Application of Environmental Potential Risk Indicator for Pesticides (EPRIP) to evaluate the environmental risks of Alternate Wetting and Drying irrigation for rice in northern Italy

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Abstract

Environmental Potential Risk Indicator for Pesticides (EPRIP) (Reus et al., 2002) was used to estimate the environmental impact of pesticides used in rice production with traditional and water-saving irrigation methods in the main Italian rice district (Lomellina, PV). EPRIP is based upon the Exposure Toxicity Ration (ETR) of the Predicted Environmental Concentration (PEC) (Padovani et al., 2004). A modified version of MED-Rice tool was used in order to evaluate PECs of seven pesticides into groundwater, surface water and paddy sediment. ETR and PEC were estimated at a local scale (field and surroundings), with short-term toxicological parameters (NOEC) and, therefore, reflecting a worst-case scenario, assuming that organisms are subjected to maximum exposure. ETR were then converted into risk points (RPs) accordingly to the following table (Trevisan et al., 2009):

Range of ETR	RISK POINT
<0.01	1
0.01-0.1	2
0.1-1.0	3
1.0-10.0	4
>10.0	5

An experimental platform was set up in the main Italian rice district (Lomellina, PV), during the agricultural seasons 2019 and 2020, to compare different irrigation management options: in particular, wet seeding and traditional flooding (WFL) and wet seeding and alternated wetting and drying (AWD) for the agricultural season 2019 were considered in this paper. Two widely used pesticides (Clomazone, MCPA) were measured in irrigation water (inflow and outflow) and groundwater. Estimated RPs following Trevisan et al. (2009) were compared to measured RPs, based on the analysed Clomazone and MCPA concentrations in water samples collected from the experimental fields. Finally, the overall EPRIP indicator was based on RPs to evaluate the probability of the predicted concentration of contaminants in the environment to overcome a supposed threshold. The results are calculated considering the probability of not exceeding the Risk Point 3 (RP3) by assuming a Poisson cumulative function.

Keywords: Pesticide, EPRIP, Agro-ecological indicator, Water use

1. **Introduction**

Italy, with 220,000 ha (FAOSTAT, 2020), is the major rice producer in the European Union (Ferrero & Nguyen, 2003). The major rice-producing regions are Lombardy and Piedmont, located in the northern-west part of the country with 43 and 50% of the total rice cultivated area, respectively (Ente Nazionale Risi, 2015). Rice is a cereal with a high water demand and its yields depend on other inputs as well (nutrients, herbicides, fungicides) (Bouman, 2009; Shao et al., 2014). The majority of the fields in the northern Italy rice area traditionally adopt a flooding irrigation system, consisting in wet seeding and continuous flooding (WFL). This irrigation method requires a huge amount of water, since fields are submerged from before sowing to a few weeks before harvest. For this reason, in recent years, the interest in adopting alternative water strategies has increased (Dunn & Gaydon, 2011; Kato et al., 2009), due to a decreased water availability in many areas and to an increased competition in water uses. Dry seeding and delay flooding (DFL) represents an example of alternative irrigation management and could lead to a water saving up to 10% in comparison to WFL (Miniotti et al., 2016). In recent years, DFL strategy adopted in Lomellina increased dramatically (Ente Nazionale Risi, 2020). Alternate wetting and dry (AWD) is an irrigation technique based on alternating dry and flooding periods from the tillering stage to the final dry period. AWD can potentially reduce irrigation water use by up to 20%, leading to a better water use in comparison to WFL and DFL (Kumar & Rajitha, 2019; Reavis et al., 2021). As a new rice irrigation strategy in Italy, AWD has being tested in the context of the MEDWATERICE project. When adopting a new irrigation strategy, advantages and disadvantages in terms of water saving, yield and environmental impacts must be assessed.

