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The evolution of cereal yields in Italy over the last 150 years: The peculiar case of rice

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Abstract

This study examined Italian yields for wheat (*Triticum* spp.), maize (*Zea mays* L.), and rice (*Oryza sativa* L.) over the period 1870–2018, in order to identify the periods when the most significant growth in yields occurred, compared to France, United Kingdom, and United States. From 1870 to 2018, yields in Italy increased by 347, 865, and 178% for wheat, maize, and rice, respectively. In wheat and maize, 84 and 95% of the increase, respectively, occurred since the end of World War II. Similar trends can also be observed in France, United Kingdom, and the United States. However the timing is slightly different. For wheat and maize in the United States, rapid yield growth occurred during the 1930s, whereas wheat yield growth occurred in the United Kindom during the 1940s, and in France yield growth occurred after World War II. The significant post-war trend of increasing yields in Italy, which is still going on for wheat, almost stopped for maize about 20 yr ago, probably due to the lack of availability of genetically modified (GM) varieties and related technologies. If the current approach against the adoption of new plant-breeding techniques is maintained, the yield gap between Italy and Europe, as a whole, is likely to widen further. In the case of rice, a significant increase in yields began to occur as early as the end of the 19th century. Between 1895 and 1940 yields in this crop increased by about three times. In the United States, a similar increase in rice yields occurred only after World War II.

1 | INTRODUCTION

In the 20th century, world agriculture has shown an increase in yields which has more than quadrupled in a century making it possible to meet the growing demands for food and consumer goods by a global population. This phenomenon peaked in the so-called "Green Revolution", a term first used in a speech given on 8 Mar. 1968 by the administrator of the U.S. Agency for International Development (USAID), William S. Gaud, who, commenting on the spread of new technologies, said: "These and other developments in the field of agriculture contain the makings of a new revolution. It is not a violent Red Revolution like that of the Soviets, nor is it a White Revolution like that of the Shah of Iran. I call it the Green Revolution" (Gaud, 2020; Wikipedia, 2020).

Conceptually speaking, the Green Revolution can be considered as the result of a panoply of scientific and technological innovations that allowed agriculture to respond to the increasing request for food and goods by a continuously growing and increasingly urbanized world population and, hence, inhabiting far away from the food sources. The technological innovations at the root of the Green Revolution originated, on

Abbreviations: GM, genetically modified; sp, subperiod.

one hand, from the fields of genetics and cultural techniques, which were aimed at developing plants that would conform to specific ideotypes (size, attitude to tillering, canopy geometry…) and, on the other, at reducing the limitations of production (thermal stress, water excess and shortage, nutrient shortage, pests and diseases…). This was already clear in the first part of the 20th century, when Oliva (1930), in the introduction to his book "The granary policy in Ancient Rome", wrote: "*the modern technique, in comparison to the ancient one, among many new and improved technical means, includes two powerful ones that can fully solve the world's wheat problem: breeds with prodigious productive capacity and cheap nitrogen, obtained industrially from the inexhaustible air reservoir*".

Furthermore, a fundamental role was played by mechanization, which made the work in the fields more efficient, timely, and less tiresome for the farmers.

From a broader view, the Green Revolution not only refers to advances in field management, but also to other aspects of the food supply chain, such as the storage of agricultural products, the food processing industry, logistics and the cold chain, and addressing the global issues of food security and food safety.

Several authors have dated the beginning of the Green Revolution to the end of World War II (Ameen, 2017) or, more recently, to the 1950s–1960s (Pielke & Linnér, 2019). For instance, in the technical note of the 1996 World Food Summit, FAO stated that: "*In the last three decades, productivity increases in the major cereals, rice, wheat and maize, have been the result of the incorporation of scientific advances in plant breeding with technological packages that have allowed the yield potential of the crops to be realized more fully and under the conditions experienced by farmers in developing countries. These increases have been referred to as the green revolution. Scientific advances have been supported by a significant growth in the commercial sectors that provide inputs to agriculture; infrastructures have improved, thereby covering large and small farmers who were previously beyond the reach of technological innovations*" (FAO, 2020a).

However, this restrictive approach does not take into account that most of the fundamental scientific discoveries on which the Green Revolution is based (plant nutrition laws, genetics laws, petrol tractors, ammonia synthesis from atmospheric nitrogen, etc.) were made during the 19th century or at the beginning of the 20th century. This leads to the question: how can the first signs of the Green Revolution be detected? One way of answering this question is to analyze the long time series of the yields of the crops in the countries that pioneered the technological innovations in agriculture. This is exemplified by the cases of two Italian regions, Lombardy, whose irrigation-based cereal–livestock agriculture was praised by the British agronomist Arthur Young in 1789 (Young, 1915), and Piedmont, whose strong inclination toward innovation (synthetic fertilizers, pesticides, tubular drainage) is testified by the correspondence between Camillo Benso, Count of Cavour, and Giacinto Corio, between 1846 and 1856 (Corio & Bogge, 1980; Visconti, 1913).

Core Ideas

- Since 1870, Italian yields have increased by 347% in wheat, 865% in maize, and 178% in rice.
- In Italy, a notable increase in rice yields started since the late 1800s,50 yr before the United States.
- In Italy, the increase of rice yield lead the way to the other crops.
- The major increase in wheat yields began in Italy, United States, United Kingdom, and France at the end of WW II.
- In Italy the yield of maize increases in the 1940s lagging behind the United States.

