



Review

# What Has Been Thought and Taught on the Lunar Influence on Plants in Agriculture? Perspective from Physics and Biology

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**Abstract:** This paper reviews the beliefs which drive some agricultural sectors to consider the lunar influence as either a stress or a beneficial factor when it comes to organizing their tasks. To address the link between lunar phases and agriculture from a scientific perspective, we conducted a review of textbooks and monographs used to teach agronomy, botany, horticulture and plant physiology; we also consider the physics that address the effects of the Moon on our planet. Finally, we review the scientific literature on plant development, specifically searching for any direct or indirect reference to the influence of the Moon on plant physiology. We found that there is no reliable, science-based evidence for any relationship between lunar phases and plant physiology in any plant–science related textbooks or peer-reviewed journal articles justifying agricultural practices conditioned by the Moon. Nor does evidence from the field of physics support a causal relationship between lunar forces and plant responses. Therefore, popular agricultural practices that are tied to lunar phases have no scientific backing. We strongly encourage teachers involved in plant sciences education to objectively address pseudo-scientific ideas and promote critical thinking.

**Keywords:** plant growth; agriculture; traditions; pseudo-science; lunar phases; physics; biology; education

## 1. Introduction

This paper addresses the existing dichotomy between what science shows regarding agriculture protocols and past and current agricultural practices in much of Europe and Latin America. More specifically, it focuses on some pseudo-scientific questions and beliefs that impregnate a large part of agricultural traditions and agronomic practices according to which certain lunar phases encourage plant growth while others compromise their development. These beliefs share our lives with scientific and technological advances not reached ever before.

After introducing the main features of the Moon and its phases, as well as the factors that determine plant growth, this study continues with a brief historical overview about what has been thought from the agricultural sector concerning the lunar influence on plants and crops. In this overview, we have included references to both earlier ages and the most recent trends within agriculture, such as biodynamic agriculture, which bases part of its operating on the close relationship between the Moon and plant growth.

Then, we analysed monographs on botany, plant biology and physiology—considered as texts of consolidated science—, searching for any mention about the Moon being a factor influencing plant growth. At the same time, we reviewed physics handbooks, focusing on which aspects or natural

processes the Moon has influence on, looking for any mention of some type of effect on living beings and, specifically, on plants.

The paper concludes with a reflection on the implications of the different existing visions lasting over time within both the field of agriculture and citizenship in general, being part of the global desirable scientific literacy.

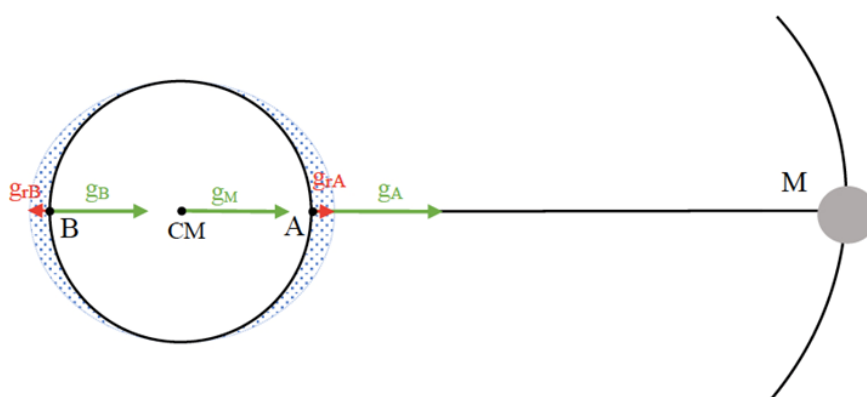
### 1.1. The Moon

This section covers the basic key aspects about the Moon required to understand most of the arguments detailed in the subsequent analysis of both scientific literature and explanations provided by some agricultural sectors.

#### 1.1.1. The Gravitational Pull

The Moon is the only natural satellite of our planet describing an elliptical orbit around it with a semi-major axis of 384,000 km, an eccentricity of 0.0549 and an angle of  $5^{\circ}9'$  relative to the ecliptic plane. The Moon takes 29.5 days to orbit around the Earth and return to its analogous position with respect to the Sun and the Earth (lunar month or synodic month) [1]. However, it takes 24.8 h for a specific location on the Earth to rotate from one exact point beneath the Moon and back (lunar day) [2,3]. The combined action of these two cycles (lunar month and day) has different effects on the Earth such as changes in tides and in the intensity of illuminance.

So, what is the explanation for the Moon's influence on tides? Tides are due to the difference in gravitational pull (or gravity acceleration) between the part of the oceans which are nearest (A) and farthest (B) to the Moon and the relative acceleration in relation to the Earth's centre of mass (CM) in such points (Figure 1).

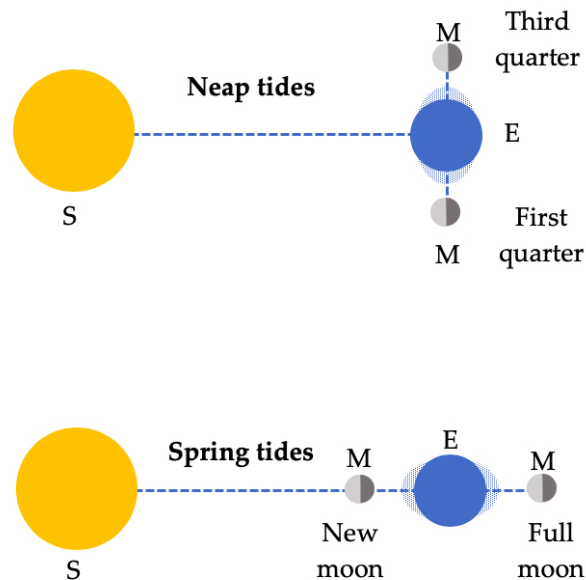


**Figure 1.** Representation of how tides are produced. In the drawing,  $g_M$  represents the acceleration in the Earth's centre of mass (CM) caused by lunar attraction;  $g_A$  and  $g_B$  are, respectively, the accelerations of points A and B located at both ends of the Earth's surface over the Earth–Moon line, and  $g_{rA}$  and  $g_{rB}$  are the acceleration in relation to the Earth's CM. Modified from Martínez et al. [1].

From the gravitational point of view, the effect of gravity on the Earth's CM produced by the Moon ( $g_M$ ) can be calculated by means of the expression  $g_M = Gm/r^2$ , being  $G$  the universal gravitational constant,  $r$  the distance Earth–Moon (E–M) and  $m$  the mass of the Moon. That is to say, the value of the Moon's gravity on the Earth's surface is approximately 2,951,800 times lower than the Earth's gravity ( $g_M = 3.32 \times 10^{-5} \text{ ms}^{-2}$ ). Therefore, the gravitational pull is negligible. Accordingly, the Sun's gravity ( $g_S$ ) on the Earth is 177 times greater than the Moon's ( $g_S = g/1627 = 177 g_M = 6 \times 10^{-3} \text{ ms}^{-2}$ ).

