

# Ecotoxicological risk assessment of agriculture intensification in Argentinean cropping lands using a fuzzy-logic based model



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## Introduction

Current agricultural models have an increasing dependence on non-renewable resources that have significant implications for the ecosystem health. Pesticides are considered one main impact force that affects both the structure and functions of agroecosystems. We assessed the environmental pesticide risk (1992-2005) of cropping systems in the Inland Pampa (Argentina) using a fuzzy-logic model. Here, the traditional mixed grazing-cropping systems were being replaced by permanent agriculture. However, there is no clear awareness of the ecotoxicological risk associated with these land use changes.

## Methods – The model

A fuzzy logic-based expert system were developed. Thresholds and membership functions were developed by means of expert opinion. The input variables are:

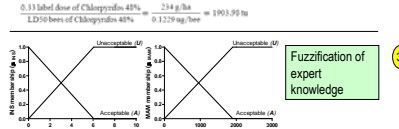
- 1) Dose (D) applied
- 2) Lethal Dose (LD50) for rats (LD50r) and bees (LD50b)

$$T_{max}(nt) = \frac{D}{LD50r} \rightarrow \text{Sum } T_{max}(nt) = \sum_{i=1}^n T_{max}(nt)$$

1

• Unacceptable value of  $\text{Sum } T_{max}(\text{Max } T_{max})$   
 0.33 label dose of insecticides 60% 200 µg/kg  
 LD50 rats of insecticides 60% 33 µg/kg  
 • Unacceptable value of  $\text{Sum } T_{max}(\text{Max } T_{max})$   
 0.33 label dose of Chlorpyrifos 45% 234 µg/kg  
 LD50 bees of Chlorpyrifos 45% 0.1239 µg/bee = 1903.96/n

2



- R1) If MAM A AND INS A THEN Pesticide Index (P)  $w_p = 1.0$   
 R2) If MAM U AND INS A THEN Pesticide Index (P)  $w_p = 0.1$   
 R3) If MAM A AND INS U THEN Pesticide Index (P)  $w_p = 0.1$   
 R4) If MAM U AND INS U THEN Pesticide Index (P)  $w_p = 0.0$
- Inferences rules (R) for combining fuzzy membership values
- 4

$$m_i = w_i \cdot \min(\mu_{MAM}(A), \mu_{INS}(A))$$

$$x^* = \frac{\sum_{i=1}^n m_i}{\sum_{i=1}^n w_i}$$

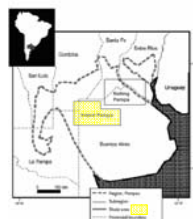
Fuzzy operators for assessing the membership of each rule (m)

Defuzzification: Inferences rules for obtaining a single crisp value

5

## Site study and database

A crop-field scale database (1992-2005) from Inland Pampa (Argentina) (Map 1), was analyzed, containing



Database contains information about pesticide use (type and dose), crop yield, field area (ha), and previous crop for 1) maize (M), spring soybean (S1), summer soybean (S2), sunflower (Su), and wheat (W) (Tables 1 and 2). Data from each year were previously clustered in 3-year time periods, resulting in 5 periods (Table 2 and 3)

Table 1. Number of fields for each crop and time period analyzed

Period	M	S1	S2	Su	W	TOTAL
92-94	1746	463	236	2033	605	5083
95-97	2159	496	425	3644	1096	7820
98-00	2537	1168	616	2886	1412	8619
01-03	811	1448	300	484	1184	4227
04-05	603	1294	306	60	1003	3266
TOTAL	7856	4889	1883	9107	5300	29015

Table 2. Total area (ha) for each crop and time period analyzed

Period	M	S1	S2	Su	W	TOTAL
92-94	102710	26888	12881	115584	38745	298460
95-97	129610	25903	22373	223202	66452	467540
98-00	132402	57081	32871	160020	71919	454879
01-03	41291	67329	14003	26442	61947	211002
04-05	29797	66963	19712	4122	48520	165214
TOTAL	438810	244152	101820	529565	285743	1597481

A noticeable change in land use in the study area was the increase in soybean cultivation from 13% of the area occupied in the period 1992-1994 to 55% in the period 2004-2005 at the expense of maize and sunflower occupied area.