Our analysis focuses on the three key cereal crops of Italian agriculture, namely wheat (*Triticum* spp.), rice (*Oryza sativa* L.), and maize (*Zea mays* L.). Wheat (durum and soft) is a winter cereal cultivated over the entire Italian territory, and its product is mainly at the basis of the bread and pasta supply chains. Maize is a summer cereal, which was traditionally a key crop for human consumption but, after World War II, became the basic feed for livestock, from which ham and grana cheese, the main Italian agri-food exports, are obtained.

Rice is another summer cereal, which is mainly grown in specialized districts in North Italy and Sardinia, and it is a product of great interest for human consumption.

The work aims to analyze the time series of Italian wheat, maize, and rice yields for the period 1870–2018, in order to identify the beginning of the phase of significant growth in yields, compared to France, United Kingdom, and the United States, chosen as reference countries. We believe that such an analysis can be useful, not only for agronomic reasons, but also because it is not possible to fully understand such an important historical phenomenon without exploring its origins and evolution over time.

This is particularly relevant when questioning the role generally played by the technological innovations in agriculture (Harwood, 2019; Pingali, 2012).

The comparative approach is, in our opinion, an original element of our work, because it allows us to appreciate the degree of uncertainty that weighs on the historical series of Italian agricultural production prior to World War I and which has often been a source of controversy among historians (see, e.g., Federico, 2003). On the other hand, comparative studies have been conducted by other authors, for example, by Calderini and Slafer (1998), who analyzed the yields of wheat during the 20th century in 21 countries, including Italy.

2 | MATERIALS AND METHODS

2.1 | Datasets

Italy has been a united nation since 1861, when the Kingdom of Italy gathered together most of the pre-Unitarian States, with the exception of Veneto, which joined in 1866, the Vatican State of the Church, which joined in 1870, and Trentino Alto Adige and Friuli Venezia Giulia, which joined in 1918.

It was decided to analyze Italian cereal yields from 1870, when the Kingdom of Italy covered 93% of the present Italian surface.

The complete time series of the average national production for the 1870–2018 period was collected from different sources:

- The Italian Historical Statistical Repository of the Italian National Institute of Statistics (ISTAT) for the 1870–2009 period (ISTAT, 2020a)
- The Corporate Statistical Database of the Food and Agricultural Organization (FAOSTAT) for the 2010–2018 period (FAO, 2020a).

The data for the national cultivated area were taken from:

- Italian Statistical Yearbooks (ISTAT, 2020b)
- The Italian Historical Statistical Repository of the Italian National Institute of Statistics (ISTAT) for the 1921–2009 period (ISTAT, 2020c)
- The Corporate Statistical Database of the Food and Agricultural Organization for the 2010–2018 period (FAO, 2020b).

Data were in fact available for the 1890–1896, 1909–1918 and 1921–2018 periods. The Italian Statistical Yearbooks reported average areas for 5-yr periods for 1870–1874 and 1879–1883. The average value was used for each year of the corresponding period.

Yearly data were obtained for the missing periods as the average of the previous 5-yr period and the following one, when data were available.

The yearly wheat (soft and durum wheat taken together), maize, and rice yields were obtained from the abovementioned data for the 1870–2018 period by dividing the production by the cultivated area (Supplemental Table S1).

Different statistical methods have been applied to analyze time series, even in the particular case of yield series (Grassini et al, 2013; Lin & Huybers, 2012; Michel & Makowski, 2013), with the specific goal of finding significant trends.

In this case, the data analysis was performed by dividing the series into subperiods, characterized by homogeneous trends, and estimating the linear trend with the least-squares method.

Italian data were compared with the yield time series of other countries, where the Green Revolution had been fully expressed, namely the United States (wheat, maize, and rice), France (wheat), and the United Kingdom (wheat).

The sources of the series were:

- The United States – Quick Stats of the United States Department of Agriculture - National Agency of Statistics (USDA-NASS, 2020);
- France – Académie d'Agriculture de France (2020);
- The United Kingdom – The University of Reading (University of Reading, 2020) for the 1885–1960 period, and the Corporate Statistical Database of the Food and Agriculture Organization (FAO, 2020a) for the 1961–2018 period.

In the light of the effect of the climate on crop productions, it is worth recalling the Köppen Geiger climate classification (Köppen & Geiger, 1936) of the analyzed areas:

- The agricultural areas in Italy mainly fall under Csa (Mediterranean) and Cfa (Humid subtropical) climates;
- The wheat areas in France and the United Kingdom mostly fall into the Cfb oceanic climate class;
- The cropping areas in the United States are mainly characterized by Temperate (C) and Continental climates (D) for wheat and (C) climates for maize and rice.

The climatic area influences the production potential of crops to a great extent (Larcher, 1995; Ray et al., 2015). The Mediterranean climate, for example, significantly limits the production of wheat, due to summer droughts, which cause an early closure of the cycle compared to, for example, the Cfb climate area, which has a larger amount of summer rainfall.

2.2 | The time series analysis

The time series were analyzed by means of a piecewise regression, a regression analysis method in which the response variable is split into two or more subperiods, and a line segment is fitted to each subperiod, with the constraint that the regression function must be continuous. Each line is connected to the other at an unknown value, called "breakpoint" (Campra & Morales, 2016; Toms & Lesperance, 2003; Tome & Miranda, 2004; Tome & Miranda, 2005). A piecewise regression is suitable when the behavior of the response variable shows abrupt changes to the explanatory variable and, in many cases, it offers a better fit than the simple linear regression model.