We can also calculate the Moon's gravity in point A ( $g_A \approx g_M(1 + 2R/r)$  being  $M$  the mass of the Earth and  $R$  its radius) and in point B ( $g_B \approx g_M(1 - 2R/r)$ ) and their relative accelerations in A ( $g_{rA}$ ) and B ( $g_{rB}$ ) regarding Earth's CM ( $g_{rA} = g_A - g_M \approx 2GmR/r^3 = 2Rg_M/r$  and  $g_{rB} = g_B - g_M \approx -2GmR/r^3 = -2Rg_M/r$ , respectively) (Figure 1). From these calculi, we observe

that the relative acceleration in relation to CM depends on the distance between A and B and on the cubed distance between the Earth and the Moon, instead of squared distance, rendering identical values in both A and B points (as  $r = 60 R$ , its value is  $10^{-6} \text{ ms}^{-2}$ , 30 times lower than  $g_M$ ) but in the opposite direction: the relative acceleration in point A ( $g_{r_A}$ ) is directed towards the Moon and in point B ( $g_{r_B}$ ) towards the opposite direction [1,4]. Therefore, there will be high tide in A and B, and low tide in those points located at  $90^\circ$  (Figure 2).



**Figure 2.** Diagram to illustrate the Sun (S)–Earth (E)–Moon (M) configuration regarding neap and spring tides. Source: designed by the authors.

For this reason, although the Sun's gravity on the Earth is greater than the one from the Moon, as tides are influenced by the inverse of the distance to cube ( $1/r^3$ ), its effect is lower than the one from the Moon, as its distance is much greater. And as tides depend on the size of the object, in the Mediterranean Sea, for instance, these are negligible due to the fact that it is a semi-enclosed, shallow and small sea (with an average depth of  $R = 1500 \text{ m}$ ). In contrast, as all the oceans are communicated, we can consider their size being the size of the Earth and, therefore, tides are apparent. In this sense, the tidal effect of the Moon over a 2 m height living being located on the Earth is about 1000 times lower (tidal acceleration =  $2 g_M h/r = 3 \times 10^{-13} \text{ ms}^{-2}$ ) than the effect produced by a mass of 1 kg at 1 m height above it ( $2.67 \times 10^{-10} \text{ ms}^{-2}$ ) [5].

Thus, because of the daily rotation of the Earth, the tides rise and fall twice each lunar day in most coastal areas and estuaries at intervals of approximately 12.4 h (tidal cycles) reflecting the lunar 24.8 h day. The amplitude of successive tides is also modulated every 14.77 days, or semi-lunar cycle. So, the highest tides, or spring tides, take place when the Sun and the Moon are aligned with the Earth (i.e., full and new moon), and the lowest, or neap tides, occur when the Sun–Earth axis and the Moon–Earth axis are at right angles ( $90^\circ$ ) to each other (i.e., first and third quarter) (Figure 2) [2,6]. These tidal forces due to the Moon and the Sun are also observed in the atmosphere and the Earth's crust [7].

### 1.1.2. Illuminance

The moonlight we see from the Earth is the sunlight reflected on the greyish-white surface of the Moon. Since the Moon orbits the Earth and the Earth orbits the Sun, the fraction of the Moon we see changes along the lunar month giving rise to the lunar phases, being new moon, first quarter, full moon and third quarter the main ones. The illuminance (defined as the amount of luminous flux striking a

surface per unit area) varies depending on the lunar phase [2,8]. In the case of the Moon, as endpoint cases we can find 0.001 lx for a new moon and 0.25 lx for a full moon to 0.01 lx for a crescent or waning moon (Table 1).

**Table 1.** Illuminance according to the Moon phase.

| Illuminance (lx) | Description                              |
|------------------|--|
| 0.001            | Clear night sky, new moon                |
| 0.01             | Clear night sky, crescent or waning moon |
| 0.25             | Full moon on a cloudless night           |
| 600              | Sunrise or sunset on a cloudless day     |
| 32,000           | Sunlight on an average day (minimum)     |
| 100,000          | Sunlight on an average day (maximum)     |

Source: adapted from RCA Corporation [9] and Schlyter [10].

As it can be seen in Table 1, the Moon's maximum illuminance is 128,000 times lower than the minimum of sunlight on an average day or 400,000 times lower than the maximum of sunlight on an average day.

### 1.2. Factors Influencing Plant Growth and Development

The revision carried out considers plant growth and development from a holistic point of view. This implies all those changes in structure and function of plants and their parts, the course of genesis, assimilation, growth and development, as well as environmental, physiological and chemical modifications, maturation and decline [11–15].

Plant growth and development is regulated by both endogenous and external factors [12,14]. Regarding endogenous factors, phytohormones are in charge of the coordination of metabolic and developmental processes at the molecular and cellular level. Phytohormones can be divided into two groups depending on their functions: (i) those involved in growth-promoting activities; (ii) those in charge of responding to wounds or to biotic and abiotic stresses [16]. Synthesis or changes in the concentration of these phytohormones transduce the perception of environmental stimulus (i.e., radiation, photoperiod, temperature, gravity or stresses as cold, heat, drought or flooding). However, which plant hormones will be triggered will depend on the plant developmental state, the type of external stimulus, the part of the plant exposed, when this stimulus arrives, etc. [14]. Phytohormones, together with external factors, can activate growth and differentiation processes and allow the synchronization of plant development and seasonal changes. Furthermore, they also regulate plant growth (intensity and direction), the metabolic activity and the storage and transport of nutrients. All these endogenous factors are determined by endogenous genetic components (genome structure and gene expression, i.e., plant genotype) [17].

The growth and development of plants can also be affected by external factors such as quality, intensity, direction and duration of radiation, temperature, position with relation to Earth's gravitational field and stresses conferred by wind, water currents or snow cover, apart from other chemical influences. These external factors can initiate, complete and regulate the timing of developmental processes (inductive mode of action) but can also act quantitatively (by altering the speed and extent of growth) and formatively (by affecting morphogenesis and tropisms) [14]. These external factors are the ones which might be affected by a potential effect of the Moon—specifically, the gravitational and illuminance effects—.

Other authors propose to split the factors that determine quality and quantity into biotic and abiotic factors [18,19]. Within the biotic factors, we find arthropods, nematodes, bacteria, fungus and viruses as well as their relationships with other plants and organisms which can be competitive, mutual or parasitic types, among others [20]. In addition, within the abiotic factors, we find soil composition, salinity, pH, temperatures, pollution, humidity (water), wind and ultraviolet radiation, among others. The interaction of biotic and abiotic factors will determine plant growth, development,

and productivity. Understanding their interactions is essential in agriculture when searching for the ideal growth conditions for each particular plant. In this sense, stress physiology research is very valuable, as it focuses on whether the full genetic potential of plants will be fulfilled and if plants will attain maximal growth and reproductive potential depending on different factors [21]. In particular, the study of abiotic stress originated from excess or deficit in the physical, chemical and energetic conditions to which plants are exposed provides farmers with guidelines for optimizing their harvests.

The references to the potential influence of the Moon on plants will have to be searched considering this influence as an abiotic factor. The excess or deficit of this factor should be studied taking into account that the Moon is always present, so the search should focus on those moon-derived sub-factors that can undergo substantial changes. The indirect possible effect of the Moon on the biotic components interacting with plants is a matter which falls outside the scope of the revision carried out in this paper.

## 2. What Has Been Thought on the Influence of the Moon on Plants

This section focuses on all those aspects related to agriculture that, according to some traditions, are determined by the Moon. To do so, we have developed a brief overview of what has been thought and written throughout history about the influence of the Moon on living beings and, in particular, plants. This analysis addresses manuals which have been used and are still used in certain agricultural sectors and information present on websites related to agriculture, gardening, agricultural machinery and so on. A special section is dedicated to biodynamic agriculture which links plant growth and lunar phases.

