# Rice cultivation in Italy under the threat of climatic change: Trends, technologies and research gaps

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REVIEW ARTICLE

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# Rice cultivation in Italy under the threat of climatic change: Trends, technologies and research gaps*

**Marco Arcieri** | **Graziano Ghinassi**

Comitato Nazionale Italiano ICID (ITAL-ICID), Ministero delle Politiche Agricole, Alimentari e Forestali, Rome, Italy

**Correspondence**
Dr. Marco Arcieri, Secretary General, Comitato Nazionale Italiano ICID (ITAL-ICID), C/o Ministero del l'Agricultura e delle Foreste, Via XX Settembre, 20 00187 Rome, Italy.
Email: m.arcieri@icid.org

**Abstract**

Italy is the largest rice-producing country in the European Union: more than two-thirds of Europe's rice with about 60% of the national production exported, mainly to Mediterranean countries and Eastern Europe. Rice production started around the middle of the fifteenth century, influencing Italian distinguished cuisine. Specialized cultivation is higly skilled and accounts for 70–80% of the global rice farming surface. The crop is grown from April to October and extends over about 240 000 ha (1.4% of the total arable area of the country). The expected production is approximately 1.4 million tonnes (MT) of paddy rice; average yield is about 6 t $ha^{-1}$, 85% of the surface being cropped with *Japonica*-type varieties, the rest with *Thaibonnet*. In last 20 years, the cultivation area has increased by about 20%, making Italy an important rice-exporting country, as the volume of exports reached 5% of total rice traded in the world and domestic consumption hardly exceeds 40% of total production. The main constraints in Italy are low temperature (at sowing and flowering time), diseases, weeds and red rice. Recent research has proved that the possibility exists to increase potential yield by means of varietal improvement, with emphasis on disease and lodging resistance, and better low-temperature and dry-conditions adaptability.

**KEYWORDS**

Italy, climate change, rice

**Résumé**

L'Italie est le plus grand pays producteur de riz de l'Union européenne: plus des 2/3 du riz européen avec environ 60% de la production nationale exportée, principalement vers la Méditerranée et l'Europe de l'Est. La production de riz a commencé vers le milieu du XVe siècle, influençant la cuisine italienne distinguée. La culture est hautement spécialisée et représente 70 à 80% de la surface rizicole. La culture est cultivée d'avril à octobre et s'étend sur environ 240 000 ha (1.4% de la superficie totale arable du pays). La production attendue est d'environ 1.4 million de tonnes de riz paddy, le rendement moyen est d'environ 6 tonnes par ha, 85% de la surface étant cultivée avec des variétés de

*La culture du riz en Italie sous la menace du changement climatique: tendances, technologies et lacunes dans la recherché.

  

type Japonica, le reste avec Thaibonnet. Au cours des vingt dernières années, la superficie cultivée a augmenté d'environ 20%, faisant de l'Italie un important pays exportateur de riz, car le volume des exportations atteint 5% du total du riz commercialisé dans le monde et la consommation intérieure ne dépasse guère 40% de la production totale. Les principales contraintes en Italie sont les basses températures (semis et floraison), les maladies, les mauvaises herbes et le riz rouge. Des recherches récentes ont prouvé qu'il est possible d'augmenter le rendement potentiel au moyen d'une amélioration variétale, en mettant l'accent sur la résistance aux maladies et à la verse, une meilleure adaptabilité à basse température et dans des conditions sèches.

**MOTS CLÉS**
riz, Italie, changement climatique

## 1 | INTRODUCTION: WHERE DID RICE COME FROM?

The exact origin of rice is not well known. However, domestication of rice is one of the most important achievements of mankind in history (Figure 1), as it has probably fed more people in the world over a longer period than any other crop. Several theories state that the plant could have originated on the slopes of the Himalayas, on the island of Java or in the area of the Cambodian lakes, between 15 000 and 8000 years ago. Excavations have also shown that in China, around 7000 years ago, rice was cropped and consumed. Fossil remains found in the valley of the Yangtze River confirm that 3000–4000 years ago in that region rice fields were already a reality. Successive finds found in India show that around 1000 BC the local populations consumed rice.

From the Far East rice cultivation began spreading west, arriving after millennia in Mesopotamia, where it was cultivated in the fourth century BC. It is undoubtedly the Greeks who made rice known to the West; it arrived in Europe as a staple food for soldiers, after the expeditions throughout Asia by Alexander the Great (Figure 2). As Plinius writes in the *Naturalis Historia*, this cereal is also well known to the Romans, even though it was only considered a healing plant at the time.

The well-known poet Horace, for instance, in a famous satire tells us of a doctor who prescribed a tea made out of rice.

The first information on the rice trade dates back to the first century. From Palestine, from the West Bank and from Syria rice cultivation reached Egypt, probably introduced by Indian populations and subsequently cultivated by the Arabs. The Arabs also introduced rice cultivation in Algeria and in Senegal, from where it expanded into the western part of the African continent. On the

**FIGURE 1** The discovery of agriculture [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 2** Alexander the Great. Ancient Roman floor mosaic from the House of the Faun in Pompeii showing Alexander fighting King Darius III of Persia in the Battle of Issus (*c*.100 BC) [Colour figure can be viewed at wileyonlinelibrary.com]

northern part of the Mediterranean, rice reached the coasts of Spain and from there it was introduced to Sicily, where many Arab books describe in minute detail the various growing phases of the crop (Figure 3).