The piecewise regression method adopted for this work was proposed by Tome and Miranda (2004, 2005) for the analysis of climate time series. It is a simple, non-linear approach that mimics the subjective analysis of a time series graphic that may be performed with a pen on a piece of paper, but it uses an objective numerical method that minimizes the mean

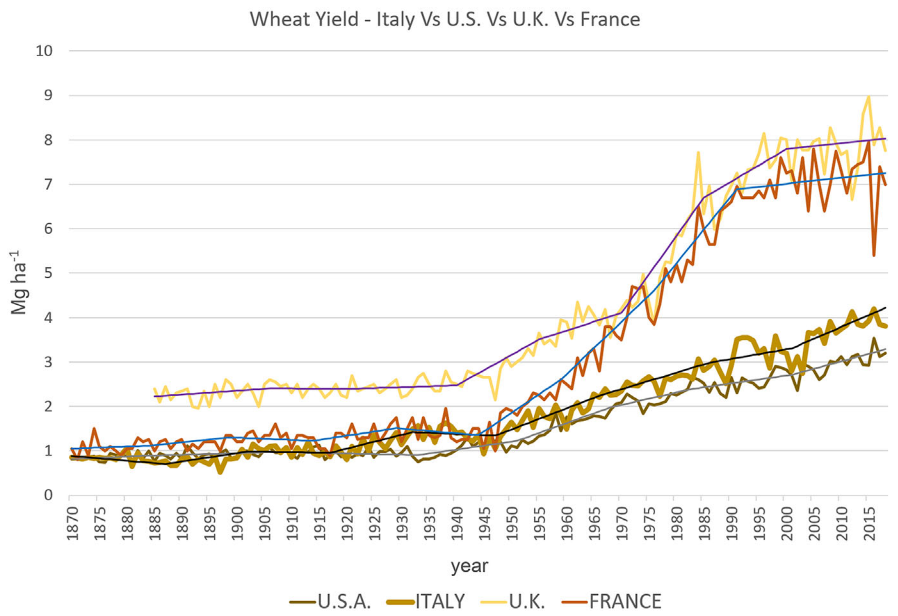

FIGURE 1 Comparison of the wheat yields between the United States, United Kingdom, and Italy. The linear trend of the subperiods, determined with the TOME AND MIRANDA method, are shown for each yield series

square error of the fitting. The method consists of fitting the data with a set of continuous line segments, where the number of segments, the location of the breakpoints between segments, and the slopes of the different segments are optimized simultaneously. The minimum interval between two consecutive breakpoints is the essential free parameter of the method. This interval, which is the minimum time window of the trend analysis, acts as a low-pass fithe and is useful to avoid the effects of inter-annual variability. The minimum interval chosen for this work was 15 yr.

The significance of the trend of each subperiod was evaluated with the *Z* test (the four tested significance levels α are expressed by the following symbols: ¶ for a significance of 99.9%, § for 99%, ‡ for 95% and † for 90%).

3 | RESULTS AND DISCUSSION

Figures 1, 2, and 3 show the average yearly yield of wheat, rice, and maize for Italy and for the other reference countries (the United Kingdom, the United States, and France) for the 1870–2018 period (149 yr). Supplemental table S1 shows the Italian time series of yield for maize, wheat and rice. Moreover, Supplemental Figure S1 reports as points the annual yields of the three crops in Italy from 1870 to 2018 and provides a visual reading of the overall trends by means of sixth degree interpolating polynomials. In order to help understand the factors that affected the yields during this 149-yr period, the series were divided into subperiods with a homogeneous trend, by means of the Tome and Miranda method. The key results are reported in Table 1 and Supplemental Tables S2–S5.

3.1 | Wheat

From 1870 to 2018, the wheat yield in Italy went from 0.85 to 3.81 Mg ha^{-1} with a percentage increase of 347% (+0.02 Mg ha^{-1} year^{-1}).

The first subperiod with a homogeneous trend (1870–1887) showed slightly declining yields (−0.0106 Mg ha^{-1} year^{-1}, which were significant at 90% in the Z test). Four subperiods then followed, with slight trends (significant at 90% in the Z test): 1888–1902, positive; 1903–1917, negative; 1918–1932, positive; and 1933–1947, negative. A similar behavior can be observed up to the early 1930s for the United States, France, and United Kingdom series. However, the United Kingdom showed consistently higher yields (average yield 1885–1945 of 2.41 Mg ha^{-1} vs. 0.95, 1.06 and 1.31 for the United States, Italy, and France, respectively).

After World War II, Italy showed a gradual improvement in yields, which were significant at 99.9% for 1948–1966, 1967–1986 and at 99% for 2002–2018. A similar trend can also be observed for the United States, where a quite gradual growth in the yields can be seen.

It is worth noting that the French yield, which was very similar to those of Italy and the United States until World War II, later increased much more rapidly and reached levels comparable to those of the United Kingdom in the last 70 yr. This slower improvement in yields in Italy has mainly happened

