Growing maize in the Iberian Peninsula: farming practices and managing the dryland (19th and 20th centuries)

Cultivar maíz en la Península Ibérica: prácticas agrícolas y gestión del secano (siglos XIX-XX)

Alberto González Remuiñán
University of Coimbra
Coimbra, Portugal
alberto.g.remuinan@uc.pt
ORCID: 0000-0001-6837-6651

Inês Gomes
NOVA School of Social Sciences and Humanities
Lisbon, Portugal
gomes.ida@gmail.com
ORCID: 0000-0001-9210-9959

Dulce Freire
University of Coimbra
Coimbra, Portugal
dulce.freire@fe.uc.pt
ORCID: 0000-0003-2969-4440

Article information
Recibido: 09/04/2024
Revisado: 08/10/2024
Aceptado: 19/10/2024
Online: 04/06/2025
Publicado: 10/10/2025

ISSN 2340-8472
ISSNe 2340-7743
DOI 10.17561/at.28.8771

ABSTRACT

Meeting the water requirements for crops such as maize through irrigation can conflict with the increasing demand for efficient water management. This paper aims to contribute to the search for solutions to achieve a more rational water use for this crop in the Iberian Peninsula. It analyses written sources and unpublished oral testimonies to highlight the value of peasant and scientific knowledge in managing water resources through farming techniques other than irrigation used before the Green Revolution. However, the logic of productivity led to the introduction of hybrids and greater water availability through the construction of irrigation infrastructures. As a result, some of these techniques fell into oblivion, thereby losing this administrative aspect of moisture. In the current environmental context, reconsidering them is both logical and necessary.

KEYWORDS: Maize, Water management, Farming techniques, Peasant knowledge.

RESUMEN

Satisfacer las necesidades de agua mediante irrigación para un cultivo como el maíz entra en conflicto con la necesidad creciente de una gestión hídrica eficaz. Analizando fuentes escritas y entrevistas orales inéditas recogidas en la Península Ibérica, este texto pretende contribuir a la búsqueda de soluciones para lograr un uso más racional del agua respecto a esta planta. El resultado es la puesta en valor de un conocimiento racional campesino y científico que, antes de la Revolución Verde, administraba los recursos hídricos mediante otras técnicas culturales además del regadío, que aquí son examinadas. Pero la lógica productivista, con la introducción de híbridos y una mayor disponibilidad de agua motivada por la creación de infraestructuras que facilitan la irrigación, ha favorecido que algunas de esas técnicas hayan caído en el olvido, perdiéndose esa vertiente administrativa de la humedad. En el contexto ambiental actual, revisarlas resulta tan lógico como necesario.

PALABRAS CLAVE: Maíz, Gestión hídrica, Prácticas culturales, Conocimiento campesino.

A cultura do milho na Península Ibérica: práticas agrícolas e gestão do sequeiro (séculos XIX-XX)

RESUMO

A satisfação das necessidades hídricas de culturas como o milho, através da rega, pode entrar em conflito com a crescente procura de uma gestão eficiente da água, face à sua escassez. Este artigo tem como objetivo contribuir para a procura de soluções para uma utilização mais racional da água para esta cultura agrícola na Península Ibérica. Analisa fontes escritas e testemunhos orais inéditos para realçar o valor do conhecimento vernacular e científico na gestão dos recursos hídricos, através de técnicas agrícolas diferentes da irrigação, utilizadas antes da Revolução Verde. No entanto, a lógica da produtividade levou à introdução de híbridos e a uma maior disponibilidade de água através da construção de infraestruturas de irrigação. Em consequência, algumas destas técnicas caíram no esquecimento, perdendo-se assim certas formas de gerir a humidade. No contexto ambiental atual, reconsiderá-las é tão lógico quanto necessário.

PALAVRAS CHAVE: Milho, Gestão hídrica, Técnicas agrícolas, Conhecimento vernacular.

La culture du maïs dans la péninsule ibérique : pratiques agricoles et gestion des terres pluviales (19e-20e siècles)

RÉSUMÉ

La réponse aux besoins en eau de cultures telles que le maïs par l'irrigation peut être en contradiction avec la demande croissante d'une gestion efficace de l'eau dans un contexte de pénurie. Cet article a pour but de contribuer à la recherche de solutions visant à une utilisation plus rationnelle de l'eau pour cette culture agricole dans la péninsule ibérique. Il analyse des sources écrites et des récits oraux inédits pour mettre en évidence la valeur des connaissances paysannes et scientifiques dans la gestion des ressources hydriques, par le biais de techniques agricoles autres que l'irrigation qui étaient utilisées avant la révolution verte. Cependant, la logique de productivité a conduit à l'introduction d'hybrides et à une plus grande disponibilité de l'eau grâce à la construction d'infrastructures d'irrigation. Par conséquent, certaines de ces techniques ont été abandonnées et certains modes de gestion de l'humidité ont été perdus. Dans le contexte environnemental actuel, les reconsidérer est aussi logique que nécessaire.

MOTS-CLÉS: Maïs, Gestion de l'eau, Pratiques culturales, Savoirs paysans.

La coltivazione del mais nella Penisola Iberica: pratiche agricole e gestione del'aridocoltura (Otto e Novecento)

SOMMARIO

Il soddisfacimento del fabbisogno idrico attraverso l'irrigazione entra in conflitto con la crescente necessità di una gestione efficiente dell'acqua, soprattutto per coltivazioni come quelle del mais. Con l'analisi di fonti scritte inedite e di interviste orali realizzate nella penisola iberica, questo testo vuole contribuire alla ricerca di soluzioni per razionalizzare il consumo idrico di questo cereale. Così facendo, si valorizza un sapere razionale contadino e scientifico che, prima della Rivoluzione Verde, gestiva le risorse idriche attraverso altre tecniche culturali oltre all'irrigazione. Il testo esamina queste tecniche, come l'uso dell'umidità. Ciononostante, la ricerca di maggiori produttività, attraverso l'introduzione degli ibridi e la maggiore disponibilità di acqua dovuta alla creazione di infrastrutture irrigue, ha fatto sì che alcune di queste tecniche siano andate perdute, venendo così a mancare l'aspetto amministrativo dell'umidità. L'attuale crisi ambientale impone riprederle in considerazione.

PAROLE CHIAVE: Mais, Gestione dell'acqua, Pratiche culturali, Saperi rurali.

Introduction

Maize is the second most produced crop in the world after sugar cane. It has undergone selection during its domestication, resulting in significant morphological and genetic diversity. Currently, it is the crop with the broadest range of cultivation[1], and there is a considerable variety of farming practices related to its management due to its water needs. Before the Green Revolution, when irrigation was less intensive and other agricultural techniques were used, peasant and scientific knowledge both played a role in managing drylands. However, the recent expansion of irrigation and the focus on hybrid maize production have blurred the management of humidity. This paper will address this aspect of maize production in Spain and Portugal, which exceeds five million tons produced annually, based on analysis of written and oral historical sources. In the current environmental context, focusing on water management techniques is both logical and necessary.

Ensuring food security for the growing world population is becoming increasingly challenging due to the frequent occurrence of droughts and water scarcity[2]. Efficient management of water resources is crucial in maize cultivation, especially with the consequent decrease in water availability for irrigation[3]. According to FAO, the evapotranspiration[4] for this cereal is between 4.000-7.500 m^3/ha, which is the amount required to meet crop water needs under non-restrictive soil and healthy conditions[5]. In some cases, the water requirements for this cereal can approach their upper limits, and when combined with heavy reliance on irrigation, excessive water usage can occur. The Ebro basin, which is the primary maize-growing region in Spain, is one such example. Various irrigation tests using sprinklers have shown consumption rates exceeding 7000 m^3/ha[6]. Therefore, analysing the Iberian case (see Figure 1) is relevant as it serves as an example of excessive water usage and can contribute to the discussion of a globally significant issue. Despite differences in hybrid production, Spain and Portugal share similar water management strategies. These territories traditionally produced maize with significantly less water. There are two cultivation regimes: rainfed in the humid agroecosystems of the north and irrigated in most of the territory. In the Iberian Peninsula, this crop historically had a significant presence between the Atlantic rivers Mondego and Garonne[7]. However, this configuration changed as the 20th century progressed. Spanish Ministry of Agriculture data shows that Aragon and Castile-Leon produce half of the national maize. In Portugal, the markedly regional distribution, with maize north of the Tagus River, changed to a spectacular increase in maize in the Alentejo, becoming the main cereal produced in the country[8].