Thus from Greeks to Romans, throughout the Arab domination and the later medieval times, until the Renaissance period, rice is only referred to as a spice, as a medicament for different kind of pathologies or just for cosmetic purposes. An account of the expenditure of the Duke of Savoy dating back to 1300 records the purchase of rice for sweet making, whilst an edict of 1340 from the city of Milan reports the tax to be paid on rice as spice that comes from Asia, via Greece. Still in 1371, rice is considered a spice and is called overseas rice or Spanish rice.

Rice experienced a real diffusion in Europe only from the Middle Ages, also as the result of the intense labour of hard-working monks' communities (Figure 4). In Italy peasants in the Middle Ages learnt from these monks the art of irrigation and land reclamation, thus greatly contributing to its widespread diffusion among the first forms of communes. It is only between the fifteenth and the sixteenth centuries that the cultivation of rice finally took place, improving the nutrition and quality of life of European people. In many states, crops were protected by appropriate measures so that the seed was not to be exported. In 1567 at the Antwerp market in Belgium, for instance, rice was equated with exchange items such as precious fabrics and weapons. In 1492 the course of human civilization changed, following the discovery of the New World by Christopher Columbus; with him and his contribution to the history of navigation, the world suddenly became smaller and the modern age began. If the Americas are, nowadays, what we do know, this is solely thanks to his intuition and courage. In 1690, following the first settlers, rice arrived in USA, particularly in the Carolina State area, where environmental conditions turned out to be favourable for production, thus enabling its expansion throughout the American continent.

In Italy rice cultivation effectively developed at the end of fifteenth century, where the first paddy field was

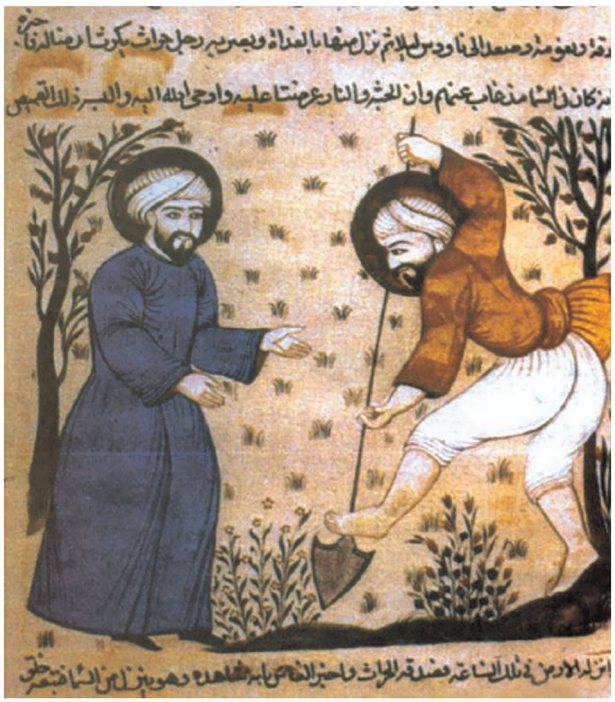

**FIGURE 3** *Book on Agriculture*. Abu Zakariya Ibn al-Awwam. Seville, Spain twelfth century [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 4** *Bernhard Altar, Scenes from the Life of Saint Bernard*. Jörg Breu the Elder, 1500 [Colour figure can be viewed at wileyonlinelibrary.com]

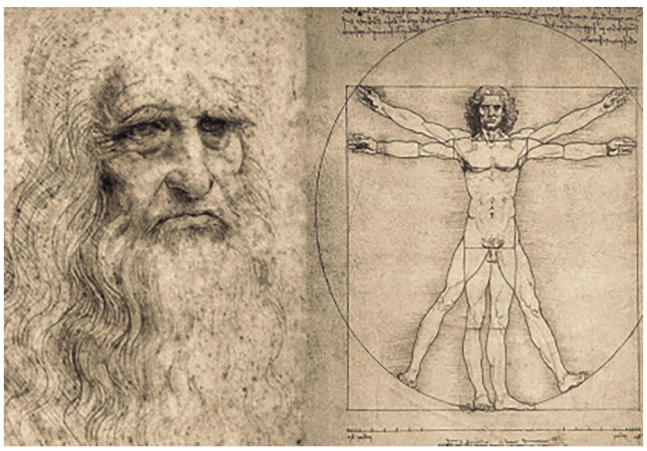

**FIGURE 5** *The Vitruvian Man*. Leonardo da Vinci, 1490 [Colour figure can be viewed at wileyonlinelibrary.com]

established in 1468 by Leonardo Colto de 'Colti in the Florence Duchy. In 1475, two letters by Duke Galeazzo Maria Sforza report authorization to export 12 bags of sowing rice from Milan to Ferrara in northern Italy. In this letter, he donated to the Duke of Ferrara seeds which he defined in a letter as extremely interesting and deserving to be cultivated. It is after the brilliant intuition of the dukes of Sforza in Mantova, northern Italy, that rice cultivation developed at the end of the fifteenth century, where modern paddy fields were established. Galeazzo Maria and his brother Ludovico Sforza thought to exploit the frequent flooding of the Po River that occurred at the time. But floods, at that time, also meant death and destruction. Leonardo da Vinci is known worldwide for his contribution to the progress of science (Figure 5). In the history of Italian rice growing, his contribution to the conception and realization of gates and canal locks in order to drain the marshlands of the Po River plains during the fifteenth century is considered priceless (Figure 6).