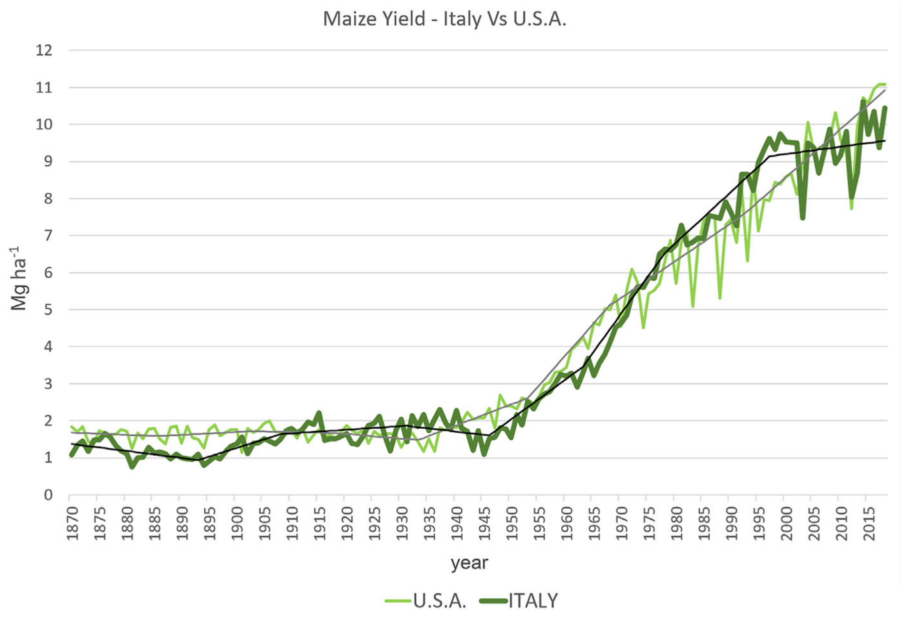

FIGURE 2 Comparison of the maize yield between the United States and Italy. The linear trend of the subperiods, determined with the TOME AND MIRANDA method, are shown for each yield series

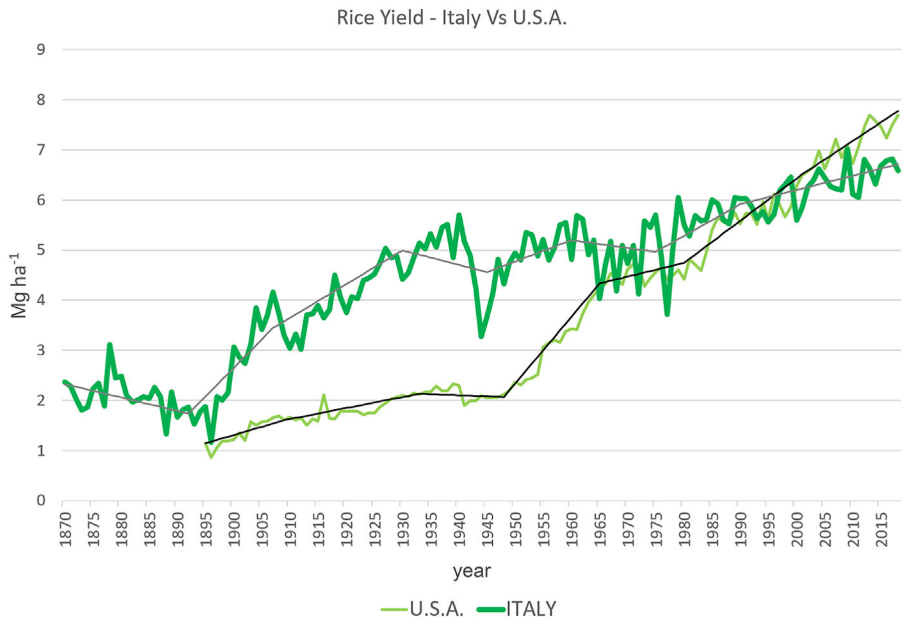

FIGURE 3 Comparison of the rice yield between the United States and Italy. The linear trend of the subperiods, determined with the TOME AND MIRANDA method, are shown for each yield series

because the Koeppen–Geiger Cfb climate of the cereal areas in France and the United Kingdom was more favorable for the high and stable yields than the Csa and Cfa climates of the Italian wheat areas. The point of change that marked a sharp increase in wheat yields in Italy coincides with the end of the World War II.

It should also be noted that the significant yield growth trend for Italy and the United States is still continuing, while France and the United Kingdom show that they have reached a plateau.

The low yield of wheat until the end of World War I can be ascribed to the fact that this cultivation was mainly widespread in marginal hilly and mountain areas, where the environmental drawbacks were higher, the use of technical means was inadequate and most of the product was devoted to self-consumption (subsistence agriculture). In this regard,

TABLE 1 Piecewise linear regression models detected for the yield time series of wheat (1a and 1b), maize (1c), and rice (1d). The decadal trends of the yields [Mg ha^{-1} year^{-1}] and the best fit (the fitted yield of the 1st year of the subperiod) are shown [Mg ha^{-1}]. The trend for the whole period (wp) is reported in the last row of each table († is for significance of 90%, ‡ for 95%, § for 99%, ¶ for 99.9%)

Table 1a

	Wheat – Italy			Wheat – USA		
	Period	best fit	Trend	Period	best fit	Trend
Subperiods (sp)	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}
sp1	1870–1887	0.8949	–0.0106†	1870–1883	0.8099	0.0055
sp2	1888–1902	0.7046	0.0188†	1884–1908	0.8872	0.0035†
sp3	1903–1917	0.9868	–0.0021†	1909–1933	0.9757	–0.0028
sp4	1918–1932	0.9558	0.0311‡	1934–1951	0.9051	0.0178§
sp5	1933–1947	1.4229	–0.0055‡	1952–1968	1.2248	0.0443¶
sp6	1948–1966	1.3406	0.0474¶	1969–1983	1.9784	0.0279‡
sp7	1967–1986	2.2403	0.0371¶	1984–2001	2.3967	0.0175‡
sp8	1987–2001	2.9827	0.0216	2002–2018	2.7117	0.0338§
sp9	2002–2018	3.3070	0.0535§			
wp	1870–2018		0.0225	1870–2018		0.0166

