



REDUCTION OF THE WEED SEED BANK IN THE SOIL AS A MANAGEMENT STRATEGY

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Key words: rice, stale seed bed, Europe, Italy

MAIN TRAITS OF RICE CULTIVATION IN EUROPEAN UNION

Rice is cultivated in the European Union (EU) on about 450,000 ha, with an average yield of 6.6 t/ha. Main European rice areas are the Po valley, in Italy, the Camargue (south of France), several areas in Spain (Ebro Delta, areas around Valencia, Sevilla, Badajoz and Zaragoza), Portugal (in the Tejo valley and in Mondego region) and in Greece, close to Thessaloniki. About 50% of the total area is located in the Po valley, Italy. About 80% of the area is cultivated by *japonica* varieties, while 20% is cultivated with *indica*-like *japonica* varieties. These have elongated grains but genetically belong to the *japonica* group.



European rice is cultivated under temperate climate conditions, that allow only one growing season per year. The irrigated system is the only growing system adopted and the rice is basically only direct seeded. The main role of irrigation is the mitigation of temperature fluctuations, while less important is the role of water to reduce weed pressure. The water comes from rivers, lakes and springs. Paddy fields are usually arranged in systems of 4-7 adjacent fields in which water flows from the topmost to the bottommost basin (giving a so called “flow-through system”). In several areas, rice is cultivated in monocropping.

About 70% of rice area is managed adopting permanent flood. In this case, rice is broadcast seeded in flooded fields. Few days after, fields are dried for some days to promote root formation and seedling establishment. After that, fields are maintained continuously flooded until about 1 month before harvest, with the exception of short periods in which herbicide treatments and topdress fertilisations are performed. This technique is often coupled with stale seed bed, which is performed mainly to control weedy rice. On the remaining 30% of rice area, rice is drill seeded in dry fields and fields are flooded starting from tillering stage onwards.

The total surface cultivated in Italy with rice is around 230,000 ha (ENR, 2017), with an average yield of 6.3 t/ha. More than 130 varieties are cultivated, but only less than 10 are grown in more



than 10,000 ha each. The high number of varieties is due to many reasons. One is the fact that the market traditionally requires varieties belonging to different EU commercial groups, which have different grain characteristics. Each single farm usually grows at least 2-3 varieties belonging to different groups to increase economical resilience to market fluctuations.

MAIN WEEDS

First reports on rice weeds dates back to beginning 19th century, when the sedges *Cyperus longus* and *Scirpus mucronatus*, together with *Echinochloa crus-galli* and other barnyardgrasses were described as the most troublesome rice weeds (Biroli, 1807). Since that years, rice weed flora underwent several changes, mirroring the evolution of the entire set of cropping practices adopted in the rice growing system. The introduction of some exotic species and the spread of weedy rice are among the most significant phenomena in rice weed dynamics.

Some major weed groups in Italian rice fields can nowadays be identified, also on the basis of the specificity of the measures required for their management: (a) *Echinochloa* spp.; (b) weedy rice(s); (c) *Heteranthera* species; (d) Cyperaceae (sedges) and Alismataceae species; (e) weeds of the drill-seeded fields.



(A) ECHINOCHLOA SPP.

Echinochloa genus include some of the most important weed species in several crops and are major weeds in European rice fields (Vidotto et al. 2007). Main species species are *E. crus-galli* (L.) P. Beauv., *E. crus-pavonis* (Kunth) Schult., *E. oryzoides* (Ard.) Fritsch, *E. Erecta* (Pollacci) Pign., and *E. Phyllopogon* auct. non Stapf.

The chemical control of these species relies mainly on herbicides such as clomazone, cyhalofop, profoxydim, azimsulfuron, bispyribac-sodium, and penoxsulam. Containment of *Echinochloa* species can also be achieved by applying imazamox when using IMI-tolerant varieties (best known as Clearfield® varieties). Resistance to ALS-inhibitors such as azimsulfuron, bispyribac-sodium, imazamox and penoxsulam have been reported for some *E. crus-galli* populations since 2007 (Heap, 2017)

(B) WEEDY RICE

Weedy rice (*Oryza sativa* L.) has become a serious threat in several EU states over the last 20 years. Weedy rice show a huge variability of morphological traits: in a survey carried out in the main rice area of Italy, about 150 different populations have been identified (Fogliatto et al., 2012). This morphological diversity is somewhat correlated to the variability of growth traits,



competition behavior and sensitivity to herbicides (Andres et al., 2014, 2015).

Chemical control of weedy rice is carried out usually before rice planting. Main herbicides available at present are flufenacet, propaquizafop, and glyphosate. Flufenacet is applied in pre-sowing while the other herbicides are used in combination with the stale seedbed. Glyphosate is sometimes applied as rescue treatment at booting-flowering stage by using wipe bar equipment, on weedy rice plants that are taller than the cultivated rice.

Clearfield[®] technology was launched in 2006 in Italy and it is nowadays available also in Spain, Greece, Portugal and Romania (not in France). It allows to control weedy rice and other weeds in crop post-emergence in IMI-tolerant rice varieties (CL varieties). According to the stewardships guidelines provided by the owner of this technology (BASF) Clearfield[®] rice varieties cannot be used in the same field for more than two consecutive years.