### 2.1. Brief Historical Overview

The Moon and the Sun hold a significant place in many mythologies and popular legends throughout the world. In particular, beliefs regarding the relationships between lunar phases and human and other organisms' behaviour are as ancient as human cultural heritage but have hardly ever found any solid scientific support [22].

Assertions concerning the existence of repetitive cycles in the Moon (phases), the Sun (day/night, solstices, and equinoxes/seasons), and Sirius (its heliacal rising) were extremely useful to develop lunar, lunar–solar and solar calendars, and to predict eclipses—just as it happened in the Egyptian, Babylonian, Greek or Chinese world. Such knowledge was continued in different cultures, mainly the Arab or the Mayan, the Aztec, and the Inca in America [23,24]. It is known that the Mayan carried out thorough observations of natural events, finding certain cyclical repetitions which allowed making predictions and organising when to sow or harvest [25].

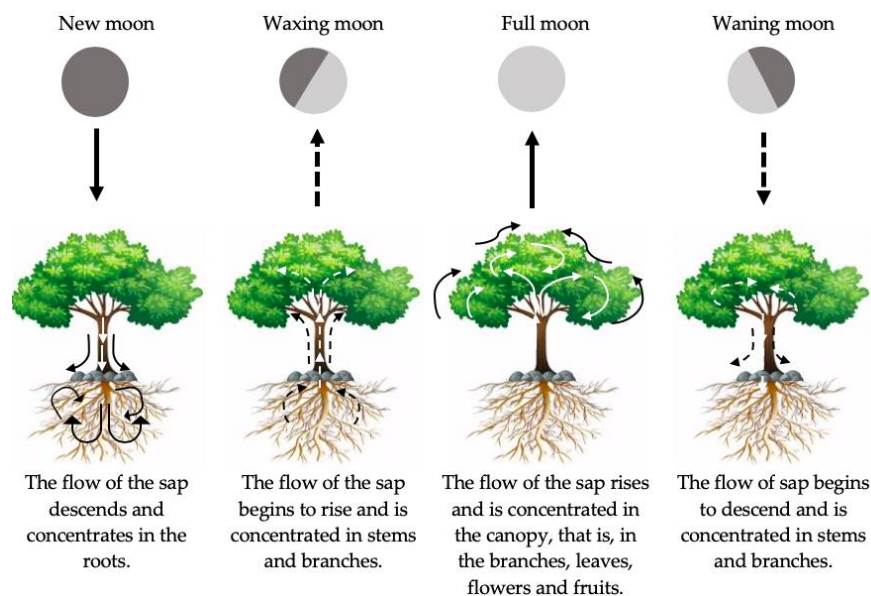
Botanists and herbalists from the seventeenth century, such as Nicholas Culpeper (1616–1654), believed that plants and ailments were determined by constellations. The Sun ruled our heart, blood circulation and spine, while the Moon had influence on growth, fertility, breasts, stomach, uterus and menstrual flow. In fact, all the body fluids, as the tides, were controlled by the lunar phases. This was the prevalent belief at that time, since astrology was broadly accepted as the key to understanding the universe [26].

Surprisingly, these beliefs are still active, as shown by Phillips [26] in his *Encyclopaedia of Plants in Myth, Legend, Magic and Lore* which includes more than 200 entries linking different plant species or genera with stars or natural elements. This author states, as we have been able to check along with personal interviews made in the agricultural and rural world of the Iberian Peninsula, that garlic (*Allium sativum* L.) has been strongly associated with the Moon, and it was thought to grow stronger as the Moon waned. However, Navazio [27], in his manual dedicated to the organic seed grower, makes no mention of the Moon as an element to consider. Potato growing (*Solanum tuberosum* L.) is also supposed to be influenced by the Moon. According to different beliefs this underground crop should be planted during the black moon, that is to say, when it is waning [26]. But, once again, Navazio [27] does not mention the need to consider this aspect in the organic cultivation. Other examples would be the white clover (*Trifolium repens* L.), which has to be seeded by the darkness of the Moon or “no-Moon”—that is

during the 24 h between the waning moon and the crescent moon—if you want it to grow, since if it is seeded under the moonlight, it will not sink into the ground [26]. Or corn (*Zea mays* L.), the seeds of which must be planted by moonlight in order to obtain a good performance [26].

Anglés Farrerons [28], in his work *Influence of the Moon on Agriculture and Other Topics of Main Interest for the Farmer and People from the City*, collects all the existing beliefs among elder farmers regarding the Moon. He dedicates specific chapters to the vine and the wine, the fruit growing, the cereals, the olive tree, several horticultural crops such as chard (*Beta vulgaris* var. *cicla* (L.) K.Koch), artichoke (*Cynara cardunculus* var. *scolymus* (L.) Benth.), garlic, celery (*Apium graveolens* L.), onion (*Allium cepa* L.), etc. Anglés Farrerons [28] also focuses on tree felling, forage harvesting, influence of animal manure or weather forecast. According to these traditions, he states when to sow, prune, harvest, etc., depending on the Moon phase and the crop, being true nonsense in some cases, just as the author suggests in his introduction.

Another work that requires special attention is that of Restrepo [29], a Brazilian agronomist who reflects the beliefs from Latin America and the Caribbean Area. He provides an interesting revision of the calendars of the ancient people and cultures as well as an extensive description of when to carry out all the agricultural practices (e.g., sow, layer, graft, prune, transplant) based on whether they are annual or perennial plants, vegetables, cereals and grains, tubers, bulbs and rhizomes. He also includes a description of how lunar phases and Moon illuminance affect the movement of the sap in plants (Figure 3).



**Figure 3.** Explanation of how lunar phases affect sap dynamics in plants according to Restrepo [29]. Redrawn and translated from Restrepo [29].

Which is the cause–effect explanation proposed to link lunar phases and sap movement? Restrepo [29] links it with the tides:

“Therefore, in certain positions of the Moon, the water from the oceans rises to reach a maximum height, and then goes down to a minimum level, maintaining this oscillation regularly and successively. It has also been checked that this phenomenon makes itself felt in plant sap”. (Translated from Restrepo [29]).

It has already been shown that the effect of the tide of the Moon on a 2 m height living being is absolutely negligible ( $3 \times 10^{-13} \text{ ms}^{-2}$ ), compared to the Earth’s gravity ( $9.8 \text{ ms}^{-2}$ ) [5]. But considering the tides, there are two high tides and two low tides each day, so if the tide caused any effect on a plant, there should be two sap rises and falls per day and none with the lunar phases. If the latter wanted to

be introduced, we have already seen that at both new moon and full moon, the tides are a bit stronger due to the fact that the Sun and the Moon are aligned (as the Sun is much farther away, its effect on the tide is much lower), but the effects of the tide are symmetrical making the water rise (Figures 1 and 2). Yet, to make matters more contradictory, Restrepo [29] assigns them different effects: the full moon takes up to the leaves the waters of the plant, and the new moon takes them to the roots. On the other hand, the illuminance is the only thing that surely varies with the Moon phases (Table 1), but it does not generate any force that can cause the movement of the sap.