Apart from irrigation, other cultivation practices play a significant role in moisture management. However, the literature has not extensively explored these issues. Historical investigations have analysed the impact of maize's arrival since the end of the 15th century on agricultural and livestock activities, demography, and the landscape in various peninsular areas[9]. Some studies have also addressed research related to this cereal[10]. On the other hand, advances in biology have increased the potential for studying crop diversity, local varieties, or seed exchange[11]. Aspects of water administration are commonly found in publications that disseminate scientific and technical knowledge. For instance, measuring the water footprint of a crop or conducting irrigation experiments[12], or the watering experiments already cited.

This paper analyses feasible solutions for achieving a more rational use of water resources, based on historical written and oral sources. The focus is on water management practices beyond the current prevalence of intensive irrigation in maize cultivation. The knowledge derived from their application will be central because, before the capitalist logic, both peasant —ancestral and organically based— and expert knowledge were intertwined. Before the Green Revolution, researchers and technicians aimed to maximise plant

1 Tenaillon; Charcosset, 2011.
2 Vila-Traver et al., 2021.
3 Zhang, 2003. Panda; Behera; Kashyap, 2004.
4 The concept results from the mix of two separate processes by which water is lost through the soil surface by evaporation and crop transpiration. The water amount required to compensate for the crop evapotranspiration loss is the crop water requirement. The irrigation requirement represents the difference between the crop water requirement and the total precipitation (Allen et al. 2006, 1-8).
5 Doorenbos; Pruitt, 1977.
6 Cavero Campo et al. 2008, 1575-76. Urrego Pereira; Martínez-Cob; Cavero Campo, 2013, 845.
7 Dubert; Saavedra. 2018, 9.
8 Faísca, 2019, 49-50.
9 Almeida, 1992; 1995. Ribeiro 1991. Godinho, 1981. Serrão, 2007. Magalhães, 2010. Alberola Romá, 1997. Pérez García, 1982. Saavedra, 2018. Aragón-Ruano, 2021, Pinilla Navarro, 2008.
10 Cabo Villaverde, 1997. Esperante; Fernández Prieto; Cabo Villaverde, 2020.
11 Tenaillon; Charcosset, 2011. Rebourg;, Gouesnard; Charcosset, 2001. Rebourg et al. 2003. Revilla Temiño et al., 1998; 2003.
12 Lovarelli; Bacanetti; Fiala, 2016.

Figure 1. The Iberian Peninsula

Iberian Peninsula location

Source: Own elaboration with Datawrapper.

yield by improving these peasant techniques. However, they eventually overlooked or ignored some crucial aspects of managing water and soil moisture. That was a consequence that followed the escalation of hybrid maize in the 1950s and the development of structures that guarantee a significant water supply, resulting in the loss of the know-how associated with selection, conservation, and cultivation techniques to grow landraces[13]. Furthermore, the heavily technological focus of the Green Revolution has overshadowed other non-mechanical advancements and processes in agriculture but less visible –of an associative, biological and technical kind. This has shaped perceptions of the non-industrialised familiar agriculture as being backward[14].

These processes of loss of knowledge represent a loss of cultural and technical heritage[15] due to new irrigation technologies and subsidies that promote agriculture conversion and herbicide use. This loss remains unexplored in a central crop such as maize.

Historical sources can provide insight into sustainable ancient knowledge regarding the management of maize water. By analysing written documents for educational purposes or scientific dissemination, as well as oral testimonies, a better understanding of past practices that are no longer in use can be gained, leading to a more comprehensive view of agricultural procedures. It is important to note that these sources preserve knowledge from before the Green Revolution and the changes that have led to the current situation in terms

[13] Fenzi; Couix, 2022.
[14] Fernández Prieto, 2001.
[15] Keesstra et al., 2018.

of production. Their significance lies in their ability to gather knowledge about the factors contributing to the success of this crop in the Iberian Peninsula during a time when more environmentally friendly water management rules took place. Additionally, research has highlighted the importance of farmer knowledge and learning techniques in developing sustainable agricultural practices and enhancing agricultural resilience[16].

In essence, this article seeks to highlight the significance of historical knowledge in devising solutions to the prevailing challenges confronting maize cultivation, particularly those pertaining to water scarcity. As historians, rather than agronomists, we do not purport to present definitive solutions. Nevertheless, by elucidating the manner in which water was managed in maize cultivation in the past, we aim to impart knowledge to agronomists, thereby facilitating the development of more resilient solutions. The techniques analysed here as a tool for searching for these solutions have a possible practical application in an agriculture 3.0 framework, which seeks to improve the efficiency of agricultural processes by applying technology[17]. Precision agriculture can benefit from the principles and rules of some traditional techniques —e.g. when, how or on which types of soils they should be implemented— revised in light of current knowledge to build automatised processes that improve the management of irrigation water and soil moisture but also have other complementary environmental advantages, such as weed management. In the case of maize, in the context of the current environmental emergency, the water scarcity problems will increasingly affect the cereal since it is a crop that requires considerable amounts of water resources in some phases of its life cycle. The search for solutions is necessary, and an interdisciplinary perspective involving more disciplines apart from agronomy is key.

This paper will first address the sources that allow the identification of practices related to water management in maize cultivation, their potentialities, and particularities. Secondly, the paper addresses irrigation, followed by a section that depicts some farming techniques to manage soil moisture –reploughing and plant arrangement. Finally, we discuss hybrids and their possible uses concerning water management. Given the nature of the sources employed in this article, the discussion will pervade the entire text. The conclusions serve to reiterate the results, thus reinforcing the findings.

Maize water needs: sources and methods for its study

Historical sources can provide detailed information about vegetables grown and consumed in specific places and times. This information allows us to access the knowledge of particular communities and social groups, as well as their changing relationships or perspectives on nature. This knowledge can be useful in developing current conservation strategies[18]. Historical sources enable us to understand past agricultural practices, some of them more sustainable than current ones, as part of that knowledge. Therefore, these documents can help us recover forgotten procedures that support more viable and ecological water use in maize cultivation.

Historical written sources can be used to analyse the relationship between maize, water requirements, and farming practices over the past two centuries. Those used in this research come from the collections of organisations from Portugal —National Library, Instituto Superior de Agronomia and Ministério da Agricultura e da Alimentaçao— and Spain —National Library, Ministerio de Agricultura, Junta para Ampliacion de Estudios and Consejo Superior de Investigaciones Científicas—.

On the one hand, agricultural manuals from the second half of the 18th and 19th centuries, written in vernacular languages to inform and educate local people on various agricultural subjects, provide insight into the perspectives of agricultural, agronomical, or botanical scholars. We have chosen Spanish and Portuguese books attempting to form a representative body of Iberian agronomic literature. The works cited were written in different places and over a century and a half, so their selection seeks to cover the disparity of climates and the possible temporal transformations in the approach to some agricultural techniques. On the other hand, scientific literature from the 20th century can be a valuable source for recognising expert knowledge on farming practices and water management. Pamphlets from governmental agencies or reports from scientific institutions can provide information on cultivation practices or plant breeding experiments

16 Šūmane et al., 2018.
17 Dhanaraju et al., 2022.
18 Gomes; Freire, 2023.

aimed at increasing production and improving farmers' routines. This set consists mainly of material from informational publications from both countries. As in the previous block, we have tried to cover the disparity of farming systems in which maize may be present by looking at publications addressing different regions.