Pesticides contamination of water bodies is a major concern in many countries all over the world. For this reason, for decades, European Union has continuously upgraded legislation in order to limit the environmental risk. Risk assessment represents the major aim for agro-chemical management in order to prevent environmental and human health negative impacts. Several risk assessment tools are available in scientific literature to manage the environmental contamination by chemicals adopted in agriculture. Those indicators are of vital importance in agricultural management and legislation formulation because have the aim to predict the potential risk based on pesticides application strategies as well as site characteristics. In this paper, environmental potential risk indicator for pesticides (EPRIP) was adopted to evaluate the environmental risks of the AWD technique tested in an experimental platform during agricultural season 2019. EPRIP is based upon the Exposure Toxicity Ratio (ETR) of the Predicted Environmental Concentration (PEC) (Padovani et al., 2004), calculated as the ratio of PEC with eco-toxicological chronic concentration. Thus, ETR reflects a worst case scenario when organisms are exposed to a potential risk. Water samples were collected from the pilot fields, and concentrations of two widely used herbicides in rice cropping (Clomazone and MCPA) were analysed in irrigation water (inflow and outflow), groundwater, and porous cups installed at two soil depths (20 and 70 cm, above and below the plough pan). Estimated Risk Points (RPs) were then compared to measured RPs (on the basis of the herbicide concentrations analysed in the water samples collected at the experimental platform). Finally, the overall EPRIP indicator was estimated, evaluating the probability of the predicted concentration of the contaminants in the environment to overcome the supposed threshold. Results are calculated considering the probability of not exceeding the Risk Point 3 (RP3) assuming a Poisson cumulative function. Starting from the European Community Directive 91/414/EEC1, concerning the placing of plant protection products (PPP) on the market, the currently adopted methods for PEC calculations for surface water were found to be appropriate for rice only when it is irrigated with methods adopted for other crops. However, it is not fully appropriate in case of continuous flooding of paddies. Therefore, a new method was developed and illustrated in this paper.

2. Materials and Methods

2.1 Experimental site

The MEDWATERICE experimental activity was carried out at the ENR - Rice Research Centre's experimental farm located in Castello d'Agogna (Pavia, Italy), within a traditional rice cultivated area. In the 2019 agricultural season the experimentation was conducted for the following irrigation strategies: WFL and AWD. Centauro variety, short-grained, was seeded in all the plots (seeding rate 150 kg/ha). In the experimental platform, a soil survey was conducted before the 2019 agricultural season through an Electro-Magnetic Induction (EMI) sensor and the collection of soil samples at different soil depths subsequently analysed for the determination of physico-chemical parameters. Each plot was provided with a piezometer in order to monitor the groundwater level and for sample collection. Two widely used pesticides (Sirtaki – active ingredient Clomazone; Tripion E – active ingredient MCPA) were periodically monitored in the irrigation water (inflow and outflow), groundwater, and soil solution collected by porous cups installed at two soil depths (20 and 70 cm, above and below the plough pan) in the plots.

2.2 Water percolation

For each of the instrumented plots, a daily water balance was computed as shown in Eq. 1, considering a time period ranging from the seeding date in the case of DFL and pre-seeding flooding in the case of WFL and AWD, to the harvesting date. A control volume ranging from the top of the crop to the bottom of the rice rooting zone was considered.

$$\Delta S = R + Q_{IN} - Q_{OUT} - ETc - P \qquad (1)$$

where: ΔS (mm) includes both the variation in ponding water (ΔL) and in soil moisture ($\Delta\theta$) within the rice root zone, R (mm) is the total rainfall, Q_{IN} (mm) and Q_{OUT} (mm) are the irrigation inflow and outflow, ETc (mm) is the evapotranspiration from soil and/or ponding water and the rice crop, and, finally, P (mm) is the percolation and it is calculated as the residual term of the water balance. All the terms in the Eq. 1 are expressed in mm; in the case of the irrigation inflow and outflow (Q_{IN} and Q_{OUT}), water volumes were divided by the respective irrigated areas. Finally, Leakage was calculated according to Eq. 2:

$$Leakage = \frac{P + OSR \cdot 0.8}{365} \qquad (2)$$

where: OSR is the rainfall out of the agricultural season, and 0.8 is assumed as the groundwater recharge coefficient, determining the effective rainfall out of the agricultural season reaching groundwater.