In modern times, another important man has to be remembered for the most important irrigation network that made rice cultivation possible: Camillo Cavour (Figure 7). In the late nineteenth century he championed the construction of an 83-km long canal that brought water from the Po River and Lake Maggiore to support agriculture in Vercelli, Alessandria, Pavia and Novara provinces. The canal is now called the Canale Cavour. The canal was a real challenge for master craftsmen at the time, being completed in only 3 years, and it led to a significant improvement of agricultural and, thus, economic conditions for the area.

**FIGURE 6** *Canal Gate Lock on the Adda River*. Leonardo da Vinci, fifteenth century [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 7** Count Camillo Benso di Cavour [Colour figure can be viewed at wileyonlinelibrary.com]

## 2 | RICE CULTIVATION IN ITALY

In Italy rice cultivation is practised where irrigation water is available in huge amounts and is characterized by low price, since natural precipitation is usually not sufficient (Maggiore, 2017). Production is mostly located in north-west part of Italy, the largest rice-producing areas being the Lombardy and Piedmont regions, even though important areas of production have subsequently developed in southern Italian regions, such as Calabria and the island of Sardinia (Figure 8). Italian paddy

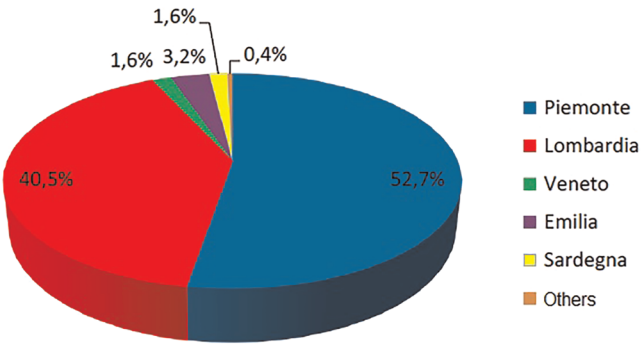


**FIGURE 8** Regional distribution of paddy fields in Italy (source: Ente Nazionale Risi, modif., 2014) [Colour figure can be viewed at wileyonlinelibrary.com]

systems are located in the most northern latitudes, where water plays the fundamental role of thermoregulation as well as irrigation. Because of the flooding, daily temperature variations of 10–15 °C are lowered to 3–4 °C. The flooding technique for paddy irrigation is practised over 10% of the total national irrigated area (2.48 Mha (million hectares)). The basic condition is to maintain a water depth of about 0.1–0.3 m above the soil surface.

The areas where Italian paddy systems are located have different soil types with different hydrological characteristics. Therefore, significant differences in terms of annual water depths due to different soil types characterize rice cultivation in different Italian regions (Figure 9). Irrigation volumes may range between 13,000 and 65,000 $m^3$/ha during the average 5 months growing season. As a consequence, the extent and management of paddy rice cultivation affect irrigation water use at the regional level both as average volume per hectare and as a percentage of the national total (Figure 9).

Most paddy rice cultivation is located in the Padana (Po River) Plain, between the alpine lakes and the left bank of the Po River. Here, water supplied to irrigated fields is mostly taken from the so-called *risorgive* springs and, to a smaller extent, from alpine rivers. The term *risorgiva* applies to the outflow of natural groundwater that occurs where hillslopes meet the plain (Figure 10).

The average temperature of water from the springs is between 10 and 14 °C all year round. This characteristic makes possible the reduction of both maximum and minimum peak temperatures, in this way keeping the climate quite constant; this is a very important situation from the ecological perspective, since microclimatic conditions have positive effects on both vegetal and animal populations, in addition to maintaining biodiversity. Water springing from *risorgive* is naturally filtered, therefore it is clear and pollutant free. On the other hand, water from western alpine rivers is colder, especially during the ice cap melting in spring. The use of this water in paddy systems requires some temperature increase before field application. Water heating occurs prior to the field inlet, in a small area called a *caldane* (Figure 21), where water movement is directed through a long route according to a comb-shaped flow. Field size depends on different factors, amongst which soil type, topography and land texture. These features thus characterize paddy rice systems both in the western and in the eastern part of the Padana Plain.

In the western part (i.e. Piedmont and Lombardy), the average size of the cropping units is about 2–3 ha, due to ground slope and soil permeability (Figure 11). In

