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Sensitivity analysis of the STICS-MACRO model to identify cropping practices reducing pesticides losses

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Introduction

- **To reduce the environmental impacts due to pesticides and to protect soil and water, new cropping systems have to be introduced**
- **However, it is difficult and costly to carry out comprehensive experiments to study the sustainability of each potential new system**
- **Recently, a new modelling approach, STICS-MACRO, was developed to simulate the fate of pesticides in the soil-plant system as a function of cropping practices and pedoclimatic conditions**

Objective

To assess the effects of various crop management practices on pesticide flows from a sensitivity analysis of the STICS-MACRO model

Materials and methods

STICS-MACRO model

- **STICS-MACRO results in the sequential use of STICS crop model and of MACRO pesticide fate model (Fig. 1) to simulate crop growth and pesticide fate in complex cropping systems**

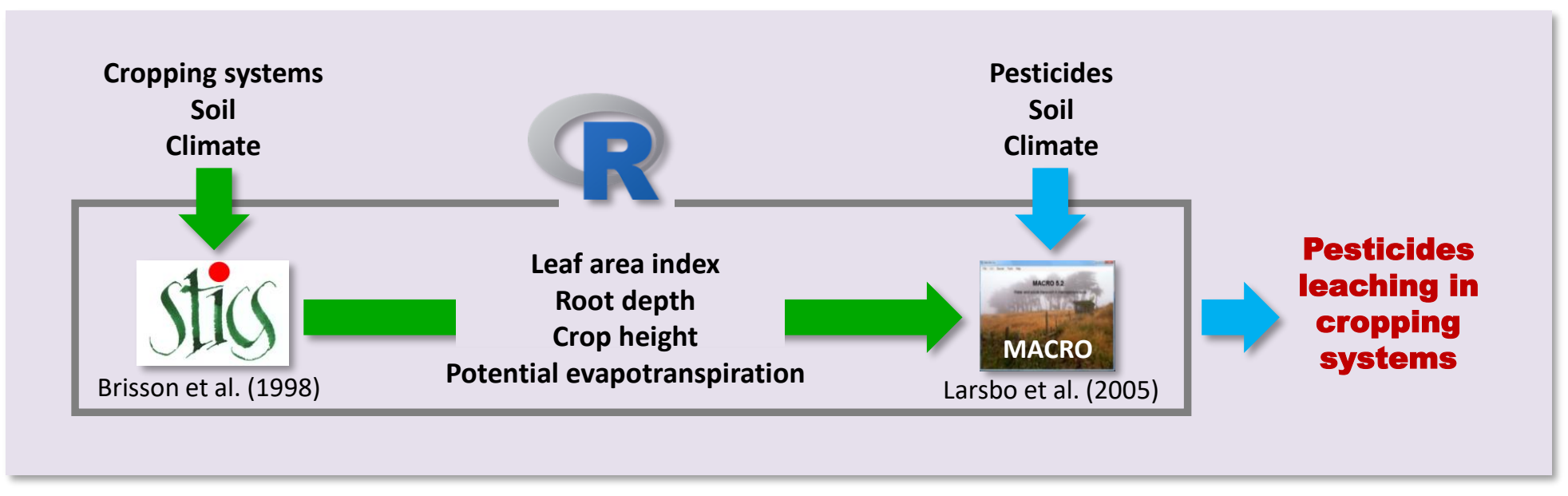

Fig. 1. Simplified representation of the STICS-MACRO model (Lammoglia et al., 2017a)

Table 1. STICS inputs used in the sensitivity analysis of STICS-MACRO and their ranges of variation (Lammoglia et al., 2017b)