Finally, it has to be pointed out that there are beliefs and practices contained in many different manuals which we did not pretend to either analyse or introduce in detail in this paper. Only as an example, we outlined best sellers, such as *The Secret Life of Plants* [30], in which certain physical, emotional and spiritual relationships between plants and our species are explained in such an appealing manner that have clearly helped to strengthen several pseudo-scientific beliefs among society and many farmers. This best seller has been explicitly refuted by texts, such as *The Not-So-Secret Life of Plants*, in which the historical and experimental myths about emotional communication between animals and plants are put to rest by researchers such as Galston and Slayman [31] or Horowitz et al. [32].

## 2.2. Agricultural Astronomy Manuals and Websites

Some authors summarise the situation such as follows [26]:

“There has been a certain amount of interest in planting according to the phase of the Moon. The basic premise being that ‘above ground crops’ should be planted in the light of the Moon, i.e., on the days between the new moon and the full moon. ‘Below ground crops’ must be planted in the dark of the Moon, that is between the full moon and the next new moon. Refinements on this require that leaf crops are planted at the new moon and fruit crops or flowers planted at the full moon”.

Apart from the agricultural traditions that could explain the use of the Moon as a calendar to organise the crops, the time of seeding, harvesting, reaping, etc., and the advice given by some authors on an individual basis, some companies have taken a step forward by developing a range of documents and even manuals appearing in the guise of scientific advice, which raise popular wisdom to the category of regulated recommendations [33–38]. Such manuals are used as reference books by many farmers at the small and large scales, and they offer a scheduled sequence of agricultural activities and, in many cases, advice regarding health care on the basis of the phases of the Moon and its ascending or descending position in the sky. But in this case, its influence is not obvious since neither gravitation nor illuminance vary.

We can also find these recommendations in the area of gardening with titles such as *Gardening by the Moon Calendar* [39]. This book provides guidance based on the following statements:

“The best rate of germination is achieved just before a full moon, when moonlight and the Moon’s gravitational pull are both at their maximum, grafting should be done on a waxing moon, because sap rises in plants during this period and this will help a graft to establish, pruning should be done on a waning moon, because the sap is now falling, and this will help cut surfaces to heal quickly and crops for storage should be harvested while the Moon is waning”.

Apart from the Moon, it includes elements about astrology to guide the practice: “the planting of fruit trees and bushes should be done when the Moon is passing through a fire constellation”. Besides, this author links the effectiveness of the response to the planetary influence on cultivating without chemicals, pointing out that chemical products desensitize agricultural land.

Many entries to websites link the influence of the Moon to the biodynamic agriculture and the zodiac, which has nothing to do with it since the zodiac are the constellations where the ecliptic passes by (the apparent path of the Sun among the fixed stars).

Some companies within the forestry, agriculture and gardening area also dedicate sections to providing advice on tasks related to the handling of vegetables, fruit trees, etc., on their websites (Table 2).

**Table 2.** Summary of the tasks recommended by a multinational company supplying forestry, agriculture, and gardening machinery according to the lunar phases.

| New Moon                | Waxing Moon                     | Full Moon               | Waning Moon            |
|-------------------------|---------------------------------|-------------------------|------------------------|
| Crop covering with soil | Prune diseased or fruit trees   | Prune                   | Sow root vegetables    |
| Fertilise               | Cultivate sandy soils           | Plant perennial species | Remove withered leaves |
| Remove weeds            | Sow flowers, leafy vegetables   | Transplant              | Water flowering plants |
| Remove withered leaves  | Grafting                        | Vegetative propagation  | Fertilise              |
| Sow grass               | Avoid watering flowering plants | -                       | Plant longleaf trees   |

Source: modified and translated from [40].

Moreover, this link between lunar phases and different aspects of cultivation rank highly in major search engines on the internet and in database image repositories, which raises many of the same ideas as Restrepo [29]—that lunar gravity changes according to the phases is the only way to explain popular beliefs concerning the influence of the Moon on plant growth. However, illuminance is the only thing that varies according to the phases, as it can be seen in Table 1. The Moon’s gravitational pull does not generate any force able to cause sap movement.

### 2.3. Biodynamic Agriculture

Part of the traditions regarding the Moon have been incorporated into biodynamic agriculture, an agricultural management system which is mainly based on the fact that the astronomical bodies influence crop production. As in other forms of organic farming, the use of industrial fertilizers, pesticides and herbicides is avoided. However, the difference lies in the use of plant and mineral preparations as additives to compost and soil sprays—“biodynamic preparations”—and in following a planting schedule for cultivation, sowing and harvesting based on cosmic forces and rhythms and, particularly, on Moon rhythm (Table 3) [41,42].

**Table 3.** Practices and products used in organic and biodynamic agriculture.

| Practice or Product  | Organic | Biodynamic |
|--|---------|------------|
| Crop rotation  | x       | x          |
| Polyculture or intercropping   | x       | x          |
| Cover cropping   | x       | x          |
| Low- or no-till  | x       | x          |
| Green manures  | x       | x          |
| Biological, cultural, mechanical and physical means of pest control                    | x       | x          |
| Biodynamic preparations that involve alchemy and homeopathy                            |         | x          |
| Lunar and astrological calendars for planting, managing and harvesting                 |         | x          |
| Stones used for channelling cosmic energy and radiant fields                           |         | x          |
| Burning of pests and weeds (pest ashing)   |         | x          |
| Sensitive testing (including biocrystallization or morphochromatography, among others) |         | x          |

Source: modified from Chalker-Scott [41].

This variant of organic agriculture, initiated in a series of lectures given by Rudolf Steiner [43] in 1924, is considered by some authors as an alternative approach to modern agriculture (see review in Brock et al. [44]), while others consider it as not being a science-based practice (see review in Chalker-Scott [41]). The latter brands it as a scam of great implantation in countries as advanced as Germany where it has its origin and from where Brussels is pressured to accept its principles. The restoration of soil quality, of the “harmony” of ecosystems, and of biodiversity can be pointed out as the main objective of biodynamic farmers. The US website for biodynamic certification marks an update of the Moon phases with a quotation from the Natural History of Pliny the Elder (23–79 CE)—the first-century Roman naturalist who wrote extensively about tides—, explaining that the Moon



“replenishes the Earth; when she approaches it, she fills all bodies, while, when she recedes, she empties them” [45].

Kirchmann [46] suggests that biodynamic agriculture has a mystical origin (called spiritualistic research by Steiner, and based on mediation and clairvoyance) that drove Steiner’s research to reject scientific inquiry because as he explained in the sixth lecture of the course, “We do not need any confirmation by circumstances or by external methods. Spiritualism is an extension of scientific thought broadening the prevailing one-sided scientific view, being true and correct”. A good example of this can be found in what Rudolf Steiner [47] wrote in 2004 insisting on the special care that should be taken when teaching questions about “moon forces”, since conventional science considers them pure superstition or mystical fantasy, being a truth that is still difficult to talk about openly. However, Kirchmann [46] maintains that “Steiner’s predictions that can be scientifically tested have been found to be incorrect”.

### 3. What Has Been Taught on the Influence of the Moon on Plants? Analyses of Handbooks and Scientific Literature

This section deals with all those aspects that are known and taught in the agronomic and biological background in relation to plant development. It also analyses the physics books that explain the influence of the Moon on our planet with the intention of clarifying whether they mention a possible relationship with plant development. Consequently, specific sections are devoted to those factors that could depend on or have an influence from the Moon, concretely in relation to the effect of gravity and the light reflected by it, both from the point of view of biology and physics. Likewise, the basic books on botany and plant physiology have been revised, paying special attention to those factors that are determining or causing stress to the development of plants.