Notwithstanding the fact that populations of weedy rice tolerant to imidazolinone herbicides have been recently reported in Italy (Busconi et al., 2012; Scarabel et al., 2012), Clearfield[®] is still an effective technology and the area cultivated with CL varieties is still growing. In the entire EU and in Italy only, CL varieties are cultivated on about 20% and 34% of total rice acreage, respectively.



(C) HETERANTHERA SPP.

Heteranthera reniformis Ruiz et Pavon, *H. rotundifolia* (Kunth) Griseb. and *H. limosa* (Sw.) Willd. are the main species spread in Italy. *Heteranthera* infestations are usually controlled with the residual herbicide oxadiazon applied in pre-sowing, which is the key herbicide for the control of these weeds. Future availability of this molecule is uncertain due to environmental concerns and some restrictions on its use are already in force.

(D) CYPERACEAE AND ALISMATACEAE SPECIES

The main species of this group are the sedges *Cyperus difformis* L., *Bolboschoenus maritimus* (L.) Palla and *Schoenoplectus mucronatus* (L.) and the water plantains *Alisma plantago-aquatica* L. and *A. lanceolatum* With.

These species could be considered a functional agronomic group as a whole, as they are often controlled by the same herbicides. The most common herbicides used against them are sulfonylureas as bensulfuron (alone or in combination with metsulfuron), ethoxysulfuron, azimsulfuron, or other herbicides as MCPA, and triclopyr.



The repeated application of ALS-inhibitor herbicides resulted in the evolution of resistance to these herbicides in populations of *A. plantago-aquatica*, *S. mucronatus* and *C. difformis*. Herbicide resistance within this group of weeds is now an important issue in almost all European rice countries.

(E) WEEDS OF DRILL-SEEDED FIELDS

About 40% of Italian rice is now planted in dry soil, and in certain provinces with sand soils this technique is applied on around 64% of the area (ENR, 2015). In this cropping system, two different weed communities can be found. The first develops during the first part of crop growing (from seeding to beginning tillering) and is represented by weeds typical of summer-annual non-flooded crops, such as *Echinochloa* spp., *Panicum dichotomiflorum* Michx., *Bidens* spp., *Digitaria sanguinalis* (L.) Scop., *Polygonum* spp., *Chenopodium album* L. and *Amaranthus retroflexus* L.. A second weed community appears when flooding conditions are created and maintained (from tillering to harvesting) and includes the same aquatic or semi-aquatic species previously described.



MANAGEMENT OF WEED SEED BANK

No matter how well is spontaneous vegetation managed, weed pressure in EU rice is always an issue. Compared to other cropping systems, weed management in rice is usually considered much more challenging. Many factors are responsible of this condition. One of the most important is the absence of crop rotation, that characterizes a large part of EU rice system. This determines the development of a weed flora which is highly-specialized and well adapted to water environment and its pressure cannot be reduced by an appropriate weed management within a crop rotation.

Moreover, the dynamics of seed bank for certain key weeds can be significantly affected by external inputs, in addition to seed rain that occurs from plants growing within the crop. This is, for example, the case of weedy rice: in the EU legislation, it is allowed the presence of some red grains in the commercial lot of rice seed and the seed sector is sometime reluctant to provide lots guarantee free from weedy rice grains. First attempts for developing a rice seed production chain free from weedy rice have been started in the 2017 season, by testing the seeding of dehulled rice in which red grains have been removed by using optical separators (see <http://www.risoitaliano.eu/sotto-il-vestito-niente-crodo/> , in Italian).



More in general, seed bank management is perceived as a cornerstone of weed management in rice only when conventional weed control programs are faulty, poorly effective or cannot be applied for some reason. This may occur, for example, in cases like these: 1) a particular species difficult to be controlled; 2) occurrence of herbicide resistance; 3) particular rice cropping systems, such as organic rice cultivation.

Case 1) can be represented, again, by weedy rice. As a consequence of the difficulties of its control, a combination of preventive, agronomic and mechanical means has been developed during the last decades in order to reduce as much as possible seed bank growth. In particular, in few years of 1990s EU rice growers largely accepted the importance of keeping weedy rice seed bank at minimum, by fine tuning for example, the use of stale seed bed technique, differentiating the tillage system adopted as function of seed bank size. Even though the use of Clearfield[®] technology is considered as one of the most effective methods for weedy rice control, stale seed bed is still largely adopted, also because it can play a role in the management of herbicide-resistant weeds.

Winter flooding has also been applied in some cases. It proved to be effective in lowering the amount of superficial seed bank by promoting suicidal germination of weed seeds produced during the last growing season.



Organic rice is still a niche (in Italy it represents about 5% of total rice), but it is capturing the attention of many growers because of the higher selling price of paddy (from 2 to 3 times the conventional one). In the last two-three growing seasons many alternative non-chemical techniques are tested by research institutions and individual farmers. One of the techniques under evaluation is the use of mulching with biodegradable films, coupled or not with the use of surface or subsurface drip irrigation. Another approach is the use of green mulching (usually with Italian ryegrass, triticale, vetch or mixtures of these and other species), terminated with roller crimper before flooding, with rice broadcast seeded immediately before green mulching termination.

More recently, also mechanical transplanting is under evaluation. The technique still needs to be optimized, as at present a major weakness is still the mechanical control of weeds, but it seems to be promising for organic cultivation. In particular, transplanting may facilitate seed bank management: by delaying occupation of the field by rice, it is possible, before transplanting, to grow a cover crop and then to perform a false seeding, or to perform to cycles of false seeding, thus contributing to lowering the seed bank.



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