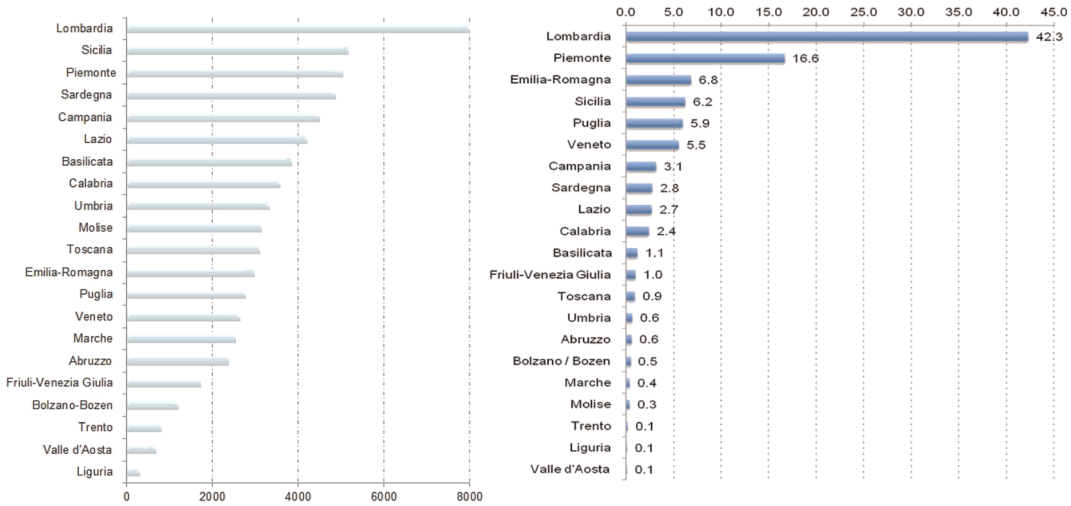


**FIGURE 9** Left: Regional average irrigation supply ($m^3$ $ha^{-1}$). Right: Incidence of irrigation in different regions of Italy, expressed as a percentage over the total. (%)
(source: Istituto Nazionale di Statistica ISTAT, 6th General Census of Agriculture, 2012) [Colour figure can be viewed at wileyonlinelibrary.com]

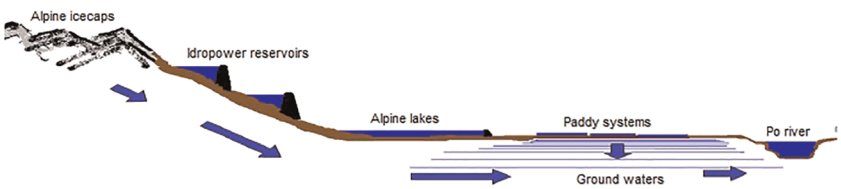


**FIGURE 10** Paddy systems within the terrestrial water cycle; downstream the '*risorgive* belt', north of the Po River
(source: Ente Nazionale Risi, modif., 2014)
[Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 11** Paddy fields in the western Padana Plain [Colour figure can be viewed at wileyonlinelibrary.com]

the eastern part (i.e. Veneto and Emilia Romagna), where the ground is flat and soil permeability is lower, plot size is about 10–12 ha on average.

Rice cultivation in Italy is mostly located in the northern regions of the Po River valley (Piemonte, Lombardia, Emilia-Romagna, Veneto) covering about 240 000 ha, which represents 1.4% of the total arable area (16 800 000 ha). Small areas are cropped in Sardinia and in southern Italy as well (Sibari Plain). Highly specialized cultivation represents 70–80% of the total rice farming surface, although in the last years soybean and maize have been successfully and increasingly grown as annual rotation crops in rice fields. Usual production is approximately 1.5 MT of paddy rice, whereas the average yield is about 6–7 t $ha^{-1}$ (Russo and Callegarin, 1997).

As can be seen in Figure 12, the production area is mainly characterized by the adoption of flooding and flow irrigation methods. After a reduction in the second half of the 1990's, the cropping area has continuously been increasing in the recent years, since year 2000 and until 2010. Trends show a steady reduction of the number of farms, whereas an increase in the extension of each farm has been witnessed. The increase witnessed in the cultivated area, about 20% during the past 10 years and until 2010, has exerted very positive effects on Italian economy as it enabled export of more than 60% of its production. These exports have greatly counterbalanced imports of large quantities of food and feed products coming into Italy.

Because of this, Italy has become an important rice-exporting country, especially considering that its domestic consumption hardly exceeds 40% of total rice production. As a matter of fact, Italians do not eat much rice (about 8.5 kg $person^{-1}$), but nevertheless this crop has always had a major role in Italian culture. Rice is thrown on newlyweds when they leave the church as a sign of good luck and prosperity, and a very common saying in Italy is: 'Rice is born in water, but dies in wine.' The famous poet Giovanni Pascoli composed a poem about a rice dish, whilst celebrated composer Gioacchino Rossini wrote a famous aria in his opera *Tancredi*, while waiting for a risotto.

Italy is famous worldwide for its exquisite dish risotto. A number of rice varieties have been developed for this purpose, such as Arborio cv. and Carnaroli cv. (*Oryza sativa* L., ssp. Japonica). The most famous Italian rice dish is *risotto alla Milanese* (Figure 13).

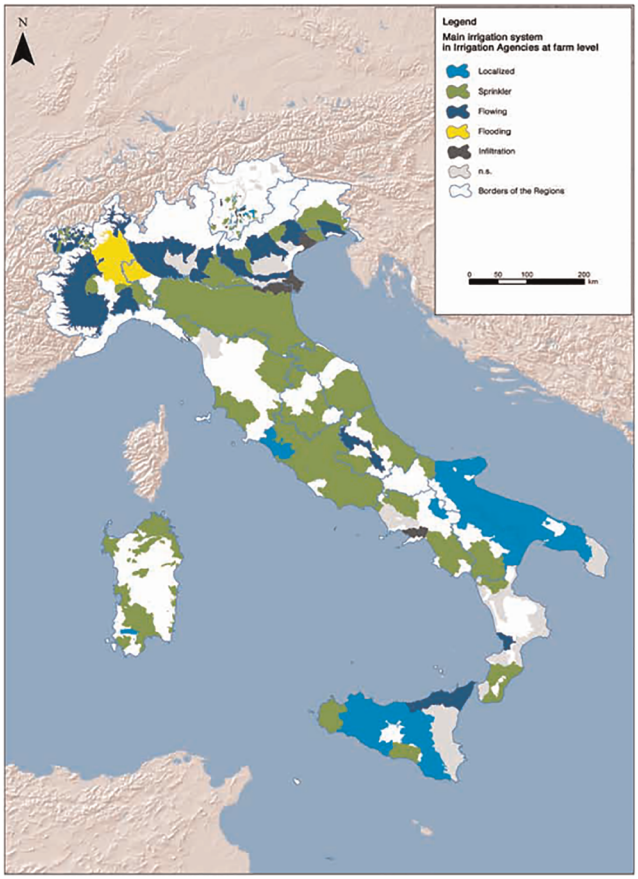


**FIGURE 12** Irrigation systems in Italy (Istituto Nazionale di Economia Agraria (INEA), 2011) [Colour figure can be viewed at wileyonlinelibrary.com]