Table 1b

	Wheat – France			Wheat – UK		
	Period	best fit	Trend	Period	best fit	Trend
Subperiods (sp)	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}
sp1	1870–1884	1.0465	0.0044	1885–1906	2.2169	0.0086
sp2	1885–1899	1.1125	0.0126	1907–1921	2.4055	–0.0006
sp3	1900–1914	1.3012	–0.0050	1922–1940	2.3966	0.0040
sp4	1915–1929	1.2268	0.0190‡	1941–1955	2.4723	0.0688§
sp5	1930–1944	1.5118	–0.0106	1956–1970	3.5038	0.0402‡
sp6	1945–1959	1.3535	0.0834¶	1971–1985	4.1061	0.1729¶
sp7	1960–1976	2.6045	0.1182¶	1986–2000	6.6998	0.0728¶
sp8	1977–1991	4.6131	0.1519¶	2001–2018	7.7914	0.0136
sp9	1992–2018	6.8921	0.00135†			
wp	1870–2018		0.0490	1870–2018		0.0514

Table 1c

	Maize – Italy			Maize – USA		
	Period	best fit	Trend	Period	best fit	Trend
Subperiods (sp)	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}
sp1	1870–1893	1.3920	–0.0189§	1870–1886	1.6871	–0.0060
sp2	1894–1908	0.9374	0.0469¶	1887–1903	1.5849	0.0078
sp3	1909–1931	1.6406	0.0097	1904–1918	1.7171	–0.0031‡
sp4	1932–1946	1.8646	–0.0174§	1919–1933	1.6700	–0.0128‡
sp5	1947–1963	1.6036	0.1091¶	1934–1953	1.4774	0.0571¶
sp6	1964–1978	3.4587	0.2053¶	1954–1968	2.6192	0.1663¶
sp7	1979–1997	6.5378	0.1371¶	1969–1992	5.1131	0.1008¶
sp8	1998–2018	9.1426	0.0198	1993–2018	7.5334	0.1303¶
wp	1870–2018		0.0649	1870–2018		0.0611

Table 1d

	Rice – Italy			Rice – USA		
	Period	best fit	Trend	Period	best fit	Trend
Subrperiods (sp)	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}
sp1	1870–1894	2.3512	–0.0267	1895–1909	1.1095	0.0332¶

(Continues)

TABLE 1 (Continued)

Table 1d

	Rice – Italy			Rice – USA		
	Period	**best fit**	**Trend**	**Period**	**best fit**	**Trend**
sp2	1895–1909	1.7375	0.1139¶	1910–1933	1.6068	0.0219¶
sp3	1910–1933	3.4453	0.0673¶	1934–1948	2.1325	–0.0043
sp4	1934–1948	4.9942	–0.0289	1949–1965	2.0679	0.1333¶
sp5	1949–1965	4.5608	0.0424¶	1966–1980	4.3343	0.0274
sp6	1966–1980	5.1970	–0.0153	1981–2001	4.7445	0.0842¶
sp7	1981–2001	4.9669	0.0633¶	2002–2018	6.5118	0.0743¶
sp8	2002–2018	5.9168	0.0284¶			
wp	1870–2018		0.0325	1870–2018		0.0455

the economist and statesman Luigi Einaudi (1910) pointed out the high territorial variability of the wheat yield in Italy, highlighting the need to abandon marginal areas and favor the more suitable and productive plains.

However, the intensification strategy advocated by Einaudi was only adopted after World War II because, between the two wars, the fascist regime promoted a National policy of self-sufficient wheat production, and launched on 25 June 1925 (Strampelli, 1933) the so-called "battle of wheat" ("battaglia del grano"), which led to the further expansion of this crop in marginal mountain territories, therefore with very low productivity. This strategy significantly reduced the effects of technological innovations in the fields of genetics (semi-dwarf varieties) and cropping techniques, which, with the support of the Fascist regime, was promoted by the geneticist Nazzareno Strampelli, who was the real great innovator of Italian cereal growing and is often considered as the father of the Italian Green Revolution (Bianchi, 1995).

It is worth mentioning that the increase in yield observed in the 1920s, and in particular after World War II, was coupled with a quite relevant increase in the quality of the grain, as pointed out by De Vita et al. (2007), who analyzed the progress made in the breeding of durum wheat cultivars during the 20th century in terms of morpho-physiological, agronomical, and qualitative traits.

However, the steady improvement that has been recorded in the last few decades did not bridge the gap with the United Kingdom or France, in particular because about 70% of this crop is represented by durum wheat, which is mainly grown in central southern regions, and sometimes in marginal areas, with yields that are remarkably lower than those of soft wheat (ISTAT, 2020c).

It is interesting to observe how the stagnation of the wheat yield, which started in 1990 in France and the United Kingdom, has not affected Italy. According to Schauberger et al (2018), the causes of the wheat yield stagnation in France after 1990 require further investigation, since the phenomenon that affected the departments in the North in particular, characterized by high average yields, cannot be fully explained by the claimed adverse climate conditions. Similarly, several factors have been proposed as possible causes for the stagnation of the wheat yield in the United Kingdom, even though no single major factor has been identified (Agriculture and Horticulture Development Board (AHDB), 2020).

3.2 | Maize

From 1870 to 2018, the maize yield in Italy increased more than eightfold (+ 865%), growing from 1.08 to 10.45 Mg ha^{-1}.

