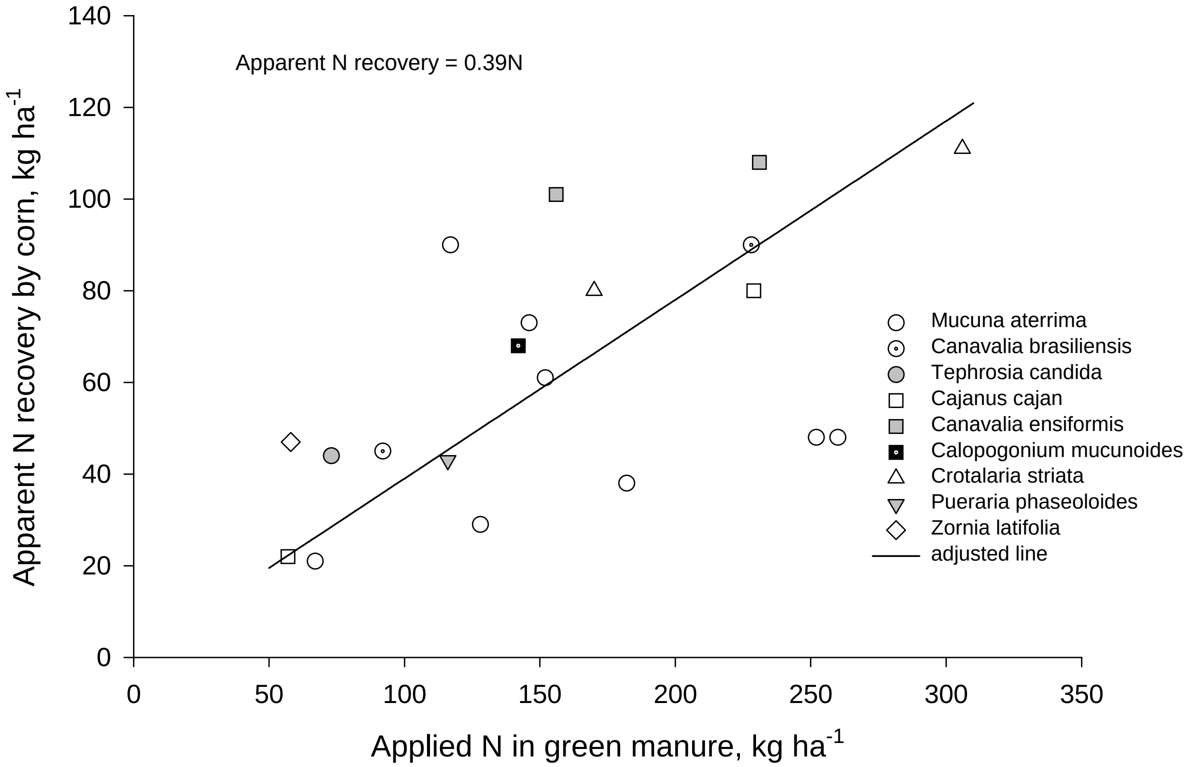

Figure 8. Green manure relationship 2: apparent N recovery by corn vs. applied N in green manures grown in the Cerrado region of South America.

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