Parameter			Maize		Winter wheat	
Symbol	**Description**	**Unit**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
CsurNres[c]	C/N ratio of organic residues	(-)	10	125	10	125
deneng[a]	Maximal fraction of the mineral fertilizer that can be denitrified	(-)	0.05	0.2	0.05	0.2
densite[a]	Plant sowing density	Plants/m²	5	20	200	400
eaures[a,c]	Water content of organic residues	% fresh weight	0	100	0	100
engamm[a]	Fraction of ammonium in the N fertilizer	(-)	0.5	1	0.5	1
$Hinit_i$[a]	Initial water content of the i^{th} (i = 1 to 5) soil horizon	%	0	30	0	30
iplt0[a]	Date of sowing	Julian day	90 (Early)	129 (Late)	275 (Early)	323 (Late)
julres[a]	Date of organic residues addition to soil	Julian day	iplt0 - 14	iplt0 - 2	iplt0 - 14	iplt0 - 2
jultrav[a]	Date of soil tillage	Julian day	iplt0 - 14	iplt0 - 2	iplt0 - 14	iplt0 - 2
$Ninit_{1\ to\ 5}$[a]	Initial NO_3 content in the i^{th} (i = 1 to 5) soil horizon	kgN ha^{-1}	0	30	0	30
Nminres[a,c]	Proportion of N mineral content of organic residues	% fresh weight	0	10	0	10
Norgeng[a]	Amount of N immobilized	kgN ha^{-1}	0.2	42	0.2	42
pgrainmaxi[a]	Maximum grain weight	g	0.24	0.36	0.24	0.36
profres[b,c]	Minimal value of the depth where organic residues are incorporated	cm	0	30	0	30
profsem[c]	Depth of sowing	cm	1	10	1	10
proftrav[c]	Maximum value of the depth where organic residues are incorporated	cm	0	30	0	30
qres[c]	Amount of organic residues added to soil	t ha^{-1}	0	30	0	30
ratiol[a]	Water stress index below which irrigation is started in automatic mode	(-)	0.2	1	0.2	1
ratiolN[a]	Nitrogen stress index below which fertilization is started in automatic mode	(-)	0.2	1	0.2	1
stamflax[a]	Cumulative thermal time between the AMF[d] and LAX[d] stages	Degree.day	390	600	390	600
stdrpmat[a]	Cumulative thermal time between the DRP[d] and MAT[d] stages	Degree.day	570	780	570	780
stlaxsen[a]	Cumulated thermal time between the LAX[d] and SEN[d] stages	Degree.day	680	800	680	800
stlevamf[a]	Cumulated thermal time between the LEV[d] and AMF[d] stages	Degree.day	190	310	190	310
stsenlan[a]	Cumulated thermal time between the SEN[d] and LAN[d] stages	Degree.day	180	300	180	300
voleng[a]	Maximum fraction of mineral fertilizer that can be volatilized	(-)	0	0.35	0	0.35

[a] From Ruget et al. (2002). [b] From expert judgement. [c] Limits imposed by STICS. [d] AMF: Maximum acceleration of leaf growth, end of juvenile phase; LAX: Maximum leaf area index, end of leaf growth; DRP: Starting date of filling of harvested organs; MAT: Physiological maturity; SEN: Beginning of leaf senescence; LEV: Emergence; LAN: Leaf index zero.

Scenarios

➡ **Eight scenarios were defined combining 2 soils, 2 crops and 2 climates**

- **Soils**
  - Different depth, physical and hydraulic properties

  Clay loam (% clay/loam/sand): 32/45/23, 2 m depth
  Silty clay loam: 39/55/06, 1 m depth

- **Crops**
  - Different pesticide application periods
  - Contrasted growing season length and water requirements

  Winter wheat (winter crop)
  Maize (spring crop)

- **Climates**

  Dry: 623 mm annual rain, T_{mean} = 12.1 °C
  Wet: 940 mm annual rain, T_{mean} = 10.7 °C

- **Pesticide**

  Dummy B substance of FOCUS (2000): DT50 = 20 days
  Koc = 17 L kg^{-1}

- **STICS-MACRO outputs**

  One year cumulative amount of water at 1 m depth (mm)
  Total amount of pesticide at 1 m depth during 1 year ($\mu g\ m^{-2}$)
  Daily maximum concentration of pesticide at 1 m depth ($\mu g\ L^{-1}$)

Sensitivity analysis

➡ **To rank all STICS-MACRO inputs related to crop management practices (Table 1), then to identify the most influential practices**

- **Morris screening sensitivity analysis method**

  Number of levels $p = 4$
  Number of trajectories $r = 50$
  - μ^* (mean), σ (standard deviation) of the elementary effects
  - Inputs were classified in 3 categories:

    Highly influential if $\mu^* > 0.5\ \mu^*_{max}$
    Influential if $0.1\ \mu^*_{max} < \mu^* < 0.5\ \mu^*_{max}$
    Non influential if $\mu^* < 0.1\ \mu^*_{max}$

- **Statistical analysis**
  - Significant differences among the rankings obtained for the 8 scenarios were determined with the test of Kruskal-Wallis
  - The test of Kruskal-Wallis was also used to study the effect of different values of each influential input on the model outputs