## Data analysis

- Model application resulted in three response variables:
- 1) Insect index (INS): Ecotoxicological risk for insects
  - 2) Mammal index (MAM): Ecotoxicological risk for insects
  - 3) Pesticide index (P): Overall ecotoxicological risk

Results from the model application on the whole database was analyzed according different source of variation:

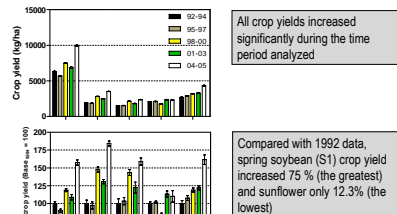
- 1) Time period
- 2) Crop
- 3) Previous crop

Also, a data-mining technique, classification and regression tree (CART), was applied in order to analyze the non-linear nature of the data structure. The pesticide index (P) output were clustered in five groups (in 0.2 intervals from 0.0 to 1.0) and these classes were classified using:

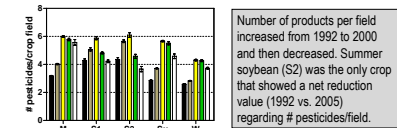
- 1) Number of products applied per crop field (# products)
- 2) Time period (SET)
- 3) Crop specie (CROP)
- 4) Normalized yield (the relative yield of each field with respect to the maximum of each crop and year)

## Results: crop yield and risk over mammals and insects

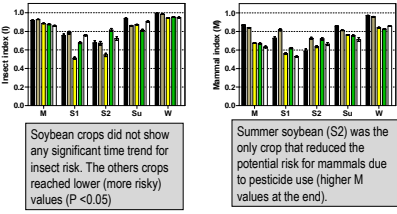
Results showed that harvested yield increased significantly in all crops during the period studied (P<0.005). In 1992-base year, spring soybean (S1) showed the greatest increment and sunflower (Su) the lowest.



Regarding the average number of pesticides applied, all crops showed a significant increment from 1992 to 2000 and a subsequent reduction from 2000 to 2005 (Spearman rank correlation, P < 0.05) and these reductions were higher in summer soybean, from 6.1 to 3.8 application/year in relation to maize, spring soybean, wheat and sunflower.

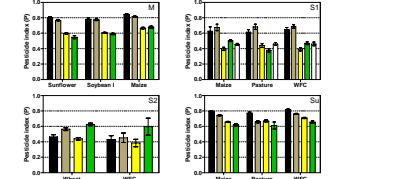
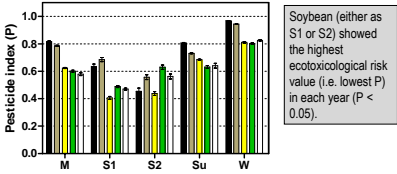


When inspecting the ecotoxicological risk from mammals (M) and insects (I) both crop and time period had significant effects on final outcome (P < 0.05). However, the insect risk (I) dynamic has a distinctive pattern than mammal risk (M). Although almost all crops (except soybean) showed lower index values (i.e. higher risk) by the end of the period studied, the index reduction were higher for mammal (M) index than insect (I) index

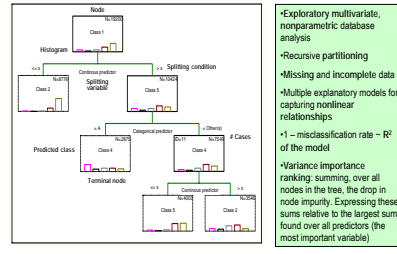


## Results: overall risk and some explanatory factors

Higher yields were associated with higher overall ecotoxicological risk (i.e. lower P values). In almost all crops analyzed the fuzzy-logic ecotoxicological indicators showed negative and significant time trend in the period studied (P<0.05). Summer soybean (S2) was the only crop that exhibited better (higher P index) risk values by the end of the period studied.

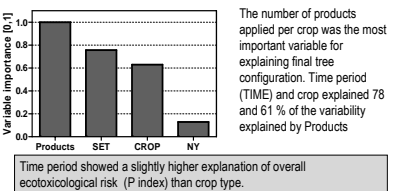
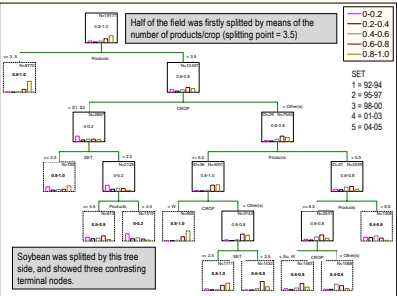


## Classification and Regression tree (CART): the structure



## Classification and regression tree: the results

The multivariate CART analysis determines a final model configuration with 10 terminal nodes and a misclassification rate of 0.41 (i.e. a model R<sup>2</sup> = 0.59). The normalized yield (NY) was not retained in the final tree. Time period (SET) was retained twice in final tree configuration using the same splitting point (SET = 2.5, which represent the average value in the splitting node)



## Conclusions

These preliminary results indicated that higher yield in all the crops analyzed were associated to higher ecotoxicological risk of the pesticides used. However, further work has to be conducted to improve the fuzzy-logic ecotoxicological model by including variables such human toxicological risk or other chemical pesticide characteristics (i.e. soil persistence, solubility).

## Contact information

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