The revision of the handbooks has been complemented with the information gathered from the analysis of different scientific articles published in data repositories, such as Web of Knowledge, Scopus or Google Scholar, using the keywords “Moon and plants” or “lunar and plants”.

#### 3.1. What Handbooks Say from the Perspective of Physics and Biology

According to traditional beliefs, the influence of the Moon on plant growth is attributed, among other factors, to the attractive forces that the satellite exerts on the Earth and more specifically on its waters. The gravitational theory of the Moon could be attributed for the first time to Kepler (1571–1630), who claimed that the ocean tides were produced by a hidden force from the Moon. Kepler believed it was due to the affinity that the Moon had for water which was one of the four basic elements [48] in [8]. Gravity was also recognised as an agent of lunar influence with the publication of “Principia” by Newton (1643–1727).

The analyses of various physics textbooks (Table 4) commonly used in science and engineering courses reveals that the term Moon appears in most of them linked to different concepts such as the distance from the Earth (as it was calculated in ancient times or as it is calculated today, with laser telemetry), the Moon’s gravity, tides, etc. With regard to the origin of tides, there are many possibilities: (i) it is not approached [49]; (ii) it is introduced in a qualitative way [50,51]; (iii) the exact dependence of  $R/r^3$  is provided where  $r$  is the distance Earth–Moon, and  $R$  is the size of the object on which the tides act—in the case of the oceans, the Earth’s radius [5]; (iv) locally, high tides are shown as an effect of the resonance [52] or tidal applications to produce energy are explained [53]. In order to find correct demonstrations of the tides, we have to deal with books on Astronomy (e.g., [4]) which, due to their extraordinary specificity, are beyond our general review.

Another factor that should be considered when approaching sap movement in plants is capillary action or capillarity, described as the spontaneous ability of a liquid to flow against gravity in a narrow space such as a thin tube or pipe (in plants, vascular tissues as xylem and phloem). This rising of liquid is the outcome of two opposing forces: cohesion (the attractive forces among similar molecules or atoms) and adhesion (the attractive forces among dissimilar molecules or atoms). In our case,

the contact area between the particles of the liquid and the particles forming the tube. Capillarity is high when adhesion is greater than cohesion and vice versa. There is another important factor in capillarity, which is the contact area, dependent on the diameter of the tube (i.e., vascular tissue). Capillarity interacts with other forces, as gravity, which should be included when considering possible gravitational effects of the Moon on plants. In this sense, Jurin's law is usually introduced, giving information on the height ( $h$ ) reached when balancing the weight of the column of a liquid and the force  $h = 2 \gamma \cos \theta / \rho g r$ , where  $\gamma$  is the surface tension ( $\text{Nm}^{-1}$ ),  $\theta$  is the contact angle,  $\rho$  is the density of the liquid ( $\text{kgm}^{-3}$ ),  $g$  is the gravity acceleration ( $\text{ms}^{-2}$ ) and  $r$  is the radius of the pipe (m). Therefore, the Moon's gravity would have to be subtracted from that of the Earth  $g = g_E - g_M$ , and since it is 288,000 times smaller, its effect on capillarity is negligible.

**Table 4.** Revision of some of the reference handbooks on physics in relation to possible mentions of the Moon affecting plants.

| Book                  | Issues Regarding the Moon                            |   |  |                         |
|-----------------------|--|---|--|-------------------------|
|                       | Gravity  | Tides   | Capillarity                                  | Luminosity              |
| Feynman [50]          | Law of Gravitation                                   | Qualitative explanation of tides  | No   | Illuminance $I = S/r^2$ |
| Gettys et al. [52]    | Point where $g_E = g_M$                              | Tides in the Bay of Fundy (e.g., resonance)   | No   | No                      |
| Giancoli [53]         | Law of Gravitation                                   | Tidal energy  | Jurin's Law and negative pressure            | No                      |
| Hewitt [5]            | Moon radius, distance Earth–Moon. Law of Gravitation | Compares Sun and Moon tides by distance. It makes approximations to introduce $R/r^3$ . Distinguishes between spring and neap tides. Applied to people. Tides in the ionosphere | Qualitative capillarity from surface tension | No                      |
| Holton and Brush [51] | Law of Gravitation                                   | Qualitative explanation of spring and neap tides  | No   | No                      |
| Tipler [49]           | Calculation of the $g_E$ on the Moon                 | No  | Jurin's Law                                  | No                      |

Source: authors' review.

Physics books, even those studying applications of physics in biology [53], do not deal with the Moon's influence on plant growth. This may be due to the fact that the Moon's gravity is, as we have seen in the Introduction (Section 1), negligible compared to that of the Earth. Regarding illuminance, since it is a topic addressed in specialized books on optics [54], it is not usually included in physics books (only one of them does, as shown in Table 4), even less lunar illuminance.

The analysis of reference handbooks and monographs dealing with plant growth and development in the background of biology, environmental sciences, forestry, and agronomy is a key issue to understanding the extent to which this is a question that is limited to agricultural practice and/or the scientific and training field. Table 5 shows a summary of six widespread and commonly used books on botany and plant physiology, making a synoptic review of the endogenous and exogenous factors that determine and modulate plant development. In particular, the focus has been placed on those Moon-dependent factors that could be beneficial or stressful for plants, specifically in relation to Moon gravity or to the light reflected by the Moon.

As mentioned in the Introduction (Section 1) and reflected in Table 5, plant growth and development are regulated by endogenous and exogenous factors. The possible effects of the Moon should be considered as abiotic external factors, either if the effect is considered to be due to the light reflected or to gravitation. Regarding light, we searched for possible quotes of the Moon when addressing light effects on seeds, plant development, phototropism, photoperiodism, phototaxis, photonasties and quantity and quality of light, etc. Focusing on gravitational influence, the search was made on different aspects of gravitropism.

**Table 5.** Revision of some of the reference handbooks on botany and plant physiology in relation to possible references to the Moon’s influence on plant growth.

| Handbook                   | Phase/Process                              | Endogenous Factors                       | Exogenous or Environmental Factors |   | Moon Mention |
|----------------------------|--|--|------------------------------------|---|--------------|
|                            |  |  | Biotic                             | Abiotic   |              |
| Arteca [12]                | Vital cycle                                | Endogenous growth substances             |                                    |   | No           |
|                            | Seeds                                      |  |                                    | Water, temp., aeration and light  | No           |
|                            | Flowering<br>Abscission                    |  |                                    | Photoperiod and vernalization<br>Temperature, oxygen and nutrients                | No<br>No     |
| Evans [13]                 | Growth                                     |  |                                    | Environment and ecosystem   | No           |
| Fosket [55]                | Development                                | Genetics                                 |                                    | Light versus darkness   | No           |
|                            | Embryogenesis, germination and development |  |                                    |   | No           |
|                            | Apical meristems and development           |  |                                    |   | No           |
|                            | Plant development                          | Plant-microbe and symbiotic interactions |                                    |   | No           |
| Vital cycle                |  |  | Phototropism and gravitropism      | No  |              |
| Raven et al. [56]          | Biological rhythms                         | Circadian and biological clocks          |                                    | Track of daylength by length of darkness  | No           |
|                            | Flowering                                  |  |                                    | Daylength as determinant of flowering time  | No           |
|                            | Photoautotrophy                            |  |                                    | Sunlight  | No           |
| Strasburguer [18]          | Growth and differentiation                 | Phytohormones                            |                                    | Temperature, light, gravity, hydromorphosis                                       | No           |
|                            | Biological rhythms<br>Movement             | Circadian rhythms                        |                                    | Photoperiod<br>Phototaxis,  | No<br>No     |
|                            | Daylength perception                       | Circadian rhythms, phytochromes          |                                    | phototropisms, photonasties<br>Light quality, phase setting, interaction of light | No           |
| Thomas and Vince-Prue [56] | Flower timing                              |  |                                    | Light quantity, moonlight<br>Photoperiodism                                       | Yes          |
|                            | Flower development                         |  |                                    |   | No           |
|                            | Bud dormancy                               |  |                                    | No  |              |
|                            | Storage and propagation                    |  |                                    | No  |              |
|                            | Germination                                |  |                                    | No  |              |
|                            | Stem elongation<br>Leaf growth             |  |                                    | No<br>No  |              |

Source: authors’ review.