According to tradition, the dish was created during the construction of the famous Milan Cathedral Duomo, at the beginning of the fifteenth century (Figure 14).

As a matter of fact, saffron spice was used at the time to colour the stained glass windows of the cathedral (Figure 15), and was added to a rice dish only as a joke... It turned out to be delicious.

In Italy, rice is a typical spring–summer crop (Figure 16). The usual crop rotation is maize, beet and other vegetables. After growing these crops, soil is readily available for cultivation, as the necessary tillage operations required remove weeds of other crops. Repeated cropping is possible, in order to cut down the expensive

**FIGURE 13** *Risotto alla Milanese* [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 14** Duomo cathedral. Milan, fifteenth century [Colour figure can be viewed at wileyonlinelibrary.com]

costs required for soil preparation, but not more than for 5–6 years in a row since it might create weed problems. Attention needs to be paid after fodder crops, because of possible excessive organic substances (harmful fermentation).

## 3 | PREPARATION OF THE PADDY FIELD

Rice in Italy is grown from April to October (Baldoni & Giardini, 2001). At the end of winter a surface light ploughing (20–25 cm) is carried out with mould-board plough. This can eventually be replaced by hoeing or digging on light, organic soils, in order to proceed to fertilization. Just before sowing there can be a light tillage, organic harrowing and a surface flattening (with laser system), in order to obtain well-levelled fields, surrounded by embankments and served by a network of supply canals and drains (Figure 17). Annual maintenance of canals, drains and embankments is quite expensive. In certain periods alternating drying and submerging is needed, providing continuous changes to the $H_2O$ level. Usually rice is grown in shallow water (10–30 cm), depending on the height of rice and weeds. There is a constant need to keep running water, because of the high demand for $O_2$ of seedlings and roots and, of course, to have an efficient thermoregulation, avoiding the use of cold water (Baldoni & Giardini, 2001).

### 3.1 | Sowing

Transplanting was once widespread in Italy (today it is only in tropical countries), especially to shorten the cycle

**FIGURE 15** Duomo cathedral stained glass. Milan, fifteenth century [Colour figure can be viewed at wileyonlinelibrary.com]

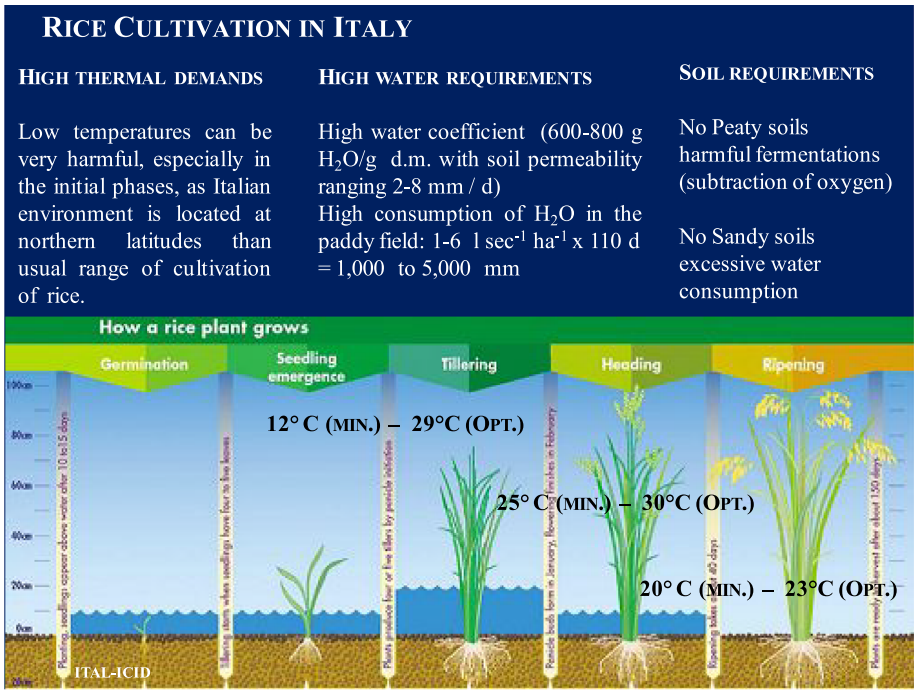


**FIGURE 16** Development stages of the rice plant. (source: Haifa, crop guide: Rice cultivation) [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 17** Preparation of the paddy field [Colour figure can be viewed at wileyonlinelibrary.com]

in cold environments, but it required a lot of manpower. Seedlings produced in nurseries (1500 $m^{-2}$, 1/10 final surface) are transplanted at about 15 cm in height and with 8–10 plants $hole^{-1}$. Today direct sowing is by far the most frequently used technique (Figure 18). It is carried out by means of:

- *broadcast seeding* on flooded rice paddy, usually with fertilizer spreader (with two impellers for better uniformity);
- *seeding in rows* on dry rice paddy, to be submerged after emergence, 65 cm between the rows. Usually 140–200 kg $ha^{-1}$ of seed are deployed—250–400 panicles $m^{-2}$.