Also, oral testimonies can provide valuable information about local knowledge and communal rules and conflicts related to water use and maize tillage activities. These practices are still remembered by peasant communities and serve as evidence of ancestral knowledge that predates the changes brought about by the Green Revolution and its production paradigm. For this reason, the content and collection of peasant knowledge holds significant historical value, as it has started to disappear since the beginning of the industrialisation of agriculture. This is due to the diminishing role of farmers, caused by the spread of productivism logic and the search for standardised solutions[19]. Peasant life histories can enhance our understanding of the landscape transformations they contributed to and the farming techniques that were essential in the past, even if they are no longer present in the modern countryside[20]. Also, local knowledge and cultural memory are essential for biodiversity conservation as they act as repositories of choices that maintain cultural and biological diversity[21]. This study includes 17 semi-structured interviews and 31 informal conversations in about thirty localities in the Galicia-Minho area (NW Iberian Peninsula). In this region, maize grows in rainfed and irrigated systems, which helps address both forms of cultivation. The material collected in this way also recorded audio and video and is still under analysis in the framework of the project that made this research possible.

The historical sources referenced in this section were meticulously examined to ascertain how water was employed in the cultivation of maize. Using different types of sources provides a broader perspective on agricultural practices, including non-academic or non-expert knowledge, often undervalued. Each one reveal influences from regional practices, as well as regional or local knowledge, and express changes in perceptions about nature and access to plants in everyday life[22]. The findings will be elucidated in the subsequent sections.

Maize irrigation: central activity in agrarian texts

Water, along with fertilizer and temperature, is one of the most influential factors on plant development. In the case of maize, the lack of water can cause significant yield variations in certain types of soil[23]. The Green Revolution logic aims to maximise yield by emphasising the abundant contribution of external inputs and resources to agriculture, particularly the first two elements, which are more easily controllable. However, this approach may not be sustainable in the long term.

The construction of water storage and irrigation infrastructures in the Iberian states to increase agricultural production has been a recurrent concern during the last centuries. However, their implementation was delayed frequently until the 20th century[24]. These structures enabled economically viable maize cultivation in environments where it was previously unsuccessful. In the Iberian Peninsula, the increase in irrigated corn is part of a transition process that involves a change in the role of irrigation. Rainfed cereals, such as wheat, were occasionally watered to increase yields. However, since the middle of the 20th century, the construction of irrigation systems has allowed the substitution of these rainfed crops for others, such as maize, that need water to grow[25]. The changes associated with this transformation are not only landscape-related but also affect the social economy and the ecology of farming systems[26].

Maize success in less humid Iberian regions was considered an indicator of the transformation of dry land into irrigated land in areas affected by the works of the great hydrographic confederations of the Ebro and the Duero rivers[27]. In Portugal, by the 1980s, corn cultivation had spread throughout the entire country, including the newly developed irrigation fields in the south[28]. The introduction in new areas has led to significant changes in the agrarian system and landscape. Additionally, the increased availability of water, combined with the productivism ideas of recent decades, has facilitated the widespread adoption of maize cultivation practices that rely heavily on irrigation.

19 Šūmane et al., 2018.
20 Riley; Harvey, 2007.
21 Nazarea, 2006.
22 Gomes; Freire, 2023.

23 Dirks; Bolton, 1981.
24 Fernández Clemente, 2000. Baptista, 1993. Almeida; Faísca; Freire, 2023.
25 Pinilla Navarro, 2008, 322-27.
26 Parcerisas-Benedé, 2016.
27 Sindicato de Productores de Semillas, 1935.
28 Faísca, 2019.

Corn irrigation has been a long-standing agricultural practice that has received attention in the literature. However, meeting the water demands for agriculture has been a challenge in many areas of the Iberian Peninsula due to climatic irregularities such as prolonged droughts or torrential rains, and limited possibilities of using many riverbeds due to ground characteristics[29]. In this context, the water requirements of the cereal act as environmental limit to its development in most of the Iberian territory. Therefore, the scarcity of this resource was the main limiting factor for its cultivation[30].

In the 18th century, João António Garrido recognised the importance of maize in bread making in the Iberian northwest. For cultivation, watering if possible and weeding were advisable[31]. On the other side of the border, agronomist José Antonio Valcárcel included a practice developed by farmers to increase maize yield where water played an important role. It involved earthing up the plants, ploughing the land again, spreading manure, covering it with a hoe, and irrigating the roots[32]. At the start of the 19th century, botanists from the Royal Garden of Madrid reviewed Herrera's General Agriculture and added information on the cultivation of this cereal. The crop had only recently arrived in the Iberian Peninsula in 1513, the year of the original text. Depending on the climate, the botanists distinguished between cultivation regimes in the “cool provinces” of the north and the “warm and dry” regions where irrigation was necessary for the cereal to grow and survive[33].

According to this text, in dry regions, it is essential to provide necessary irrigation for plant conservation and development when needed, at the risk of perishing during summer. However, specific moments require some irrigation. The first is when the plant produces its primary leaves, watering the soil as needed. The second moment is shortly after hilling to encourage plant vegetation. Additionally, the farmer was required to thin out the plants that had grown too closely together, replant any empty spaces in the field, and eradicate all weeds. After four to five weeks, the field required another watering[34].

However, the authors did not establish precise rules for irrigation due to the vast differences in the forms of organization required to carry out this action. As a result, each farm plot presents a unique irrigation challenge that must be carefully considered[35]. The absence of irrigation infrastructure may have hindered the exploration of new, potentially wasteful patterns. Thus, traditional agricultural literature from the 18th and 19th centuries did not mention established irrigation patterns or new ones based on experimentation.

The use of oral testimonies is notably useful in identifying these irrigation rules. Memories can date back to ancient organic-based agriculture prior to the transformation of agroecosystems following the implementation of Green Revolution guidelines. The elders of each community remember calendars passed down from their parents and grandparents. These calendars were cyclically repeated, adapted to the weather, and had specific times of use for each neighbour. The process started at sunset but could continue until late at night, depending on the water demand due to evaporation and moisture conservation concerns related to daytime temperatures. The activity encouraged community meetings and created social scenes that lasted for hours, while other farms waited their turn.

The development of agricultural research in the last century has transformed this local agricultural knowledge. Careful experimentation has been carried out to improve irrigation and other tillage practices. Research has focused on actions, times, and possible yields in detail, seeking standardisation of methodology and the development of protocols. It can be argued that local knowledge has reached a stage of professionalisation and become technical. Numerous tests have helped to understand the details of irrigation in relation to the physiological development of maize. Additionally, this knowledge has been shared with farmers for their benefit throughout the 20th century.

Maize is not tolerant to extreme water contributions, whether it be excess or deficiency. This is due to fluctuating water needs during its growth and poor tolerance to flooding, which makes the design of the irrigation process complex. It is important to note that irrigation can also affect fertilisers and lead to a loss of nutrients through washing[36]. After germination, a slight water shortage can benefit root development[37]. However, as the life cycle progresses, the situation is reversed. The plant's highest water requirements occur

29 Ortiz Cañavate; Ortiz Cañavate, 1895, 6-16.
30 Seabra, 1938, 32.
31 Garrido, 1749, 25.
32 Valcárcel 1765, III, 260.
33 Arias y Costa et al., 1818, I, 205.
34 Arias y Costa et al., 1818, I, 206-7.
35 Paulo da Costa, 1981, 46.
36 Aguilar Portero; Rendón Velázquez, 1983, 15.
37 Castañón, 1945, 9.

during the 30 to 40 days between two to three weeks before male flowering and two to three weeks after pollination[38]. During this crucial phase, the plant requires a substantial amount of water. Insufficient water supply can result in severe crop losses. Therefore, despite the relatively short irrigation period, it is essential to ensure an adequate water supply[39]. Of course, the practice and the water amount provided change according to the climate, the temperature, or the soil type.

Therefore, irrigation needs to be planned with consideration for its efficiency, which relates the volume of water transpired by the crops to the volume of water used for watering[40]. However, efficiency decreases progressively with increasing water supplies beyond a certain level. In contrast to fully irrigated maize, deficit irrigation programmes can be implemented with optimisation schedules to prevent water stress effects. This approach results in significant water savings at the cost of a slight decrease in yield, leading to increased water productivity –because the amount used produces an optimal yield[41].