The 1870–1893 period was characterized by slightly declining yields (−0.0189 Mg ha^{-1} year^{-1}, significant at 99% in the Z test). The following period (1894–1908) showed a highly significant increase (+0.0469 Mg ha^{-1} year^{-1}, significant at 99.9%). A steady phase followed (1909–1931), and this was succeeded by a phase with the strong negative drop partly related to World War II (1932–1946, −0.0174 Mg ha^{-1} year^{-1}, significant at 99%). The after-war period was characterized by three consecutive periods that showed a steep increase, which are significant at 99.9% (+0.1091 Mg ha^{-1} year^{-1} for 1947–1963, +2.053 for 1964–1978, and +1.371 for 1979–1997). A plateau was reached after 1997, which is similar to that observed for wheat in France and the United Kingdom. The trend observed for the United States, which may be considered the place where the maize Green Revolution first took place towards the mid-1930s, is very interesting. In the United States, after a long phase with a negative trend, which is significant at 95% (1904–1933), a phase, which covers four subperiods, started, with a significant (at 99.9%) positive trend that has continued until today.

In Italy, the point of change that marked the beginning of the Green Revolution for maize coincides with the arrival of the new hybrids technology after the end of the Second World War, even though the 1894–1908 period, with its positive trend, could be interpreted as a pioneering phase of the Green Revolution. The new hybrids rapidly spread, mostly replacing the vitreous fracture varieties that were in use until then. Thus, maize has become the base of relevant cereal–livestock production chains like that at the base of premium products like "Grana" cheese and Parma and San Daniele raw hams.

Compared to wheat and rice, maize has benefited from the effects of the Green Revolution more recently. The genetic improvement of this crop, the only allogamous of the three selected species occurred on vitreous autochthonous varieties at the end of World War I by the Royal Experimental Station of Bergamo, which was founded in 1919. The first director of this research facility was Tito Vezio Zapparoli, who had previously been a breeder of sugar beet (*Beta vulgaris* L.), another important allogamous crop. The yield increased by 0.0469 Mg ha^{-1} year^{-1} in the 1894–1908 period, and more moderately, by 0.0097 Mg ha^{-1} year^{-1}, in the 1909–1931 period. After World War II, Luigi Fenaroli, director of the Experimental Station of Bergamo, gave a strong boost to the Italian maize yields. Fenaroli went to the United States for an internship, thanks to a grant provided by the United Nations Relief and Rehabilitation Administration (URRA) and, in 1947, brought the first double cross hybrids from the United States to Italy (Merli, 1948), with single cross hybrids following later.

It is worth noting that, contrary to the United States, the significant post-war trend in yield growth in Italy ended in 1997. This may partially be explained by the lack of technological updating with genetically engineered maize varieties (herbicide-resistant and insect-resistant genetically modified (GM) varieties), which prevents an effective and economically acceptable protection against weeds and European corn borer (*Ostrinia nubilalis*). The uncountable damage caused by the insect is closely related to the yield reduction, the increase in contamination by fumonisins and to the consequent reduction of the profitability of the crop that has determined a reduction in the care and investments of farmers (Pellegrino et al., 2018). The result of these phenomena has been the reduction of the maize-cultivated area in Italy, from 1 million ha in 1997 to 600,000 in 2019, with a significant reduction in supply rates for Italy.

3.3 | Rice

In the period between 1870 and 2018, the rice yield in Italy showed an increase of 178%, from 2.37 to 6.59 Mg ha^{-1}.

Again in this case, the first phase (1870–1894) was characterized by slightly declining yields (−0.0267 Mg ha^{-1} year^{-1}, not significant in the Z test). The following two subperiods (1895–1909 and 1910–1933) showed a relevant and highly significant increase in yields (0.1139 and 0.0673 Mg ha^{-1} year^{-1}, respectively, significant at 99.9%). Then, a phase with a slight negative trend followed (1934–1948, −0.0289 Mg ha^{-1} year^{-1}, not significant in the Z test), driven by the pronounced drop due to World War II. The post-war period was marked by three periods with a steep increase, which are significant at 99.9% (+0.0424 Mg ha^{-1} year^{-1} for 1949–1965, +0.633 for 1981–2001, and + 0.284 for 2002–2018). A discontinuity in the post-war growth trend can be observed for the 1966–1980 period (−0.0153 Mg ha^{-1} year^{-1}, not significant in the Z test).

Yield data have been available for the United States since 1895 and, up to the 1930s, the series showed a slight growth, which is not comparable in size with the Italian one, which is much more relevant. To find something similar, it is necessary to consider the 1949–1965 period, during which the United States had a pronounced yield growth (+0.1333 Mg ha^{-1} year^{-1}), which led this country to have similar production levels, albeit lower, to the Italian ones. Lastly, the United States has outperformed Italy since the 1990s, and particularly in the 2014–2018 period, with an average yield of 7.50 Mg ha^{-1}, against 6.64 Mg ha^{-1} in Italy.

The period that marked the beginning of a significant evolution in the yields of this crop, which lasted until 1933, can be traced back to 1895. A similar growth trend has never been attained in the subsequent periods.

In Italy, rice was the first crop to record such a significant increase in yields as early as the end of the 19th century, with yields growing from 1.17 Mg ha^{-1} in 1896 to 5.70 Mg ha^{-1} in 1940 (+387%). No parallel increase was observed in the United States, which grew from 0.87 to 2.29 Mg ha^{-1} (+163%) in the same period, or in Japan, where the production grew from 2.1 to 3.0 Mg ha^{-1} (+ 143%) in the same period, as evidenced by the time series of the Japanese Ministry of Agriculture (Horie et al., 1995).