Considering endogenous factors, we searched for possible interactions of Moon radiation and photoperiod, as well as gravity, on the transduction of the perception of those environmental stimuli as well as the possible determination by endogenous genetic components. An important internal process in plants, animals, fungi and cyanobacteria is that related to circadian rhythms that refer to any biological process that displays oscillation, driven by circadian clocks, synchronized with solar time. Plant circadian rhythms are related to seasons and determine, for example, when to flower to maximize the success of pollinator attraction. Circadian rhythms also determine leaf movement, growth, germination, gas exchange or photosynthetic activity, among others. All monographs reviewed mentioning circadian rhythms refer exclusively to synchronization with the light cycle of the surrounding environments of plants, considering the Sun as light source that can determine or influence these cycles.

This search in what is considered consolidated science and is incorporated to handbooks has revealed practically no mention of the Moon (Table 5). We have only found an anecdotic reference, in relation to the possible influence of moonlight on flowering in Thomas and Vince-Prue [57]. These authors explain the work of Salisbury [58], who had indicated that the effective red-light threshold for flowering is higher than the amount of red light produced by the Moon. In addition, it is important to consider that the shade provided by the leaves of the plant itself can reduce the radiation received to 5–10% of the direct moonlight [59]. Thomas and Vince-Prue [57] state that it seems unlikely that full moon light can influence flowering, even in the most sensitive plants, highlighting the scarcity of research on this issue. In this book the authors mention the work of Kadman-Zahavi and Peiper [60], who carried out research with *Pharbitis nil* (L.) Roth—a very sensitive short-day species—which they exposed to moonlight or shielded for different periods. They concluded that, although it is possible that moonlight is perceived, it had no effect on the experience developed

with a short-day species that is particularly sensitive to radiation. The difficulty of isolating the “Moon” factor was highlighted, pointing out the possible influence of shade treatment on plants in other environmental factors that could in turn have an effect on flowering [60]. On the other hand, they indicated that the full moon was only present on very few days of the lunar cycle, so its effect should be negligible under natural conditions.

### 3.2. What Research Papers Say from the Perspective of Physics and Biology

We consider a reference and starting point for the review of scientific articles, the brief paper published in *Nature* by Cyril Beeson in 1946, entitled “The Moon and Plant Growth” [61]. In this paper, the author writes “Beliefs that phases of the Moon have a differential effect on the rate of development of plants are both ancient and world-wide” and concludes that the research carried out to that date had not been able to demonstrate a correlation between the Moon and vital processes of terrestrial plants pointing out that, if any research does, the relationship was so unclear that it has no implications for agriculture.

In the 1950s, Frank A. Brown [22,62,63] undertook different investigations in which he studied the possible lunar rhythmicity in organisms. Most of this research was carried out on marine organisms closely linked to the tides—such as algae, crustaceans, molluscs—he also studied the physiological aspects of terrestrial plants. Brown et al. [22] studied the persistent rhythms of O<sub>2</sub>-consumption in potatoes, carrots (*Daucus carota* L.) and brown seaweed (*Fucus*) and searched for a possible influence of barometric pressure rhythms of primary lunar frequency, noting that they are of much lower amplitude than the solar ones. The study was inconclusive in relation to what external rhythmic forces are involved in the rhythms of O<sub>2</sub>-consumption, as many of them exhibit some degree of correlation with barometric pressure. In barometric pressure  $p = \rho gh$ , as its expression depends on  $g$ , we would have the same case as with capillarity: the effect of  $g_M$  should be subtracted from  $g_E$  and, as we have seen,  $g_M$  is approximately 300,000 times lower than  $g_E$ , so the effect of the Moon on barometric pressure is negligible. The authors discuss the possibility that some of the responses attributed to external factors are due to endogenous rhythmic components. This connection between internal and external factors is supported by Wolfgang Schad [64], who states that “all chrono-biological rhythms are always exo-endogenous, sharing their autonomous inner clock to some degree with the periodicity of the environment, both sides being connected by the long process of evolution”, remaining unanswered, the question of how the balance between endogenous and exogenous factors oscillates.

Some authors mention the influence of the lunar phases in a tangential way, without getting to clarify anything. One example explores the resistance of circadian clocks to transient fluctuations in night light levels in nature (i.e., change in cloud cover or stellar/lunar illumination) [65]. Van Norman et al. [66], when differentiating the circadian and infradian rhythms, indicate that the former are the best characterised with a period of around 24 h, while the infradians have periods of more than 24 h and can be due to the tides, lunar, seasonal, annual or longer. In other publications, the authors actively search, without finding them, for relationships between the Moon and some organisms. A paradigmatic case is the study conducted by Bitzand Sargent [67], who unsuccessfully tries to relate the growth rate of the fungus *Neurospora crassa* Shear & Dodge to the influence of a supposed lunar magnetic field (which, as we explain in detail in this article, is even more negligible than the gravitational field). Recently Mironov et al. [68] mentioned a circalunar growth rhythm in a research carried out with genus *Sphagnum*. They found an acceleration in the growth of the mosses studied near the new moon, and a slowdown in growth near the full moon.

Regarding biodynamic practices in agriculture, Hartmut Spiess carried out chronobiological investigations of crops grown under biodynamic management, developing experiments to test the effects of lunar rhythms on the growth of winter rye (*Secale cereale* L.) and little radish (*Raphanus sativus* L., cv. Parat) [69,70]. Spiess [69,70] tried to clarify some of the varying results that a number of studies conducted in the 1930s and 1940s had left unclear. This author also focused on studies made by M. and M.K. Thun [71] establishing a relationship between the position of the Moon relative to the zodiac

(sidereal rhythms), planting dates and crop growth, which served as a basis for the publication of calendars. Spiess' [69,70] results pointed out that the effects of lunar rhythms were weak, and especially the effects of the sidereal rhythms described by Thun and Thun were not apparent. In contrast to these papers, Kollerstrom and Staudenmaier [72], pointed out that, although Spiess' [69,70] experiments were well designed, there was a lack of care in the data analysis. According to these authors, the results published to date of its publication suggested that lunar factors may have a practical significance for agriculture.