Reploughs and plant arrangement: "forgotten" sustainable techniques

Technicians have focused on improving farming practices beyond irrigation, such as reploughing and adjusting plant arrangement to increase soil water content. These practices are relevant for both irrigated and rainfed crops, but particularly important for the latter due to the unreliable water supply caused by fluctuations in rainfall, which can leave plants without water for extended periods. Therefore, these actions are closely related to soil moisture management and one of their main objectives is to reduce evaporation[42].

Reploughing involves removing the top layer of soil without damaging the roots once the maize has started to grow. This practice aims are to increase soil permeability to air and water[43], resulting in a stratum of loose soil that is suitable for hilling —the piling up of soil around the plant stem—. It promotes uniform water distribution during irrigation and covers the lower nodes that emit adventitious roots with soil, providing greater strength and stability to the plant[44]. It eliminates weeds that harm the main crop by competing for resources through transpiration[45]. Reploughing helps to prevent water stored in the soil from being lost too quickly through direct evaporation, which attenuates when the soil surface is loose and spongy. Additionally, reploughing promotes the settling of significant amounts of dew water in the upper layers of the soil[46]. In the early 20th century, it was considered that consecutive reploughing led to a higher and safer harvest while also preparing the land for the next crop after maize. Based on popular wisdom, some technicians claimed that "replough is equivalent to watering" or "a replough worth as much as watering." In regions with limited water resources, ignoring this practice could result in a ruined harvest[47].

Therefore, the benefits of reploughing are numerous in terms of water management: it helps eliminate weed competition, facilitates water conduction over the surface, reduces evaporation, and aids in fixing water from dew on the ground. Although this knowledge improved in the first decades of the 20th century, some scholars collected it in the 19th century. The connection between reploughs, earth up, and humidity was already established. Authors wrote that avoiding the growth of harmful plants around maize can prevent soil crust formation, whereas piling up soil around the stem can help moisture reach the deeper roots[48]. But if the weather was dry, those tasks must have been superficial to preserve the humidity of the upper layer of the ground[49].

However, the reploughing process requires significant labour to control the weeds. So, its abandonment is also related to the use of herbicides, which act as labour-saving agents. During the 1970s and 1980s, manual reploughing was still prevalent in both Iberian territories, particularly among small landowners. Technicians criticised the increase in cultivation cost resulting from the extraordinary work. They also attempted to explain why farmers avoided using these chemicals, citing high prices and distrust towards their effectiveness as the main reasons[50]. But the use of these herbicides —as well as new irrigation techniques— through European and

[38] Paulo da Costa 1981, 24.
[39] Aguilar Portero; Rendón Velázquez, 1983, 19.
[40] Playán Jubillar et al., 2000, 2-3.
[41] Zhang, 2003.
[42] Arana, 1932, 2. Seabra, 1938, 32-33.
[43] "Lavrador", 1913, 26-27.
[44] Aguilar Portero; Rendón Velázquez, 1983, 10, 16.
[45] Seabra, 1938, 30-31.
[46] Arana, 1935, 11.
[47] Arana 1932, 2-8; 1935, 11. Seabra. 1944, 6.
[48] Quinto, 1818, I, 209.
[49] Zayas, 1879, 32.
[50] Gomes Varela Morte, 1973, 36. Moreno-González; García González 1982, 12-15.

national subsidies that encourage the absence of tillage has been partly responsible for this loss of part of the cultural heritage and social bonds based on water management[51]. This phenomenon is due to the replacement of water-conserving tillage techniques —such as reploughing— with irrigation and herbicide control methods. Furthermore, it is crucial to consider the problems associated with managing natural resources since the transition to herbicides has also led to increased sediment production, runoff, soil erosion, and contamination of both soil and water reserves[52].

In water management, plant arrangement is another important technique besides reploughing. For maize, informative publications generally recommend increasing densities, with some limits which, if exceeded, would lead to plants disturbing each other. Too high densities would cause excessive competition among plants for available resources, thinning of the stem, lodging, and ultimately yield loss[53]. Conversely, wider spacing may encourage excessive plant tillering and the growth of underdeveloped cobs[54]. On the other hand, plant density is closely related to its layout on the ground and has changed to adapt to technological progress. This guarantees the passage of machines due to obvious space issues.

The review of historical references in agriculture manuals reveals that the analysis of these actions was initially more related to improving yields than water management. The main objective of these texts was to achieve an adequate arrangement of the plants to facilitate the subsequent necessary agricultural tasks as they grew. Valcárcel suggested a layout in groups of five lines, distant ten inches to one foot from each other, and five-foot gaps between the groups to allow the pass of the cultivator plough[55]. Instead, the botanists of the Royal Garden of Madrid recommended a distance of two and a half to three feet between furrows and a foot and a half between grains in each line[56]. Meanwhile, the clergyman Boedo y Cardois noted a practical and adaptive technique where plants should be spaced further apart if the maize was particularly vigorous[57].

It was not until the 20th century that scientific literature acknowledged the relationship between plant density and water management. Some authors have argued that when thinning out, the number of plants per hectare should not exceed the number that can fully develop and ripen, i.e. those allowed to grow by soil moisture[58]. However, the issue is even more complex since the connection is established not only with soil humidity but also with atmospheric moisture because the leaves of the plants act as a barrier between the fall of dew and the soil. Thus, plant arrangement as a farming practice in terms of water management links to the capacity of reploughing to fix dew humidity. In the late 1920s, Cruz Gallástegui, the Galician Biological Mission director, emphasised the crucial importance of this factor and its influence on yield:

> "In a plot covered with vegetation (…) the dew falls on the leaves of the plants, and since they cannot absorb it, it evaporates again during the day, and vegetables do not use it. But if the plants leave empty spaces of uncovered ground (…) the dew falls not only on the leaves but also above the land. It is absorbed with eagerness (…) If the sowing is haphazardly or in furrows, when the maize receives the second weeding, there are usually 35 to 36 thousand plants per hectare (…) When the maize reaches 50 to 60 centimetres in height (…) the plants touch each other by the leaves and the dew deposits on them without catching up the ground. Therefore, this distance is insufficient. One yard –85 centimetres– is the optimal separation that we have found at which production, far from suffering a decrease, actually increases"[59].

Recently, technicians have recognised that inadequate plant density is a crucial limiting factor in maize production[60]. In Iberian educational texts, a general tendency is to adopt a distance of 0,70 to 0,80 meters between rows, with similar densities in irrigated and dryland areas but generally higher in the former. Moving towards other drylands in the interior and south, the distance increases[61]. However, it is important to note that different technicians may reach different conclusions due to the wide variability of contexts, influenced by climatic and meteorological factors, the nature of the soil, and the variety and cycle of the maize

51 Keesstra et al., 2018, 12.
52 Keesstra et al., 2016.
53 Moreno-González, 1992, 200.
54 Aguilar Portero; Rendón Velázquez, 1983, 9-10. Gomes Varela Morte, 1973, 33.
55 Valcárcel, 1765, III, 259.
56 Arias y Costa et al., 1818, I, 205.
57 Boedo y Cardois, 1858, 95.
58 Arana, 1932, 2.
59 Gallástegui Unamuno, 1927, 9-10.
60 Moreno-González, 1992, 198.
61 Arana, 1935, 11. Besnier Romero 1963, 24. Aguilar Portero; Rendón Velázquez, 1983, 10.

used[62], whether it is for grain or forage[63]. Regarding this issue, there is a consensus among most experts that broadcast sowing, which involves randomly dropping seeds on the ground, is a wasteful and inefficient use of resources.

Currently, experts agree that density plays a crucial role in enhancing rainfall water efficiency, and moderate values aid in achieving this objective when combined with certain mulching strategies. Furthermore, the plant canopy's interception decreases, as noted by Gallástegui almost a century ago. This aspect is particularly significant in arid or semi-arid regions and areas where maize is grown under dryland regimes[64]. However, to increase density, sowing smaller varieties with less height has also been considered[65].

On its part, opinions from technicians about reploughing and hilling diverge. Reploughing, especially before sowing, can improve water retention and soil penetration, leading to better root development and higher yields. Hilling can also promote root growth, control root diseases and weeds, and increase harvest. However, it may contribute to soil erosion and, in some contexts, can be considered an unnecessary practice that harms root anchoring[66]. Additionally, both actions require extra work, resulting in increased costs.