The historian Bracco (2002) highlighted that, because of the drop in yields that characterized the 1870–1890 period, the rice sector reacted strongly by improving the production processes and promoting a new organization of rice farming, aimed at obtaining a greater profitability. In this context, the first International Congress on Rice Production, held in Novara in 1901, the third in Vercelli in 1906 and the fourth in Pavia in 1912, discussed and disseminated relevant innovations, such as fertilization planning, transplanting, weeding, the introduction of new varieties, like "Chinese originario", and new machinery for tillage, sowing, harvesting, and rice processing (Novello, 1936, Bracco, 2002; Crosio & Zarbo, 2020).

In this regard, it is interesting to highlight the key and the pioneering role played in the Green Revolution by the statesman Camillo Benso, Count of Cavour, through his farming activities in the rice sector, as demonstrated by the 1846–1856 correspondence with his business partner Giacinto Corio (Bogge, 1980; Visconti, 1913). The letters talk about the

TABLE 2 Pre War 5-yr averaged yields and prices of wheat, maize, and rice. The minimum prices and yields are highlighted in bold (Farolfi e Fornasari, 2011)

Period	Wheat		Maize		Rice	
	Price	Yield	Price	Yield	Price	Yield
	€ Mg^{-1}	Mg ha^{-1}	€ Mg^{-1}	Mg ha^{-1}	€ Mg^{-1}	Mg ha^{-1}
1861–1865	**0.0133**	**–**	**0.0086**	**–**	**0.0086**	**–**
1866–1870	0.0143	–	0.0090	–	0.0090	–
1871–1875	**0.0160**	**0.84**	**0.0114**	**1.39**	**0.0102**	**2.05**
1876–1880	0.0158	0.89	0.0110	1.36	0.0104	2.45
1881–1885	**0.0123**	**0.77**	**0.0090**	**1.03**	**0.0084**	**2.04**
1886–1890	**0.0117**	**0.74**	**0.0078**	**1.07**	**0.0092**	**1.90**
1891–1895	**0.0121**	**0.77**	**0.0078**	**0.95**	**0.0096**	**1.77**
1896–1900	**0.0128**	**0.77**	**0.0076**	**1.17**	**0.0104**	**2.09**
1901–1905	**0.0125**	**1.02**	**0.0084**	**1.40**	**0.0106**	**3.20**
1906–1910	0.0142	1.02	0.0092	1.57	0.0118	3.59
1911–1915	**0.0172**	**1.01**	**0.0106**	**1.90**	**0.0116**	**3.53**
1916–1920	**0.0329**	**0.95**	**0.0220**	**1.55**	**0.0250**	**3.95**
1921–1925	**0.0686**	**1.13**	**0.0526**	**1.63**	**0.0624**	**4.29**
1926–1930	0.0782	1.20	0.0494	1.73	0.0518	4.78
1931–1935	**0.0554**	**1.43**	**0.0316**	**1.86**	**0.0314**	**4.98**
1936–1940	0.0744	1.47	0.0476	2.07	0.0452	5.32

experimentations carried out on the three farms in Leri, Montarucco, and Torrone (synthetic fertilizers, new rice varieties, innovative harvesters and machinery for rough rice processing) and also about the close and fruitful relationship between farmers and the agricultural commodity exchange markets.

The pronounced positive rice yield trends in Italy between 1895 and 1940 were the result of the increasing application of technological innovation in the fields of genetics (new varieties of ssp. *Japonica* a specifically designed for the Italian environment) and cropping techniques.

The key to rice cultivation in this period was transplanting, a technique that made the most of the environmental resources of the summer season. After World War II, transplanting was gradually abandoned due to the increasing demand of manpower from the industrial sector. It is important to highlight that this early technological innovation in rice cropping took place in some specialized districts of North Italy (in Piedmont, Lombardy, Veneto, and Emilia Romagna) and Sardinia, thus making a rapid spread of innovations possible. A similar geographical specialization as a booster of yields can be also detected in the U.S. Corn Belt for maize (Green et al., 2018) and in the Indo Gangetic Plain for wheat (Aggarwal et al., 2004).

A few years ago, hybrid rice varieties of U.S. origin started to spread in Italy. Their very promising development, thanks to a general increase in yields of around 20%, still requires some work to select the most suitable varieties for the country's specific environmental conditions.

3.4 | The quality of Italian time series

As far as the quality of the historical long-time series analyzed in this work is concerned, all the official statistics that were available were collected and analyzed (ISTAT, 2020a, 2020b, 2020c) to obtain the best possible information.

Some authors question the reliability of the agricultural statistics pertaining to the 19th century (Federico, 2003). In this regard, it could be interesting to compare the decadal average yields of cereals with the 5-yr average prices reported by Farolfi and Fornasari (2011), as shown in Table 2. As confirmation of the reliability of our data, the minimum yields for the 1886–1895 period are in agreement with the minimum prices, which were caused by cereal being imported from the United States (Farolfi & Fornasari, 2011). The relevance of this crisis is also witnessed by the impoverishment of the rural population, which was documented by the spread of pellagra, a disease caused by the lack of nicotinic acid in populations with a monotonous diet based on maize flour. This disease was mainly present in the rural population in North Italy, and reached a maximum prevalence of 366 cases per 100,000 inhabitants in 1881, a level that has never been attained since (Fornari et al., 2013; Ginnaio, 2011; Mariani Costantini, 2007). This crisis was overcome, at the end of the 19th century, when innovation started to show its positive effects.