Early sowing is better for late ripening cvs, but it can be risky for cvs with high thermal requirements (ssp. *indica*).

## 3.2 | Water management

Rice is a highly water-demanding plant. Its cultivation requires a great availability of resources, as their lack can

(a) (b)

**FIGURE 18** (a) Broadcast seeding, (b) seeding in rows [Colour figure can be viewed at wileyonlinelibrary.com]

affect the normal growth of the crop, affecting yields in the final production. Traditional cultivation techniques, such as the submersion system in lowland paddy fields, require high volumes of water, ranging on average between 15 000 and 20 000 $m^3$ $ha^{-1}$, depending on the season (Figure 19).

But even though it is usually grown as a submerged crop, it is not necessarily linked to this condition (Baldoni, 2008). After emergence, at least three dry cycles are usually performed (Figure 20):

1 *Rooting* (with 2–3 leaves)— occurs at the middle of June;
2 *Fertilization and weeding*—at the end of June;
3 *Before harvesting (ripening)*—that is, at the end of August or September, according to the growing area.

Water comes from collective irrigation systems, wells, springs or rivers. The level is continuously adjusted, according to the thermal demands of the plant, but also to avoid incidence of pests and weeds. Water temperature has to be kept between 12 and 14 °C (April–May in northern Italy). Before entering rice fields, it is heated by means of *caldane* (Figure 21), winding canal pathways exposed to the sun and designed to warm up water.

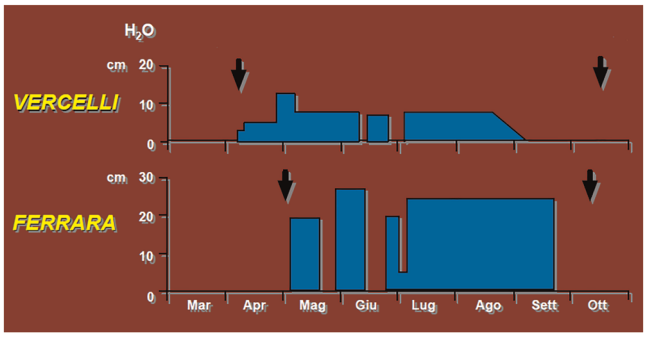


**FIGURE 20** Water management for rice cultivation in Italy (Baldoni, 2008) [Colour figure can be viewed at wileyonlinelibrary.com]

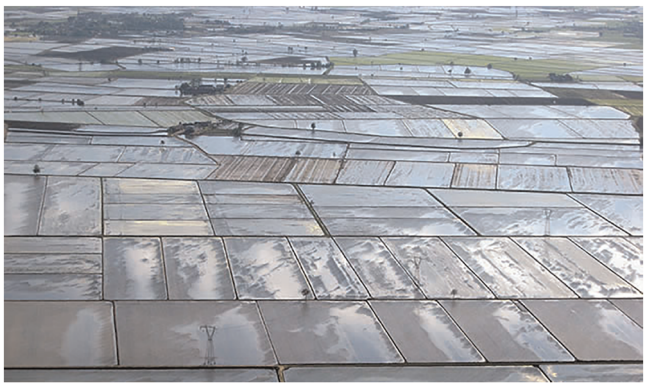

**FIGURE 21** Typical *caldane* pathways in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

## 4 | HARVESTING

Harvesting period in Italy can be classified thus:

Early cvs: Mid of September;
Late cvs: Mid of October.

Yields usually range between 6 and 6.5 t $ha^{-1}$ of paddy rice with 13% humidity, which is higher than the world average (4.0 t $ha^{-1}$) and higher than wheat (milled rice yield is 55%). In dry paddy fields (about 2 weeks before harvest), harvesting is carried out with a 23–25% level of moisture, whilst a drying process (to 13–14% of humidity) takes place in dryers at 35–40 °C. In some areas of the country manual harvesting and grain separation can still be found, but in specialized areas it is usually carried out by means of half-track or normal

**FIGURE 19** Typical landscape of rice cultivation in Italy [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 22** Rice harvesting in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

combines (Figure 22), with a 3–5 m working bar and a labour capacity of 1 h $ha^{-1}$.

## 4.1 | Weed management

Localization of the cultivation of rice (north-west of the Po Valley) has always been linked to high water availability, thus weed management has always been a major issue.

Today weeding is 100% chemical (Figure 23), with at least two products used. This of course makes for:

- very high chemical inputs;
- very high costs.

In the past (1950–1960s) it used to be carried out by hand, but it can be easily imagined that this was very demanding in terms of labour, requiring up to about 350 h $ha^{-1}$of work, thus in time becoming economically unsustainable.

## 4.2 | Main constraints

Main problems for the cultivation of rice in Italy are:

- *climate.* It remains the most limiting factor considering that the rice area is mostly located in northern Italy (>45° N). Cold temperatures (5 °C or less) can occur at sowing time (in April), causing damage to seedlings and poor establishment in rice fields (Figure 24).