Therefore, discussing farming techniques in general terms can be challenging due to the need for adaptation to the environment and its unique characteristics and also because maize is a plant highly influenced by its growing conditions. The same seed can have different expressions in different places, a phenomenon known as genotype × environment interaction[67]. However, as we can observe, despite all these factors, scientists and technicians have researched and attempted to improve some of those practices to favour a better development of maize through better management of water resources.

Plant breeding for adaptation. The development of hybrids

Experimentation with hybrids since the early 20th century has been relevant in water management. The rediscovery of Mendel's inheritance laws and Johannsen's method of inbred lines enabled their controlled production, completely transforming agriculture and agricultural economy[68]. The preceding practices pursued a better administration of the water available through direct supply or by managing the moisture remainder on the ground. However, the objective of this alternative approach is not mainly to preserve the resource but to adapt to the conditions resulting from its scarcity. As a result, drought-resistant lines were created, promoting more efficient plant development under water stress. It is a suitable trait for maize in most of the Iberian Peninsula since drought is the worst enemy for its cultivation in the southern regions[69]. Thus, increasing aridity can only boost interest in the progress of this research field.

Before the emergence of hybrids, there was already a debate among supporters of rainfed and irrigated land in Iberian territory regarding maize improvement related to water management. Some argued for increasing dryland maize production due to the region's natural conditions. On the other hand, some critics have deemed this approach unfeasible due to the low productivity of national rainfed varieties and the fact that their seeds quickly become impoverished if not carefully selected[70]. This confrontation connected with a broader discussion developed in Europe for several decades, revolving around the understanding of plant breeding and its adaptation to regional environmental conditions. In this debate, which continues to the present day, Harwood[71] distinguished between local strategies –producing plants that are well adapted to the local environment and then trying to increase their yields– and cosmopolitan strategies –developing varieties that perform well in several places with similar environmental traits, reproducing some factors under intensive farming conditions. However, in this matter, the political development in the Iberian Peninsula, with dictatorships in both states, limited the diversity of approaches, the innovative framework and its possibilities[72].

Finally, a controlled production of hybrids that disrupted these debates prevailed. A productive point of view took precedence over the adaptive one, relying on

62 The references in different places of the peninsula and for different times, in addition to those already mentioned, are abundant (Naredo 1917, 7. Paulo da Costa 1981, 36-37. Moreno-González; García González 1982, 10)
63 Gomes Varela Morte, 1973, 33.
64 Abuzar et al., 2011. Zheng et al., 2018.
65 Sangoi, 2001.
66 Bian et al. 2016.
67 Álvarez; Ruiz de Galarreta, 1999.
68 Pinar, 2000, 314.
69 Seabra, 1944, 5.
70 “Lavrador”, 1913, 9, 15.
71 Harwood, 2012, 45-46.
72 Pinar 1999. Saraiva 2010.

external inputs such as fertilizer and water. This has led to a tendency towards a preferential use of certain productive varieties, including lines from the American corn belt that are highly irrigated. The result was the progressive abandonment of autochthonous varieties and a growing scientific concern around the phenomenon in recent decades[73]. The erosion in genetic diversity prompted the establishment of germplasm banks to conserve these local varieties. In the middle of the century, many remained in the plots of small farmers[74]. In Spain and Portugal, these collections started at the end of the 70s[75].

As a result, large amounts of regional material have been made available for hybrid breeding programs. Before the arrival of hybrids, some technicians advised its preferential use over any other foreign variety[76]. With natural characteristics and sociocultural criteria that determined their distribution –such as seed exchange networks or belonging to ethnolinguistic groups[77]– the genetic diversity of these landraces is crucial to achieving new varieties suitable to specific uses and natural contexts, contributing to more resilient and diversified agricultural systems[78]. They possess valuable traits well-suited for adapting to environmental changes. However, if these changes accelerate, the natural evolving capacity of these local varieties may not be enough to ensure adaptation. In such cases, technicians have considered other strategies based on transgenic seeds, but this approach also presents significant challenges[79].

In this framework, improving existing genetic material or the introduction of new samples for adaptation was not carried out to overcome a single problem, such as water scarcity in a particular region. Instead, hybrid breeding programmes combine several overlapping objectives, including drought resistance as part of a broad programme for general adaptation and yield improvement, but also adaptation to different soil types, diseases, and vulnerabilities such as lodging, as well as specific traits such as early emergence or ripening.

These programs are highly specialized and typically only accessible to institutions with the capacity to operate over the medium term: private companies, public bodies or often a combination of both. In the case of maize, the reason is that it takes an average of seven to eleven years to obtain inbred lines representative of several desirable traits[80]. The Mabegondo Agricultural Research Centre (CIAM) in A Coruña and the Aula Dei Experimental Station (EEAD) in Zaragoza are two prominent institutions that have worked towards obtaining adaptive improvements in maize in Spain during the 20th century. They are both highly concerned with water management issues that directly impact the agroecosystems in their respective environments.

In the case of the arid interior regions of the Iberian Peninsula, annual activity reports of the EEAD reflect the lines followed in the field of experimentation with maize in this centre created in the 1940s. In recent decades, the prevailing approach has been to obtain hybrids adapted to local conditions, with a focus on agricultural, social, edaphic, and climatic factors. However, it is imperative to maintain maize varieties to ensure a solid genetic foundation for future projects. The aim is to conserve various local, national, and foreign populations as a basis for breeding work[81]. This centre operates in the Ebro basin, which is the main maize-growing region of the peninsula. In the 1950s, the centre registered six hybrid varieties suitable for cultivation in a large part of the country. During this period, they were tested under different irrigation conditions.

Concerns regarding water deficits are also relevant at CIAM, located in the humid and rainy northwest of the peninsula, but with regular summer droughts. Maize breeding programmes in this century-old institution have produced hybrids adapted to these humid conditions to achieve several desirable traits. Firstly, these programmes aimed for early vigour, displaying quick growth in maize despite the low temperatures and flooded soils in the area, which are typically detrimental to cereals. That is also a form of effective management of water resources, specifically in cases of excess. Secondly, the centre's programs aimed to improve the timing of both flowering and harvesting, again in response to the adverse weather conditions in the Galician region. Additionally, the desired traits included high yield,

[73] Ruiz de Galarreta; Álvarez, 2001, 391. Ordás Pérez; Malvar; de Ron 1994, 149.
[74] Sánchez-Monge, 1962, 2.
[75] De la Rosa; Martín 2016. Pego et al. 1977.
[76] Delegaçao Portugueza dos Produtores Chilenos de Nitrato de Sodio, 1912; Seabra, 1938, 16-17.
[77] Orozco-Ramírez et al. 2014.
[78] Fenzi; Couix, 2022, 328.
[79] Mercer; Perales; Wainwright, 2012.
[80] CSIC-Estación Experimental de Aula Dei, 1973, 14.
[81] CSIC-Estación Experimental de Aula Dei, 1983, 15-16.

resistance to lodging, and drought tolerance, enabling the plants to withstand periods of low water supply, including rainfed conditions[82].

Conclusions

This paper discusses various water resource management practices for maize cultivation that were already in use during the 19th century. Peasants have implemented some of them for centuries, while only advances in botanical science made others possible. But it is essential to highlight that at the beginning of the 20th century, specialists attempted to improve and standardize peasant knowledge based on scientific principles. While irrigation had a central role as the most common and geographically widespread technique, other farming practices were also important, especially in areas where maize was cultivated under rainfed conditions. Due to the irregularity of rainfall patterns, managing the remaining soil moisture was crucial. Such techniques vary depending on the moment, place, infrastructure, and available scientific knowledge. These aspects can even contribute to altering the traditional vision of the crop, for instance, from rational irrigation water management with the help of some complementary tillage practices –now devalued– to intensively irrigated cultivation to maximize yields.