Without a doubt, one of the botanists who dedicated the most effort and publications to the search for relationships between the Moon and plants was Peter Barlow. Barlow [73–85] devoted part of his research to decoding the influence of the Moon on biological phenomena. Specifically those aspects that take place in plants [73], such as the movements of leaves [74–76], stem elongation [77], fluctuations in tree stem diameters [78], the growth of roots [79–81], biophoton emissions from seedlings [82–84], and chlorophyll fluorescence [85]. According to Barlow et al. [76], and other works of the same author, at least in the cases analysed, the rhythm of leaf movements seem to have been developed or entrained in synchrony with the exogenous lunisolar rhythm experienced either on the Earth or in Space. Barlow [76] believed that plant movements were related with water movements within the plant: as ocean tides are produced by lunisolar gravitational force, water movement in the pulvinus could be responsible for leaf movement, explanation that we have previously discussed.

From all external factors, the perception of light plays a significant role as it can modify biosynthesis by photostimulation and act as a trigger initiating the different stages of development (Table 6). Reversible responses of plant to changes in light conditions can allow them to adjust their leaf or flower position (photonastic and heliotropic movements, respectively) to modulate the incoming radiation. Germination is also severely affected in some plants by light exposition. In fact, some seeds only germinate when they are exposed to a particular red to far-red ratios (660/730 nm), and in a particular moment [14].

**Table 6.** Radiation effects on developmental processes in plants.

| Process                                   | Mode of Action <sup>1</sup> | Spectral Range <sup>2</sup> | Fluctuation <sup>3</sup> |
|---|-----------------------------|-----------------------------|--------------------------|
| Seed germination and bud break            | I                           | R/FR, B                     | P                        |
| Stem elongation                           | Q, F                        | R/FR                        | P                        |
| Stem orientation                          | Q, F                        | B                           |                          |
| Leaf orientation                          | Q                           | R/FR                        | C                        |
| Flowering process                         | I                           | R/FR                        | C                        |
| Development and filling of storage organs | I                           | R/FR                        | P                        |
| Dormancy                                  | I                           | R/FR                        | P                        |
| Enzyme synthesis                          | I                           | R/FR                        |                          |
| Enzyme activation                         | I                           | R/FR                        |                          |
| Membrane potentials                       | I                           | R/FR                        |                          |

<sup>1</sup> I = Inductive; Q = Quantitative; F = Formative. <sup>2</sup> B = Blue light; R/FR = Red-to-Far-Red ratio. <sup>3</sup> P = Photoperiodism; C = Circadian rhythm. Source: modified from Larcher [14], Kronenberg et al. [86] and Salisbury [87].

Despite light being crucial for plant life, just a few studies have explored the effect of moonlight on plant physiology and their results are not conclusive. Kolisko [88] observed that the period and percentage of germination and subsequent plant growth was influenced by the phase of the Moon at sowing time. And according to Bünning and Moser [59], light intensities as low as 0.1 lx, which correspond approximately to moonlight intensities (see Table 1), may influence photoperiodism in plants and animals whose threshold values of photoperiodic time-measurement is on the order of 0.1 lx. They suggest that light intensity may reach 0.7 lx or even 1 lx when the altitude of the Moon is at 60° or higher altitudes in tropical and subtropical regions (respectively), clearly influencing photoperiodic reactions. However, they observed that in short-day plants such as *Perilla ocymoides* L. and *Chenopodium amaranticolor* H.J.Coste & Reyn., light intensities similar to those of the full moon favoured rather than inhibited flowering [59]. They justified the circadian leaf movements observed

in *Glycine*, *Arachis* and *Trifolium* plants as an adaptive mechanism to reduce the intensity of full moon received in the upper surface of the leaf avoiding plant misinterpretations of confounding full moonlight as it would be long day [59]. However, Kadman-Zahavi and Peiper [60] rejected this hypothesis concluding “that in the natural environment moonlight may have at most only a slight delaying effect on the time of flower induction in short-day plants” (p. 621). Furthermore, Raven and Cockell [89] suggested that photosynthesis on Earth can occur in the photosynthetically active radiation (PAR) range of  $(10^{-8}-8 \times 10^{-3})$  mol of photons  $\text{m}^{-2} \text{s}^{-1}$ , and PAR values of moonlight at full moon goes from  $(0.5-5) \times 10^{-9}$  mol of photons  $\text{m}^{-2} \text{s}^{-1}$ , suggesting that moonlight is not a significant source of energy for photosynthesis on Earth.

Recently, Breidler et al. [90] described that the photoreceptors present in *Coffea arabica* L. plants are able to perceive full moonlight and this full moonlight PAR is inadequate for photosynthetically supported growth. Plants perceive it as blue light with a very low R/FR ratio, yet this weak light has a great impact on numerous genes. In particular, it affects up to 50 genes related to photosynthesis, chlorophyll biosynthesis and chloroplast machinery at the end of the night. Moreover, full moonlight promotes the modification of the transcription of major rhythmic redox genes, many heat shock proteins and carotenoids genes suggesting that the moonlight seems to be perceived as a stress factor by the plant.

In other cases, full moonlight is correlated with a successful pollination of *Ephedra* species. Rydin and Bolinder [91] observed a correlation between pollination and the phases of the Moon on the gymnosperm *Ephedra foeminea* Forssk., specifically with the full moon of July. During that period, non-mature cones secreted enough pollination drops to apparently attract pollinators that can use the full moon to navigate and also be attracted to the glittering drops in the full moonlight. According to the authors, when insects are not used as pollinators, as it happens in other species of *Ephedra*, the adaptive value of correlating pollinating with the full moon is lost.

In the literature review carried out, some works were found that deal with two different topics that could have relationship with the Moon: polarization and magnetism. According to Semmens [92–94] during certain periods, moonlight is partially polarised, “the maximum effect being with the oblique reflexion of half-moon, or somewhat later for the waxing and earlier for the waning moon” and that polarised light can favour the diastase, which catalyses the hydrolysis, first of starch into dextrin and immediately afterwards into sugar or glucose, to favour germination, as he observed in crushed mustard seeds in the presence of this polarised light. Macht [95] studied the effect of (not lunar) polarized light on seeds of *Lupinus albus* L. and his results were consistent with previous findings of the action of diastase on starch. However, as far as we know, apart from those works no other research papers have been focused on the role of lunar polarized light. Despite, a full body of evidence supports that polarized moonlight has a biological significance in the vision and orientation of nocturnal animals [96,97]. Although we are at the very beginning of understanding the extent to which and why nocturnal animals use the lunar polarization, we do know that the land area over which it is viewable in pristine form is relentlessly shrinking due to human activity. In this sense, Kyba et al. [98] showed that urban skyglow has a great degree of linear polarization and confirmed that its presence diminishes the natural lunar polarization signal. They also observed that the misalignment between the polarization angles of the skyglow and scattered moonlight could explain the reduction of the degree of linear polarization as the Moon rises. Regarding nocturnal animal navigation systems based on perceiving polarized scattered moonlight, these authors highlighted the necessity of considering polarization pollution models in highly light-polluted areas. In any case, there is almost no doubt that the level of polarization of moonlight would be extremely small: so minimal, that its effect would be completely negligible in plants [98].

On the other hand, some studies suggest an influence of the lunar magnetic field. There is evidence that some animals, fungi, some protists and some bacteria seem to be able to react to the variation of the Earth’s magnetic field [99–101]. The question that arises is whether plants are also able to respond to these fields and whether the Moon is capable of producing some magnetic field

that plants can respond. There is abundant literature discussing magnetoreception in plants [102–106], but no conclusive results have been reported with direct application to agriculture.