Moreover, a sudden decrease of temperature or strong diurnal variations can occur at flowering time, because of thunderstorms in August (Figure 25), causing spikelet sterility and/or more favourable conditions for blast attacks. In recent years, tornadoes and strong winds during the ripening stage have caused severe lodging of the tallest varieties;

**FIGURE 23** Weed management in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 24** Typical frost event in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 25** Typical wind and rainstorm event in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

- *diseases.* Blast and brown spot are at present the main diseases, but they rarely cause great damage to the crop, depending on climatic conditions;
- *weed populations* remain one of the main limiting factors for rice production in conditions of intensive cultivation;
- *others.* Red rice has become a main constraint in the last years as it remains in the soil, especially in the case of monoculture.

## 4.3 | Key challenges

The key challenges for the cultivation of rice in Italy are:

- improving the quality of national production in order to adequately meet requirements of a fast-growing changing market (Figure 26).

**FIGURE 26** Italian rice ready to be commercialized [Colour figure can be viewed at wileyonlinelibrary.com]

- raising rice productivity, thus making farming profitable, globally competitive and climate-resilient with the crop, by producing more with less resources (Figure 27).
- coping with growing costs of agricultural inputs and declining real farm incomes, due to the instability of prices;
- increasing global competitiveness under liberalized trade conditions;
- improving small farm production efficiency by promoting ecosystem-based agriculture, within the context of sustainable intensification and climate change (Figure 28).

## 4.4 | Key issues

The key issues for the cultivation of rice in Italy are:

- increased severity and frequency of extreme weather events, such as intense thunderstorms and recently, strong tornadoes (Figure 29).

- far more frequently recurring high temperatures, which raise incidences of drought, pests and disease (Figure 30).

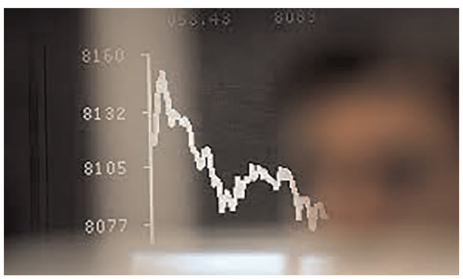


**FIGURE 27** Stock exchange fluctuations [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 28** Typical rice crop landscape [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 29** Tornado phenomena have occurred recently in Italy [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 30** Drought events have also occurred recently in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

- growing proportions of rice-cultivated areas are drought-prone, while intense urbanization is diverting irrigation water to domestic use;

- water scarcity, especially, which has become a serious production constraint in northern Italy, as almost 60% of fresh water flows directly to rice paddies (Figure 31).

Management practices to take into account:

- alternative agricultural practices to improve soil fertility;
- multi-cropping rotations (rice–vegetables);
- soil sampling/analysis and site-specific nutrient management;
- balanced fertilization and use of organic fertilizers;
- thorough land preparation and land levelling;
- integrated pest management or IPM;
- harvest and post-harvest management;
- proper agricultural water management for efficient water use and conservation: intermittent flooding and alternate wet/dry water-saving techniques;
- farming system diversification in order to achieve increased farm incomes, improved family nutrition and enhanced climate resilience;
- development and diffusion of agricultural technologies capable of enhancing better farmer access to irrigation scheduling by means of efficient agricultural advisory and information systems;
- improve market efficiency through post-harvest facilities and farm-level and value-chain infrastructure.

## 5 | THE WAY AHEAD: DRY CULTIVATION AND ORGANIC RICE

Climate change and price unpredictability represent severe challenges for Italian producers and agricultural companies, forced to adapt their production processes to the needs of the globalized world (Mayer *et al.,* 2019). At present, no increase of the rice cultivation area in Italy is expected in the near future, whereas, in contrast, a decrease might probably occur if the rice price goes down, or production is affected by globalization dynamics (Venturini, 2016). Thus, increase of rice yield can generally be expected by means of the introduction of new varieties with improved traits, such as disease resistance or tolerance, salinity and low temperature tolerance, reduced culm length and lodging resistance or, also, the adoption of new cultivation techniques and water resources management systems (Gulab *et al.,* 2015). This is why, in recent years, Italian rice cultivation has been going through a phase of great transformation, given the diffusion of alternative forms to traditional cultivation. One of these is dry cultivation.

**FIGURE 31** Water scarcity is becoming a serious threat to agriculture in northern Italy [Colour figure can be viewed at wileyonlinelibrary.com]

### 5.1 | Dry cultivation

The development of rice cultivars with improved tolerance to cultivation under reduced water regimes (upland like), with turned irrigation, today offers very interesting perspectives and represents a major objective of research in order to save water (Cavigiolo *et al.,* 2007). As a matter of fact, the repeated occurrence of particularly dry weather conditions in recent years has created conditions of water scarcity in northern Italy, with serious consequences for yields of the main irrigated crops, such as rice. Sowing is carried out on dry soil, burying the seed at a 2–3 cm depth. Water requirements are postponed for about 30–45 days. After this phase the cultivation remains flooded and water management is very similar to a traditional paddy field.

The advantages of practising dry seeding can be defined thus:

- less water (20% is required compared to conventional seeding);
- less emission in the atmosphere of combined water vapour and gases caused by fermentation;
- fewer mosquitoes and similar insects, thus less herbicide in the ground;
- less nitrates and lower maintenance of embankments.