Specialised literature from the 18th and 19th centuries rarely includes rules regarding irrigation. While there are some notes on watering periodicity, each community developed their own methods based on necessity and coexistence, which were not always conflict-free. However, the depiction of reploughs or plant arrangement was thorough because the success of a crop depended on managing the available soil water, especially given the difficulty in carrying out irrigation. In the study area, it is important to note that these techniques are almost geographically universal, which explains the attention they received in the past. So, they can and should be developed in most environments where maize is present.

However, the absence of some mentions is also important as they reflect social value or scarcity, which are fundamental principles for resource management systems and practices. For instance, in humid areas, there are reports of how atmospheric water can be a threat. If calm rains follow immediately after windy weather, the plants can recover. However, the combination of sudden rains and strong winds can destroy the maize field[83]. Of course, no references to irrigation are typical of places where watering is not necessary. In areas where rainfall is abundant, some interviewees deny the need for irrigation, while others are uncertain about its use or remember specific instances only during hot summers. The variety of testimonies highlights the diversity of water management practices for maize.

In recent decades, the use of hybrid corn has become widespread. This type of maize relies on external inputs such as fertilizers, pesticides, and water for growth, which has led to a decontextualized agriculture, disconnected from the environment due to the paradigm of the Green Revolution. Additionally, the overuse of hybrids has resulted in a narrow genetic base for this cereal. The failure to use locally adapted maize varieties resulted in their extinction. However, since the 1960s-70s, it has been possible to conserve these indigenous varieties through seed collection and preservation in germplasm banks, which are now available for new plant breeding programmes.

The development of water infrastructures for watering maize and the progressive increase in hybrids led to neglecting those other water management practices, which were equally important as irrigation. This paper highlights the significance of such practices over several centuries. In the current context of climate emergency, looking back at these practices may provide solutions to save water resources. The memory and oral testimonies of farmers' rules and practices about rational water management in maize cultivation, and the existence of a rich literature of scientific experiments in a place like the Iberian Peninsula –where maize was highly successful before the Green Revolution changes in production patterns– can point the way forward. For an increasingly technological, computerised and precision agriculture, the principles and rules of these traditional sustainable techniques –sometimes organised even at the local level– can help to design new actions that contribute to more efficient management of water resources and greater agricultural resilience.

[82] Moreno-González, 1992, 201.

[83] Boedo y Cardois, 1858, 95-96.

Acknowledgements

The main research for this paper was developed in the framework of the "ReSEED Project—rescuing seeds' heritage: engaging in a new framework of agriculture and innovation since the eighteenth century". It has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement 760090), having Dulce Freire as the principal investigator, and is hosted by the University of Coimbra at the Centre for Interdisciplinary Studies (UIDB/00460/2020).

Bibliography

Abuzar, M. R.; Sadozai, G. U.; Baloch, Mohammad Safdar; Baloch, A. A.; Shah, Imdad Hussain; Javaid, Tasifa & Hussain, Nazim. 2011: Effect of plant population densities on yield of maize. *Journal of Animal and Plant Sciences*, 21(4), 692-695.

Aguilar Portero, Manuel; Rendón Velázquez, Manuel. 1983: Cultivo del maíz en regadíos de climas cálidos. *Hojas Divulgadoras*, 1(83), 1-20.

Alberola Romá, Armando. 1997: Cultivos americanos en tierras valencianas durante la Edad Moderna: el maíz: introducción y desarrollo, en Morilla, José; Gómez-Pantoja, Joaquín; Cressier, Patrice (eds.), *Impactos exteriores sobre el mundo rural mediterráneo: del Imperio Romano a nuestros días*, Madrid (España), Ministerio de Agricultura, Pesca y Alimentación, 307-322.

Allen, Richard; Pereira, Luis; Raes, Dirk; Smith, Martin. 2006: *Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de los cultivos*. Roma (Italia), Estudio FAO: Riego y Drenaje.

Almeida, Luis Ferrand. 1992: A propósito de milho "marroco" em Portugal nos séculos XVI-XVIII. *Revista Portuguesa de História*, 27, 103-143.

Almeida, Luis Ferrand. 1995: Sobre a introduçao e a difusao do milho maís em Portugal, en Almeida, Luis Ferrand, *Páginas dispersas: Estudos de História Moderna de Portugal*, Coimbra (Portugal), Instituto de História Económica e Social, 229-259.

Almeida, Maria Antónia; Faísca, Carlos; Freire Dulce. 2023: Regadío y desarrollo agrícola en Portugal: repercusiones de la construcción de presas en el Alentejo (1958-2022). *Mundo Agrario*, 24 (55). https://doi.org/10.24215/15155994e209

Álvarez, Ángel; Ruiz de Galarreta, José. 1999: Genotype-Environment Interaction in Maize Landraces from Northern Spain. *Journal of Genetics and Breeding*, 53, 177-81.

Aragón-Ruano, Álvaro. 2021: The Diffusion of Maize in the Cantabrian Region and Its Economic and Demographic Consequences during the Ancient Regime. *Rural History: Economy, Society, Culture*, 32 (1), 23-40. https://doi.org/10.1017/S0956793320000102

Arana, Marcelino. 1932: Instrucciones para el cultivo del maíz en secano. *Hojas Divulgadoras*, 1/2-32, 1-9.

Arana, Marcelino. 1935: Necesidad de aumentar la producción del maíz en España y modo de conseguirlo. *Hojas Divulgadoras*, 11-35, 5-12.

Arias y Costa, Antonio; Boutelou y Agraz, Claudio; Clemente Rubio, Simón; Elizondo, José; Lagasca, Mariano; Martí, Francisco; Martínez Robles, Francisco; Pascual, Agustín. 1818: *Agricultura General de Gabriel Alonso de Herrera, corregida según el texto original de la primera edición publicada en 1513 por el mismo autor y adicionada por la Real Sociedad Económica Matritense*. Madrid (España), Imprenta Real.

Baptista, Fernando Oliveira. 1993: *A política agrária do Estado Novo.* Porto (Portugal), Afrontamento.

Besnier Romero, Fernando. 1963: La siembra del maíz a máquina. *Hojas Divulgadoras*, 3/4-63, 1-24.

Bian, Dahong; Jia, Guiping; Cai, Lijun; Ma, Zhiying; Eneji, A. Egrinya; Cui, Yanhong. 2016: Effects of Tillage Practices on Root Characteristics and Root Lodging Resistance of Maize". *Field Crops Research* 185, 89-96. https://doi.org/10.1016/j.fcr.2015.10.008

Boedo y Cardois, Manuel. 1858: *Elementos de agricultura*. Betanzos (España), Imprenta de J. Castiñeira.

Cabo Villaverde, Miguel. 1997: O labor da misión biolóxica de Pontevedra ata 1936 e a reforma da agricultura galega en Cruz Gallastegui Unamuno. *Cuadernos de Estudios Gallegos*, 44 (109), 103-52. https://doi.org/10.3989/ceg.1997.v44.i109.219

Castañón, Guillermo. 1945: El maíz forrajero. *Hojas Divulgadoras*, 13(45), 1-16.

Cavero Campo, José; Jiménez, Laura; Puig, Miriam; Faci González, José; Martínez-Cob, Antonio. 2008: Maize Growth and Yield under Daytime and Nighttime Solid-Set Sprinkler Irrigation. *American Society of Agronomy*, 100(6), 1573-79. https://doi.org/10.2134/agronj2008.0092

CSIC-Estación Experimental de Aula Dei. 1973: Memoria 1973. Zaragoza (España).

CSIC-Estación Experimental de Aula Dei. 1983: Memoria 1983. Zaragoza (España).

De la Rosa, Lucía; Martín, Isaura. 2016: Las colecciones de germoplasma de variedades tradicionales, en Ruiz de Galarreta, José; Prohens, Jaime; Tierno, Roberto (eds.), *Las variedades locales en la mejora genética de plantas.* Vitoria-Gasteiz (España), Servicio Central de Publicaciones del Gobierno Vasco, 43-59.

Delegaçao Portugueza dos Produtores Chilenos de Nitrato de Sodio. 1912: *A cultura do milho, batatas, cebolas, prados e hortaliças. Por meio dos adubos chimicos empregando o nitrato de sodio.* Lisboa (Portugal), Typographia Castro Irmão.