2.3 EPRIP assessment for rice padding

In the $\text{EPRIP}_{\text{rice}}$ method, PEC in the surface water (PEC SW), in the paddy water (PEC PW), in the sediment (PEC SED) and in the groundwater (PEC GW) were considered. It is important to note that, in this paper, the term "surface water" (SW) refers to water in non-target areas (e.g. drainage canals) whereas the term "paddy water" (PW) is used for water in the cropped field. Similarly, the term "sediment" (SED) refers to sediment associated with surface water in non-target areas and the term “soil” is used only for the cropped field. For the initial PEC calculations, “groundwater” (GW) is defined as water in the saturated zone at 1 m below the soil surface.

MedRice’s equations, modified by Fragkoulis et al. (not published yet) are used to assess PEC into PW, SED, GW. The paddy water level is set at 10 cm. PECs determined for each compartment (GW, SW and SED) were converted in ETR using pesticide toxicity for non-target organisms in surface and paddy water (minimum value between the NOEC for Algae, Daphnia and Fish) and in sediment (NOEC values for Eisenia fetida) derived from international eco-toxicological and toxicological data-bases (PPDB). For GW the legal limit of 0.1 µg/L was used as legal end-point. ETR were converted into risk points- accordingly to Table 1 (Trevisan et al., 2009):

Table 1. Normalisation of ETR values into Risk Points (RPs)

Range of ETR	RISK POINT
< 0.01	1
0.01 - 0.1	2
0.1 - 1.0	3
1.0 - 10.0	4
> 10.0	5

The overall EPRIP indicator is based on RPs and evaluates the probability of a predicted concentration of contaminants in the environment to overcome a supposed threshold. The results are calculated considering the probability of not exceeding the Risk Point 3 (RP3) assuming a Poisson cumulative function expressed by Eq. 3.

$$f = \sum_{k=0}^{k=n} \frac{\lambda^k e^{-\lambda}}{k!} \qquad (3)$$

Where λ is the average risk point and k is the risk threshold (RP3).

2.4 Active ingredients

A total of 7 different pesticides were applied to AWD and WFL plots as reported in Table 2. Moreover, the table includes toxicological, mobility and degradation parameters collected from international eco-toxicological and toxicological data-bases (PPDP, 2007).

Table 2. Active Ingredients ecotoxicology, soil adsorption/mobility and degradation

	NOEC SW (µg/L)	NOEC Sediment (µg/kg)	Koc	DT50 water-sediment (days)	DT50 soil (days)
Clomazone	50	85750	300	54	22.6
MCPA	15000	46000	74	17	24
Oxadiazon	0.88	66500	3200	126.5	502
Cyhalofop-butyl	130	5000	5247	0.1	0.2
Lambda-cyhalothrin	0.0022	3125	283707	15.1	175
Halosulfuron-methyl	5.3	4940	109	10.4	26.7
Azoxystrobin	44	3000	589	205	84.5

2.5 Water sampling, reagents and herbicides analysis

Immediately after collection, all water samples (groundwater and surface water,) were transferred to frozen storage (-20 ºC +/- 5°C).

Herbicides - Clomazone (Supelco, PESTANAL®, analytical standard) and MCPA (Honeywell Riedel-de-Haën) - were separated with a RP-18 column (150x2.1 mm, Kinetex 5 um Phenomenex) and quantified by high performance liquid chromatography (HPLC) with triple quadrupole mass detector. Oasis HLB cartridges (Supelco, Supel™-Select HLB SPE Tube) were considered as suitable SPE devices for pre-concentration of the herbicides in this study due to their hydrophilic and lipophilic characteristics as reported in (Tran et al., 2007).

3. Results and discussion

3.1 Field parameters

Plots irrigated by applying the two different irrigation strategies where characterized as reported in Table 3. In particular, soil organic content (OC%), soil texture, leakage and field areas measured or estimated are reported in the table.