On the other hand, Federico (2003) underlined the poor reliability of the 19th century data on cultivated surfaces and questioned the relevance of the above-described crisis, arguing that the living conditions of the rural population at that time did not deteriorate. Federico considered, for instance, the increase in height of the military conscripts during this period as a demonstration against the severity of the crisis. In this regard, it is important to state that this debate originated from the radical reform of agricultural statistics conducted by the economist Ghino Valenti in 1909, which generated controversial opinions on the quality of pre-reform data (Romani, 1963).

From this point of view, it is also interesting to consider the analysis of Porisini (1971), on wheat yields in Italy over the 1815–1922 period, on the basis of a broad investigation of both private (mainly administrative documents from large farms) and public sources (statistics drawn up by the public administration for cognitive or fiscal purposes). The author concluded that data from public sources (the same used for our work) are somewhat unreliable for the 1815–1882 period, show a limited accuracy for the 1887–1907 period, and are more accurate after 1909, as the result of Ghino Valenti's reform of agricultural statistics.

The comparison made in this work of the data from Italy and the United States, France, and the United Kingdom has led us to conclude that the Italian yield series may also be used for the period preceding Valenti's reform, bearing in mind the higher level of uncertainty that characterizes the older series. However, our conclusions are in line with those reached by Romani by other means (1963).

3.5 | The concept of green revolution

It is important to underline that the term "Green Revolution" has been adopted in this work without considering the criticisms of this concept expressed by various parties (Pingali, 2012; Pimentel & Pimentel, 1990; Harwood, 2019). However, the concept of the "failure of the Green Revolution" is, in our opinion, partial in that it does do not consider that the global food security is today based on the enormous increases in the yield in the 20th century that was driven by the massive technological innovation (Mehta, 2018). Furthermore, if the Green Revolution had not taken place, the satisfaction of the needs of food and consumer goods would have led to an unsustainable expansion of cultivated land, with the quadrupling of greenhouse gas emissions of agricultural origin (Burney et al., 2010).

In our opinion, it is equally true that, in light of past experience, it is mandatory to aim for a further development process founded on economic, social, and environmental sustainability (Pingali, 2012) and on the full exploitation of the heritage of scientific knowledge accumulated over the years (Evans & Lawson, 2020).

Furthermore, it is also interesting to report the criticism of the term "Green Revolution" expressed by Pielke and Linnér (2019). They argued that the Green Revolution was just a political myth of averted famine, created in the 1950s and 1960s by scientists who predicted that a global crisis would emerge in the 1970s, and after, caused by a rapidly growing global population that would cause global famine as food supplies were not able to keep up with the demand. Pielke and Linnér concluded that the process defined as "revolution" was instead gradual, and recommended the alternative term "Green Evolution", in which sustainable improvements in agricultural productivity did not necessarily avert a global famine, but nonetheless had a profound effect on shaping the modern world.

4 | CONCLUSION

This study focused on the historical yield of wheat, maize, and rice in Italy. The time series starts in 1870 when, with the annexation of the State of the Church, the Italian territory reached 93% of the current surface. The aim of the work was to identify the most significant growth phases of the yields for the three crops in Italy compared to those in the United States, France, and Great Britain.

The results show that, in Italy, the most important growth in maize and wheat yields occurred only after World War II. Similar trends can also be observed in the reference countries, with the beginning of significant yield growth phases in the early 1930s for wheat and maize in the United States, in the 1940s for wheat in the United Kingdom and after World War II for wheat in France. The significant post-war trend of increasing yields in Italy, which is still ongoing for wheat, almost stopped for maize about 20 yr ago, mainly due to the non-availability of GM varieties and limitations in the application of new breeding technologies.

In the case of rice, a significant increase in yields occurred in Italy as early as the end of the 19th century, at the end of the agricultural crisis caused by cereal imports from the United States, which led to a significant drop in the prices of domestic agricultural products. Thanks to the high degree of specialization of rice farms and the rapid spread of new technologies, yields of this crop increased by about three times between 1895 and 1940.

The elements of uncertainty that emerged during the collection of the yield time series were overcome, at least in part, by comparing them with those of other countries and by checking what other authors had written, dealing with the same problems. Therefore, we are confident that the final data set can be useful for agronomic and socio-economic analyses.

However, we believe that our study can be further investigated by comparing it with other time series, such as (a) time series of thermal and rainfall data, which are important determinants of grain yield, and (b) time series of yields from other European countries, such as Spain and Germany, or non-European countries, such as Japan, for rice.

A further aspect that could be explored is the role played by technical assistance services to farmers in triggering and spreading the green revolution in Italy. A final element worthy of attention for the future development of our work is that of the economic, social, and environmental aspects of the sustainability of cereal production in Europe, which has been one of the world's granaries for millennia.

In this context, it is important to understand why, since the late 1990s, some European yield series have shown a marked plateau. This effect might highlight that limitations to technological innovation in agriculture can have significant effects on food security and food sovereignty.

In our view, a reflection on this aspect should have more relevance in the ongoing debate on the future of agriculture in the European countries.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Luigi Mariani: Conceptualization; Data curation; Formal analysis; Methodology; Writing-original draft; Writing-review & editing. Aldo Ferrero: Conceptualization; Methodology; Writing-original draft; Writing-review & editing. gabriele cola: Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Writing-original draft; Writing-review & editing.

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