Dhanaraju, Muthumanickam; Poongodi, Chenniappan; Kumaraperumal, Ramalingam; Sellaperumal, Pazhanivelan; Ragunath, Kaliaperumal. 2022: Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture. *Agriculture* 12 (10), 1745. https://doi.org/10.3390/agriculture12101745

Dirks, Victor; Bolton, Everett. 1981: Climatic factors contributing to year-to-year variation in grain yield of corn on brookston clay. *Canadian Journal of Plant Science*, 61 (2), 293-305. https://doi.org/10.4141/cjps81-042

Doorenbos, Jan; Pruitt, William. 1977: *Crop Water Requirements*. FAO Irrigation and Drainage Paper 24. Roma (Italia), FAO.

Dubert, Isidro; Saavedra, Pegerto. 2018: Maíz, patata, coloniales... El impacto de los cultivos americanos en la agricultura y el comercio europeos, siglos XVI-XIX. *Obradoiro de Historia Moderna*, 27, 7-18.

Esperante, Bruno; Fernández Prieto, Lourenzo; Cabo Villaverde, Miguel. 2020: Old and new plants from the Americas to Europe: potatoes, corn and the genetics of double hybrid corn (1800–1940). *Rural History: Economy, Society, Culture,* 31, 53-62. https://doi.org/10.1017/S0956793319000396

Faísca, Carlos Manuel. 2019: A produção agrícola no Alentejo (1929-2018): uma primeira abordagem. *Revista de Estudios Económicos y Empresariales,* 31, 39-64.

Fenzi, Marianna; Couix, Nathalie. 2022: Growing maize landraces in industrialized countries: from the search for seeds to the emergence of new practices and values. *International Journal of Agricultural Sustainability,* 20(3), 327-345. https://doi.org/10.1080/14735903.2021.1933360

Fernández Clemente, Eloy. 2000: *Un siglo de obras hidráulicas en España: de la utopía de Joaquín Costa a la intervención del Estado*. Zaragoza (España), Universidad de Zaragoza.

Fernández Prieto, Lourenzo. 2001: Caminos del cambio tecnológico en las agriculturas españolas contemporáneas, en Pujol, J.; González de Molina, M.; Fernández Prieto, L.; Gallego, D. y Garrabou, R. (coords.), *El pozo de todos los males: sobre el atraso en la agricultura española contemporánea*. Barcelona (España), Crítica, 95-146.

Gallástegui Unamuno, Cruz. 1927: *Métodos para aumentar las producciones de maiz*. Pontevedra (España), Diputación de Pontevedra.

Garrido, João António. 1749: Livro de agricultura em que se trata com clareza, e distinçaõ do modo, e tempo de cultivar as terras de paõ, vinho, azeite, hortaliças, flores dos jardins, e pumares de fruta, como também da criaçaõ dos animaes domesticos, e da cassa dos bravios. Com muitos segredos, e importantes avizos, para que os homens do campo recolhaõ mais copiozo fruto do seu trabalho nas obras da agricultura. Lisboa (Portugal), Officina Alvarense.

Godinho, Vitorino Magalhães. 1981: Recursos tradicionais e inovações - O milho maiz", en Godinho, V.M. (ed.), *Os descobrimentos e a Economia Mundial*. Lisboa (Portugal), Presença, 4, 7-52.

Gomes, Inês; Freire, Dulce. 2023: Seeds of knowledge: paving the way to integrated historical and conservation science research. *Journal of Environmental Studies and Sciences*, 13, 376-88. https://doi.org/10.1007/s13412-023-00826-9

Gomes Varela Morte, José. 1973: *Cultura do Milho Híbrido no aproveitamento hidroagrícola do Roxo*. Évora (Portugal), Escola de Regentes Agrícolas de Évora.

Harwood, Jonathan. 2012: *Europe's Green Revolution and Others Since. The rise and fall of peasant-friendly plant breeding*. London (England), Routledge.

Keesstra, Saskia; Mol, Gerben; De Leeuw, Jan; Okx, Joop; Molenaar, Co; De Cleen, Margot; Visser, Saskia. 2018: Soil-Related Sustainable Development Goals: Four Concepts to Make Land Degradation Neutrality and Restoration Work. *Land*, 7(4). https://doi.org/10.3390/land7040133

Keesstra, Saskia; Pereira, Paulo; Novara, Agata; Brevik, Eric; Azorin-Molina, Cesar; Parras-Alcántara, Luis; Jordán, Antonio; Cerdà, Artemi. 2016: Effects of Soil Management Techniques on Soil Water Erosion in Apricot Orchards. *The Science of the Total Environment* 551-552, 357-366. https://doi.org/10.1016/j.scitotenv.2016.01.182

Lavrador, 1913: *O Milho. Sua cultura aperfeiçoada e rendosa*. Livraria do Lavrador, XI, Porto (Portugal), Officinas do Commercio do Porto.

Lovarelli, Daniella; Bacenetti, Jacopo; Fiala, Marco. 2016: Water Footprint of crop productions: A review. *Science of The Total Environment* 548-549, 236-251. https://doi.org/10.1016/j.scitotenv.2016.01.022

Magalhães, Joaquim Romero. 2010: Do tempo e dos trabalhos: a agricultura portuguesa no século XVII. *Revista Portuguesa de História*, 41, 59-72. https://doi.org/10.14195/0870-4147_41_3

Mercer, Kristin; Perales, Hugo; Wainwright, Joel. 2012: Climate Change and the Transgenic Adaptation Strategy: Smallholder Livelihoods, Climate Justice, and Maize Landraces in Mexico. *Global Environmental Change*, 22(2), 495-504. https://doi.org/10.1016/j.gloenvcha.2012.01.003

Moreno-González, Jesús. 1992: Mejora, evaluación y agronomía de maíces híbridos para zonas húmedas, en Barrecheguren, M. (Ed.), *100 años de investigación agraria 1888-1988: conmemoración do centenario da creación da Granxa Escola Experimental de A Coruña, actualmente CIAM*. Vol.2. Santiago de Compostela (España), Consellería de Agricultura, Gandería e Montes, 197-209.

Moreno-González, Jesús; García González, José. 1982: Cultivo del maíz en las zonas húmedas de España. *Hojas Divulgadoras*, 6-82, 1-20.

Naredo, Manuel. 1917: El maíz. *Hojas Divulgadoras*, 13(17), 1-8.

Nazarea, Virginia. 2006: Local Knowledge and Memory in Biodiversity Conservation. Annual Review of Anthropology, 35(1), 317-35. https://doi.org/10.1146/annurev.anthro.35.081705.123252

Ordás Pérez, Amando; Malvar, Rosa; de Ron, A. 1994: Relationships among American and Spanish Populations of Maize. *Euphytica*, 79(1), 149-61. https://doi.org/10.1007/BF00023586

Orozco-Ramírez, Quetzalcóatl; Brush, Stephen; Grote, Mark; Perales, Hugo. 2014: A Minor Role for Environmental Adaptation in Local-Scale Maize Landrace Distribution: Results from a Common Garden Experiment in Oaxaca, Mexico. *Economic Botany,* 68 (4), 383-96. https://doi.org/10.1007/s12231-014-9285-4

Ortiz Cañavate, Fernando; Ortiz Cañavate, Miguel. 1895: *Problemas agrícolas: cereales de secano*. Madrid (España), Imprenta de Antonio Menárguez.

Panda, Rabindra; Behera, Subrat; Kashyap, Pradeep. 2004: Effective Management of Irrigation Water for Maize under Stressed Conditions. *Agricultural Water Management,* 66(3), 181-203. https://doi.org/10.1016/j.agwat.2003.12.001

Parcerisas-Benedé, Lluís. 2016: Efectos de la introducción del regadío en la agricultura española: el caso de Vilassar de Mar, Barcelona (1850-1937). *Agua y territorio/Water and Landscape*, 7, 92-108. https://doi.org/10.17561/at.v0i7

Paulo da Costa, José. 1981: *O milho e a sua cultura*. Direcçao Geral de Extensão Rural. Ministerio da Agricultura, Comércio e Pescas.