Table 3. Plots data for each irrigation method

Irrigation method	OC%	area (m^2)	Soil texture	Leakage (mm/d)
AWD	2.02	1402.60	Silt-loam	5.54
WFL	2.00	1400.26	Silt-loam	6.30

3.2 Overall EPRIP$_{rice}$

After PEC estimation, RPs were calculated in order to estimate the overall EPRIP$_{rice}$ and are reported in Table 4. The highest contribution to the overall EPRIP was due to GW RPs. This result was expected considering the legal end-point of 0.1 µg/L used in the GW RP calculation compared to the NOEC toxicological concentrations.

Table 4. RPs and EPRIP$_{rice}$: Probability of a predicted concentration of contaminants in the environment to exceed Risk Point 3 (EXC_PROB_3%) for each irrigation method

	WFL and AWD		
	RP SW	**RP sed**	**RP GW**
Clomazone	2	1	4
MCPA	1	1	5
Oxadiazon	3	1	1
Cyhalofop-butyl	1	1	1
Lambda-cyhalothrin	2	1	1
Halosulfuron-methyl	2	1	4
Azoxystrobin	1	1	4
	EPRIP$_{rice}$		
EXC_PROB_3 %	12		

Table 4 reports also the probability of a predicted concentration of contaminants in the environment to exceed Risk Point 3 (EXC_PROB_3%) for both irrigation methods. Note that Risk Point 3 (RP3) means PECs from 1 to 1/10 of the eco-toxicological or legal end-point. Results show the EPRIP probability for both irrigation methods is equal to 12% (Table 4). This result is due to the same RPs obtained in the two scenarios.

These results underline that no differences where observed between AWD and WFL plots, despite the water management was different. Moreover, EPRIP values for AWD and WFL were identical.

3.3 Experimental RPs for Clomazone and MCPA

Collected water samples from the experimental fields were analysed and the maximum concentration value of both MCPA and Clomazone registered in the agricultural season were used to calculate the experimental RPs reported in Table 5.

Table 5. Experimental RPs for each irrigation method for Clomazone and MCPA herbicides. In brackets RPs estimated through the EPRIP model are reported, if different from the experimental values.

AWD

	RP SW	RP GW
Clomazone	2	5 (4)
MCPA	1	4 (5)

WFL

	RP SW	RP GW
Clomazone	2	3 (4)
MCPA	1	3 (5)

When compared, the experimental SW RPs show no differences for the two irrigation strategy and both herbicides (Clomazone and MCPA). Moreover, predicted SW RPs and experimental SW RPs were found to be exactly the same. The only difference between estimated and experimental RPs was observed in case of GW. Predicted values were in the majority of the cases highest than the experimental ones, and this could be explained considering that PEC where estimated under the worst case scenario.

Finally, in both surface water and groundwater, the final measured concentrations for the two herbicides at the end of the agricultural season (Sep) were found to be close to the initial ones (Apr), and always below the standard quality level imposed by the Italian legislation.

4. Conclusions

In order to assess the environmental risk of the experimented water-saving irrigation strategies, the $\text{EPRIP}_{\text{rice}}$ model was applied. $\text{EPRIP}_{\text{rice}}$ results showed that AWD technique has the same environmental impact than WFL, with a probability of the predicted concentration in the environment to exceed Risk Point 3 (EXC_PROB_3%) of almost 12%. As a general consideration, it can be observed that the $\text{EPRIP}_{\text{rice}}$ approach shows a very limited impact of the two irrigation strategies on the environment when the chemical input factors are managed appropriately (such as in the experimental platform). In particular, with respect to AWD, which is one of the promising rice irrigation strategies proposed in the MEDWATERICE project for the Mediterranean area, $\mathrm{EPRIP}_{\mathrm{rice}}$ shows that this technique does not exacerbate the impacts on the environment when compared to the traditional irrigation technique (WFL).

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