Our planet has a magnetic field, called geomagnetic field, with an intensity of approximately  $(25\text{--}65) \times 10^{-6}$  T, ridiculously small compared to a commercial magnet (about 0.01 T) or a 0.2 T neodymium magnet. Although there are studies that argue that billions of years ago the Moon generated a magnetic field probably even stronger than the current magnetic field of the Earth, the lunar dynamo ended around one billion years ago [107,108]. The intensity of the present-day magnetic field on the lunar surface is  $<0.2 \times 10^{-9}$  T, indicating that the Moon currently does not have a global magnetic field [109]. A magnetic field of this numerical value is approximately 225,000 times less than the Earth's, and if divided by the distance Earth–Moon ( $3.84 \times 10^{10}$  m), we can easily conclude that the possible effect of a hypothetical lunar magnetic field on the Earth would be much more negligible than that of the gravitational field.

Other theories claim that it is not the lunar magnetic field that affects, but the disturbance in the Earth's electromagnetic field caused by the lunar gravitational changes that take place during the full moon [4]; or also that Moon effects to the Earth's magnetosphere [110]. In both cases, the assumed effects would be (as we have seen in the calculations for the gravity case) completely insignificant.

A general analysis of the above-mentioned literature highlights the heterogeneity in the information sources regarding year of publication and discipline of the journal. On the one hand, there are very recent papers [68,90] but also literature from more than half a century ago [61,92–94]. On the other hand, there are peer-reviewed papers indexed in the Q1 of JCR in specific publications on Plant Science discipline, as *Annals of Botany* [75,79,80], *BMC Plant Biology* [90], *Frontiers in Plant Science* [104], *Journal of Plant Research* [103], *New Phytologist* [81], *Planta* [76], *Physiologia Plantarum* [68], *Plant Cell* [65,66] or *Plant Physiology* [67], with a long and consolidated trajectory in the field and with a pool of reviewers with solid expertise. Other articles are published in the Q2–Q3 of JCR in the same category as *Plant Biology* [77] and *Protoplasma* [78,83], or in other categories as Horticulture or Agronomy (e.g., *Biological Agriculture and Horticulture* [69,70,72]). Other papers included belong to other disciplines: *Astrobiology* [89], *Biology Letters* [91], *Icarus* [109], *Philosophical Transactions of the Royal Society B: Biological Sciences* [96], *Nature* [61,92–94], *Naturwissenschaften* [84], indexed in Q1–Q2 JCR lists. Nevertheless, there are also some papers not included in JCR lists but in other repositories as *Communicative and Integrative Biology* [73], *Earth, Moon and Planets* [64], *Pathophysiology* [110] and *Star and Furrow* [71].

This analysis also raises the question of the extent to which the authors have a good basis in the physics behind all these phenomena, given that to date Moon has not been proved to affect plant biology regarding consolidated physics.

#### 4. Next Steps from the Perspective of Science Teaching

We are concerned about the insidious spread of pseudo-scientific ideas, not only in the field of plant science (which determines many of the behaviours, habits and techniques of many farmers in rural areas) but into the broader population through both formal and informal education. As science educators, we are especially concerned about the widespread belief in pseudo-science throughout the general populace and especially in science teachers [111–114]. Solbes et al. [114] showed that 64.9% of a sample of 131 future science teachers agree or partially agree with the expression “The phase of the Moon can affect, to some extent, several factors such as health, the birth of children or certain agricultural tasks”.

Given this worrying scenario, teachers must promote critical thinking as an essential part of citizenship development. Critical thinking implies being informed about issues or problems, not limiting oneself to the dominant discourses in the media, understanding alternative, well-argued positions and being able to analyse the evidence supporting each of them, studying the problem in its complexity, so that scientific, technical, social, economic, environmental, cultural and ethical dimensions are involved, etc. [115–117]. We believe that it is crucial for teachers to be aware of

these beliefs in order to address them from a scientific perspective, as has been demanded for some time [118,119].

One way to approach pseudoscience is to involve students in the proper process of reasoning and knowledge building in science, and research-based teaching is postulated as a suitable teaching methodology to address the problem [120]. In the same way that Lie and Boker [121] analysed the perceptions of complementary therapies of medical students who claimed to have pseudo-scientific beliefs related to health, it would be of great interest to address these issues with agronomic students. In this line, a teaching–research sequence has been developed [122] with future science teachers, in which the strategy followed was to plant seeds of different plant species in each of the phases of the Moon and to measure their growth once a lunar cycle was completed. The participants specified the research question and the initial hypothesis. In addition, they established the experimental design as a whole, fixed the dependent, independent, and constant variables, the materials, the sequence of the sessions, etc. [123,124]. As a result of the proposal, still under analysis, it is expected that students will develop a critical attitude towards pseudoscience and improve their training in research methodologies. Didactic proposals of this type could help, not only in teacher training, but also in any scientific study, promoting critical thinking.

With this work, we wanted to draw attention to one of the many facets of current pseudo-scientific ideas, especially in agriculture. However, we want to emphasize that dismantling these ideas, which, as we have seen, lack in any scientific basis, should not be incompatible with knowing and preserving agricultural traditions that are an important part of an ethnographic and anthropological heritage, as some institutions such as the Food and Agriculture Organization of the United Nations (FAO) claim [125–128]. Many of these traditions (e.g., organic farming, traditional and seasonal crops) allow a harmonious and sustainable coexistence with their natural environments, compatible with the conservation of biodiversity, varieties of certain species.

Furthermore, this paper encourages new research on this long-lasting topic of the possible influence of the Moon on plants in order to clarify many aspects that still remain unanswered or which have not been approached. Considering that modern ecophysiology requires a good understanding of both the molecular aspects of plant processes and the environment, future studies will necessarily have to move to a higher level: scaling from physiology to the Globe [129], considering relationships between plant ecophysiological processes and those occurring at ecosystems but also including social aspects—as traditions, farmers' behaviours and protocols, etc.—that can determine the environment where plants grow.

This review opens the door to possible research that would help to complete the picture of the extent to which certain pseudo-scientific ideas have permeated different sectors of the population. In this sense, it would be interesting to carry out an in-depth analysis of what farmers, as well as students in careers related to the agriculture sector and plant biology, think about the relationship of the Moon with the growth and development of plants.

## 5. Conclusions

Science has widely established different evidences: (i) the Moon's gravity on the Earth cannot have any effect on the life cycle of plants due to the fact that it is  $3.3 \times 10^{-5} \text{ ms}^{-2}$ , almost 300,000 times lower than the Earth's gravity; (ii) since all the oceans are communicated and we can consider their size being the size of the Earth, the Moon's influence on the tides is  $10^{-6} \text{ ms}^{-2}$ , but for a 2 m height plant such value is  $3 \times 10^{-13} \text{ ms}^{-2}$  and, therefore, completely imperceptible; (iii) the Moon's illuminance cannot have any effect on plant life since it is, at best, 128,000 times lower than the minimum of sunlight on an average day; (iv) the rest of possible effects of the Moon on the Earth (e.g., magnetic field, polarization of light) are non-existent.

The logical consequence of such evidence is that none of these effects appear in physics and biology reference handbooks. However, many of these beliefs are deeply ingrained in both agricultural traditions and collective imagery. This shows that more research should be undertaken on the possible



effects observed on plants and assigned to the Moon by the popular belief, addressing their causes, if any. It would also be interesting to address these issues in both compulsory education and formal higher agricultural education in order to address pseudo-scientific ideas and promote critical thinking.

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