This practice guarantees a favourable environmental impact because of reduced water requirements, less energy demand and lower incidence of weeds to fight against. Under this water regime it was established that plants received one-fifth of the total water volume needed for conventional culture in submersion. A very interesting example of this possible new approach in research has been the CEDROME project (INCO-2005-015468), which

has been conceived in order to 'Develop drought-resistant cereals to support efficient water management in the Mediterranean area'. It has been funded by the European Commission and coordinated by the University of Leiden, in the Netherlands. Within the framework of this project, an assessment of seven Italian rice cultivars for their main agronomic, quality and phytosanitary traits has been performed in a 2-year field trial, comparing conventional agro-systems with the upland similar (Figure 32).

**FIGURE 32** Experimental site of the CEDROME project (Greppi *et al.,* 2007) [Colour figure can be viewed at wileyonlinelibrary.com]

At the end of the experiment, it was observed that water shortage caused a yield reduction of 40% on average, as a result of a decrease in the 1000 seed weight, tiller density and panicle sterility. However, amongst all the others, three cultivars showed a markedly good performance under water stress: cv. Eurosis, SIS R215 and Augusto showed very interesting yield and milling results with new given conditions, reaching values of about 80% of yield when compared to conventional culture, with highest values of water productivity. Moreover, optical microscope analysis of the root system of plants under a reduced water regime has highlighted a significant difference in the two growing conditions. Roots grown in submergence showed a total absence of fungal colonization, as compared to those in conditions of dryness. On the other hand, dryland conditions stimulated in rice roots a natural colonization with arbuscular mycorrhizal (AM) fungi, which are well known to play a beneficial role in the general physiology of the plant (Figure 33).

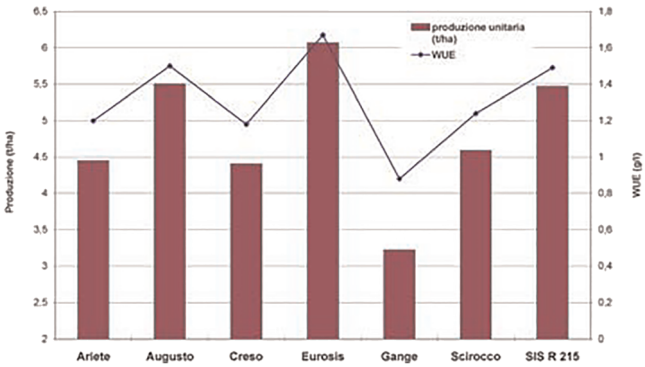


**FIGURE 33** Yield pattern and water use efficiency of cvs cropped under water-stress conditions (Greppi *et al*., 2007) [Colour figure can be viewed at wileyonlinelibrary.com]

## 5.2 | Organic rice

Organic farming continues its double-digit growth trend: in 2016 it increased food sales by 20%. As recent market research has highlighted, there is a growing attention by consumers to food on the table: they want to know about the properties of raw materials, their origin, if they are obtained as a result of sustainable production that respects the environment. Behind this desire for traceability there is an increase in the demand for organic food products, safe from a human food point of view, but also respectful of the environment. Recently, India, Pakistan and Thailand competed together with the export of almost all organic rice to Italy, with an increase of 38%

(a) (b)

**FIGURE 34** (a) Mulching of rice seedlings by biodegradable material, (b) organic rice cultivation [Colour figure can be viewed at wileyonlinelibrary.com]

in the few past years. So in recent years, many Italian companies have introduced alternative techniques such as mulching, historically used to grow vegetables, in rice cultivation. This has been possible with the creation of biodegradable sheets, made of organic material, such as potatoes and corn (Figure 34 (a)). Films are laid out in paddy fields to prevent weed growth, without using chemical products. Mulch is provided by a special machine which spreads the sheets, creating at the same time special holes where rice seeds are released. Rice seedlings are thus able to grow, while weeds remain suffocated under the covering film, which does not allow light to filter. Mulched rice cultivation, with its 12,500 ha, only represents 6% of the area cultivated with organic rice, but about a quarter of the land is now under conversion. In the next few years, mulching will cover about 10% of the organic rice area in Italy: it still represents just a niche at national level, but depicts a future aimed at environmental sustainability and a quality product (Figure 34 (b)).

## 6 | CONCLUSIONS

The increasing awareness regarding present unsustainable agricultural methods and cultivation techniques, coupled with the ineluctability of climate change, have recently been fostering new research programmes, focused on breeding for yield stability and grain quality, for cold and disease resistance as well as for salt tolerance, as well as the introduction of new weed control techniques, biotechnologies (anther culture, transformation) and innovative forms of managing the crop such as precision agriculture (Sacco and Romani, 2015). The encouraging results obtained might well lead the way to unprecedented levels of production for Italian rice, bringing higher resilience to this crop's cultivation, especially considering the quality and quantity of grains. In addition, research experiences on different strategies of water management to reduce the depth of the water table at the beginning of the irrigation season (i.e. winter flooding) are still in progress (Miniotti *et al.,* 2016). The aim is to reduce the volumes of irrigation water in order to cope with increasing variability in distribution and uncertainty of water availability. First results seem to be quite encouraging, as well as the general attitude towards the water problems around the management of paddy rice areas. After centuries of activity, the agrarian landscape of paddy rice cultivation has definitely been modelled and characterized, assigning to that land a cultural role of great importance within the context of national heritage. Looking at the future, some degree of optimism can be realistic, despite the criticalities of climate change.

**ORCID**

*Marco Arcieri* https://orcid.org/0000-0001-9771-6571

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