Pego, Silas E.; de Andrade, L. F.; dos Maia S. N., J.; Martíns, M. A. 1977: *Banco Nacional de Germoplasma de Milho. Novo projecto para a sua formaçao*. Braga (Portugal), Núcleo de Melhoramento do Milho. Estação Agrária de Braga.

Pérez García, José Manuel. 1982: O Millo en Galicia: un estado da cuestión. *Revista galega de estudios agrarios*, 7-8, 87-104.

Pinar, Susana. 1999: La introducción de la genética en España durante el primer tercio del siglo XX. *Llull: Revista de la Sociedad Española de Historia de las Ciencias y de las Técnicas,* 22(44), 453-74.

Pinar, Susana. 2000: Sobre genética y plantas. La evolución de los métodos de mejora de plantas en la España anterior a la Guerra Civil. *Cronos: Cuadernos valencianos de historia de la medicina y de la ciencia,* 3(2), 313-48.

Pinilla Navarro, Vicente. 2008: El desarrollo de la agricultura de regadío en la cuenca del Ebro en el siglo XX, en Pinilla Navarro, V. (coord.), *Gestión y usos del agua en la cuenca del Ebro en el siglo XX*. Zaragoza (España), Prensas de la Universidad de Zaragoza, 309-34. https://doi.org/10.26754/uz.978-84- 7733-997-7

Playán Jubillar, Enrique; Faci González, José; Cavero Campo, José; Dechmi, Farida; Lecina Brau, Sergio. 2000: Casos de estudio: ahorro de agua en los regadíos de Aragón. V Conferencia Internacional "Nuevas Fuentes de Suministro de Agua". Valencia, 24-25 noviembre 1999.

Quinto, Agustín. 1818: *Curso de agricultura práctica. Conforme a los últimos adelantamientos hechos en esta ciencia y a las mejores prácticas agrarias de las demás naciones de Europa*. II vols. Madrid (España), Imprenta de Collado.

Rebourg, Cécile; Chastanet, Monique; Gouesnard, Brigitte; Welcker, Claude; Dubreuil, Pierre; Charcosset, Alain. 2003: Maize Introduction into Europe: The History Reviewed in the Light of Molecular Data. *Theoretical and Applied Genetics 106* (5): 895-903. https://doi.org/10.1007/s00122-002-1140-9

Rebourg, Cécile; Gouesnard, Brigette; Charcosset, Alain. 2001: Large Scale Molecular Analysis of Traditional European Maize Populations. Relationships with Morphological Variation. *Heredity,* 86 (5), 574-87. https://doi.org/10.1046/j.1365-2540.2001.00869.x

Revilla Temiño, Pedro; Soengas Fernández, María; Cartea González, María; Malvar Pintos, Rosa; Ordás Pérez, Amando. 2003: Isozyme Variability among European Maize Populations and the Introduction of Maize in Europe. *Maydica,* 48 (2), 141-52.

Revilla Temiño, Pedro; Soengas Fernández, María; Malvar Pintos, Rosa; Cartea González, María; Ordás Pérez, Amando. 1998: Isozyme Variation and Historical Relationships among the Maize Races of Spain. *Maydica* 43, 175-82.

Ribeiro, Orlando. 1991: O milho, a vida rural e a expansão portuguesa, en Ribeiro, Orlando (Ed.), *Opúsculos Geográficos*, vol. 4., *O mundo rural*. Lisboa (Portugal), Fundação Calouste Gulbenkian, 193-206.

Riley, Mark; Harvey, David. 2007: "Oral histories, farm practice and uncovering meaning in the countryside". *Social & Cultural Geography* 8(3), 391-415. https://doi.org/10.1080/14649360701488823

Ruiz de Galarreta, José; Álvarez, Ángel. 2001: Morphological Classification of Maize Landraces from Northern Spain. *Genetic Resources and Crop Evolution*, 48, 391-400. https://doi.org/10.1023/A:1012074606561

Saavedra, Pegerto. 2018: El maíz en el sistema agrario y en la alimentación en Galicia, siglos XVII-XIX. *Obradoiro de Historia Moderna*, 27, 49-80. https://doi.org/10.15304/ohm.27.5523

Sánchez-Monge, Enrique. 1962: *Razas de maíz en España*. Madrid (España), Ministerio de Agricultura.

Sangoi, Luis. 2001: Understanding plant density effects on maize growth and development: An important issue to maximize grain yield. *Ciencia Rural* 31 (1), 159-68. https://doi.org/10.1590/S0103-84782001000100027

Saraiva, Tiago. 2010: Fascist Labscapes: Geneticists, Wheat, and the Landscapes of Fascism in Italy and Portugal. *Historical Studies in the Natural Sciences,* 40 (4), 457-98. https://doi.org/10.1525/hsns.2010.40.4.457

Seabra, António Luis. 1938: *O milho. Preceitos para a sua cultura racional*. Lisboa (Portugal), Companhia União Fabril & Imperial Chemical Industries, LTD.

Seabra, António Luis. 1944: *Regras para a cultura do milho nos alqueives*. Lisboa (Portugal), Direcção Geral dos Serviços Agrícolas. Serviço Editorial da Repartição de Estudos, Informação e Propaganda.

Serrão, José Vicente. 2007: A agricultura portuguesa no século XVIII: progresso ou atraso?, en Motta, M. (Ed.), *Terras lusas: a questão agrária em Portugal*. Rio de Janeiro (Brasil), Editora da UFF, 31-70.

Sindicato de Productores de Semillas. 1935: *Boletín del Sindicato de Productores de Semillas*, 20.

Šūmane, Sandra; Kunda, Ilona; Knickel, Karlheinz; Strauss, Agnes; Tisenkopfs, Talis; de los Rios, Ignacio; Rivera, María; Chebach, Tzruya; Ashkenazy, Amit. 2018: Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *Journal of Rural Studies*, 59, 232-41. https://doi.org/10.1016/j.jrurstud.2017.01.020

Tenaillon, Maud Irène; Charcosset, Alain. 2011: A European Perspective on Maize History. *Comptes Rendus Biologies*, 334 (3), 221-28. https://doi.org/10.1016/j.crvi.2010.12.015

Urrego Pereira, Yenny; Martínez-Cob, Antonio; Cavero Campo, José. 2013: Relevance of Sprinkler Irrigation Time and Water Losses on Maize Yield. *Agronomy Journal*, 105 (3), 845-53. https://doi.org/10.2134/agronj2012.0488

Valcárcel, José Antonio. 1765: *Agricultura general y gobierno de la casa de campo: en que por estenso se trata de todos los Bienes del Campo, con los nuevos descubrimientos, y metodos de cultivo para la multiplicacion de los Granos, y del aumento en la cria de Ganados, y en lo demas dependiente de una Casa de Campo: todo con especiales avisos, e instrucciones.* 5 vols. Valencia (España), Joseph Estevan Dolz.

Vila-Traver, Jaime, Aguilera, Eduardo; Infante Amate, Juan; González de Molina, Manuel. 2021: Climate Change and Industrialization as the Main Drivers of Spanish Agriculture Water Stress. *Science of The Total Environment*, 760. https://doi.org/10.1016/j.scitotenv.2020.143399

Zayas, Francisco. 1879: *Cultivo del maíz*. La Habana (Cuba), La Propaganda Literaria.

Zhang, HePing. 2003: Improving water productivity through deficit irrigation: examples from Syria, the North China Plain and Oregon, USA, en Kijne, J.; Barker, R.; Molden, D. (Eds.), *Water productivity in agriculture: limits and opportunities for improvement*, Cambridge (USA), Cabi Publishing, 301-9.

Zheng, Jing; Fan, Junliang; Zhang, Fucang; Yan, Shicheng; Guo, Jinjin; Chen, Dongfeng; Li, Zhijun. 2018: Mulching mode and planting density affect canopy interception loss of rainfall and water use efficiency of dryland maize on the loess plateau of China. *Journal of Arid Land*, 10(5), 794-808. https://doi.org/10.1007/s40333-018-0122-y