➡ **8 scenarios**
➡ **1700 input combinations**

13600 simulations

Results and discussion

Identification of the influential crop management inputs on STICS-MACRO outputs

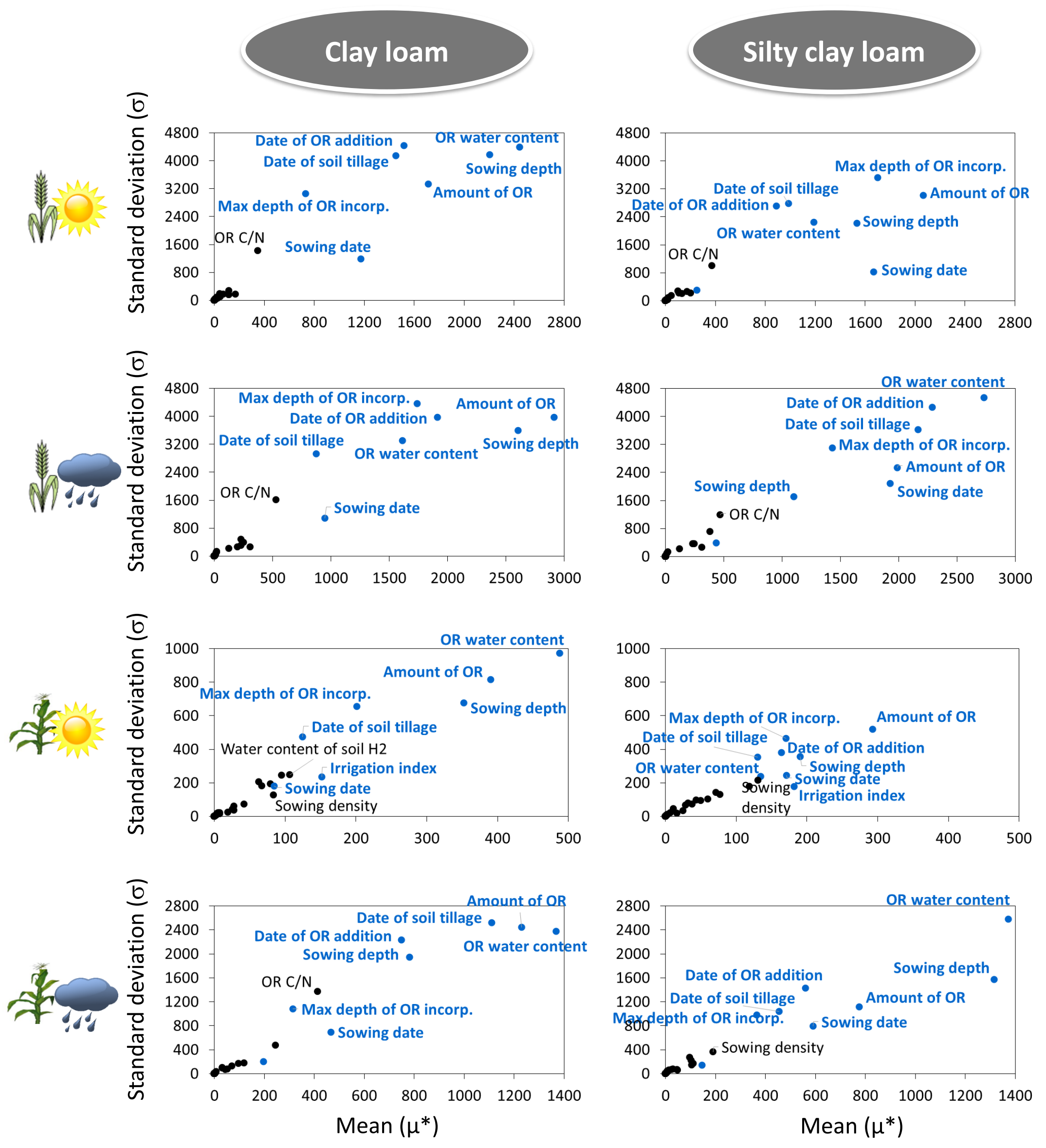

Fig. 2. Scatter plots of the results of the Morris sensitivity analysis. The graphs show the sensitivity of the STICS-MACRO output "Total amount of pesticide at 1 m depth during one year ($\mu g\ m^{-2}$)" to the inputs. OR: Organic residues; Hi: Soil horizon i (Lammoglia et al., 2017b). Similar trends were observed for water flows and maximum pesticide concentrations.

8 influential input parameters

- **In any case, 8 very influential input parameters:**

  Amount of OR added to soil*
  OR water content*
  Sowing depth
  Date of OR addition to soil
  Depth of OR incorporation
  Sowing date
  Date of soil tillage
  Irrigation index
  *Correlated parameters

- **μ^* and σ are higher for clay loam than for silty clay loam soil, and for wheat than for maize**

- **STICS-MACRO is a non-linear and non-additive model**

Cropping practices to manage pesticide flows in the environment

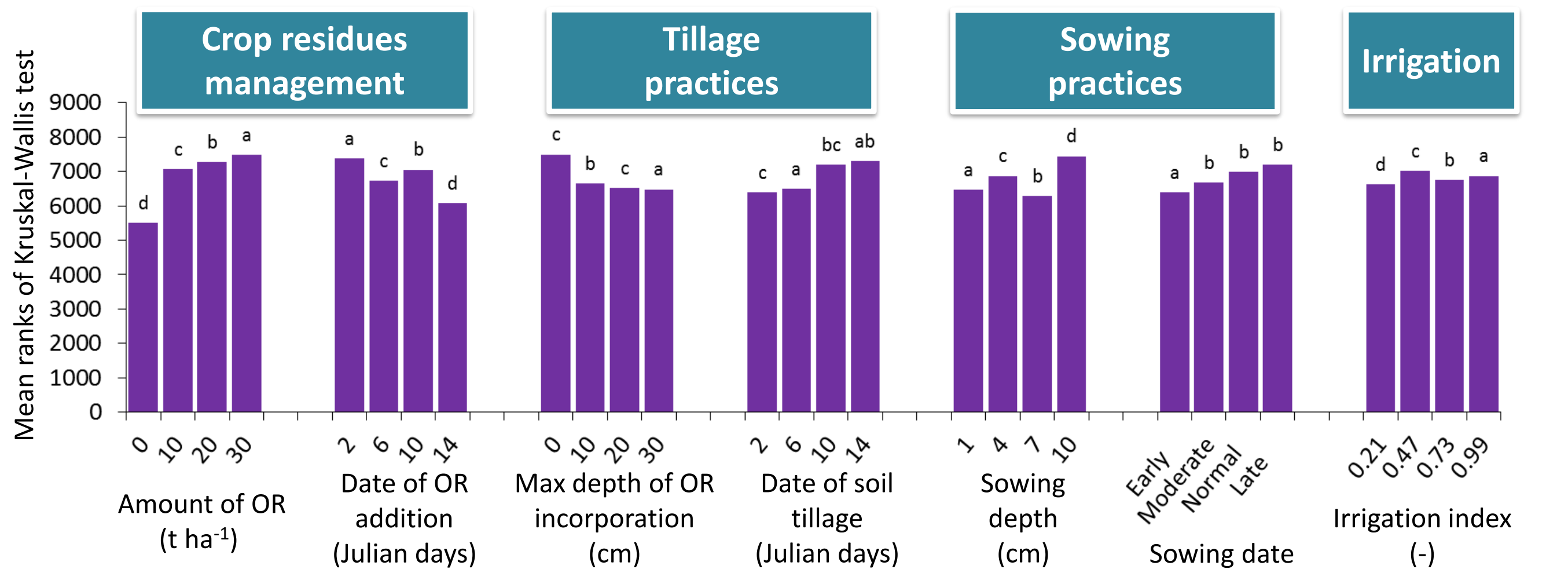

Fig. 3. Response of cumulative amount of pesticide at 1 m depth to the eight very influential STICS-MACRO crop management inputs. Means followed by the same letter across one parameter are not significantly different at *P* < 0.05 (Lammoglia et al., 2017b). Similar trends were observed for water flows and maximum pesticide concentrations.

4 cropping practices able to manage pesticide flows

- **Cropping practices to decrease pesticides leaching:**
  - **No mulch of organic residues**

    The presence of mulch increases soil water content so water percolation and pesticide leaching
  - **Conventional tillage**

    No-till enhances water infiltration and soil moisture storage, in agreement with field observations
  - **Sowing practices**

    Plant density and corresponding transpiration drive the amount of water available for percolation
  - **Optimum irrigation threshold**

    Optimum threshold minimizes pesticide losses while maintaining good water input

- **The effects of soil, crop and climate conditions tested in this work were less important than those of cropping practices**

Conclusion and perspectives

- **Water and pesticide transport could be highly affected by cropping practices, and in particular by organic residues management, then by tillage**
- **To improve the assessment of pesticide fate in complex cropping systems, the changes in soil structure and in water holding capacity of the soil following organic residues addition, and the effect of the change in soil organic carbon content on pesticide sorption and degradation, not simulated by STICS-MACRO, have to be considered**

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