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(54) Title: AN ELECTROMAGNETIC STIMULATOR FOR ALTERING THE PLANT GROWTH BEHAVIOUR

(57) Abstract
An electromagnetic stimulator for stimulating the plant development is presented. The stimulator is applied to at least one plant at a predetermined stem portion (24) thereof, and comprises a magnetic field source (26) producing a magnetic field having magnetic force lines directed substantially perpendicular to the stem portion (24). The magnetic field interacts with radial and/or longitudinal electric current (ions) loops inside the stem (24), thereby altering the plant growth behavior.
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FIELD OF THE INVENTION

This invention is in the field of plant treatment techniques and relates to an electromagnetic stimulator for altering plant growth behavior to accelerate the plant development process.

BACKGROUND OF THE INVENTION

It is known that the entire process of plant growth is composed of two main stages:

(1) vegetative plant propagation by rooting of cuttings; and
(2) secondary growth of the plant up to desired results (e.g. dimensions).

Conventional techniques, which are widely used in nurseries and greenhouses, typically utilize various chemical materials for treating cuttings and soil in order to stimulate root formation and the growth of plants. Fig. 1 illustrates a flow diagram of the main steps of one of the conventional rooting methods.

Cuttings that are to undergo the rooting process are taken from a tree. Foliage is removed only from the lower part (h₁) of each cutting, while the upper part (h₂) of the cutting remains foliaged. The foliage-free part h₁ of the cutting is then dipped into a powder or solution of a suitable hormone substance, such as the synthetic auxin "Indolyl-3-Butric acid (IBA)”, commercially available from Sigma Chemical CO., U.S.A. This chemical material penetrates through a relatively friable end section of the cutting, affecting the growth hormone thereof, and thereby stimulates the root formation. As to the upper, untreated part (h₂) of the cutting, the foliage produces natural auxin which is transferred towards the lower
part h₁ and also affects the root formation at a further stage, the so-called “Mass Root Formation Treatment”. More specifically, treated cuttings are transplanted into special cells filled with soil, where they are further treated over a long period of time on special tables provided with a heating system under the cells and a water sprinkling system.

The above process is typically utilized for the mass production of semi-woody and woody hard-to-root cuttings such as various types of Junipers and Conifers, as well as other horticultural and forest trees and shrubs of great commercial importance. According to statistic data, the percentage of rooting success in such cuttings is within the range of 20 % to 50 %, and the root initiation process takes too long (over 3 months). For example, for such a popular decorative tree as the Juniper “Moonglow” successful rooting takes place in 25-30% of the hormone treated cuttings, and the root initiation period takes 3-4 months. Moreover, plants such as the Pistachio, Avocado, Magnolia, etc., cannot be developed by the conventional vegetative propagation technique, and are therefore grown from seeds or plant tissue.

Additionally, one of the main problems existing in nurseries and greenhouses is associated with the extremely long growth period (over 3 years) of young decorative trees and shrubs, such as various types of Junipers, Conifers, Magnolias, etc. As for fruit trees, such as the Apple, Cherry, Mango, Lemon, etc., their pre-fruiting period is also quite long. Needless to say that the decrease in the secondary growth period of these young trees is of great commercial importance.

Various methods and means have been developed which are aimed at stimulating the vegetative plant propagation of cuttings by applying static and alternating electromagnetic fields thereon. Such techniques are disclosed, for example in U.S. Patent No. 5,077,934, EP Publications Nos. 0039163 and 0459540. Notwithstanding the fact that these techniques achieve better results in comparison to the hormone-based technique, they require very complicated
treatment procedures and relatively expensive devices, and therefore are not suitable for mass production (i.e. at the level of hundreds of thousands or more cuttings).

JP Publications Nos. 09187169 and 09275785 disclose a device for the treatment of plants by the use of a static magnetic field. This device has too complicated construction to be employed in the mass production of plants, and is not suitable for young trees of small diameters (2mm and more). Additionally, this device cannot be applied to a tree having curved stems (which is always the case). The device significantly impedes the process of natural evaporation from the stem surface of the tree, which is very important for young trees of small dimensions.

**SUMMARY OF THE INVENTION**

There is accordingly a need in the art to improve conventional magnetic field based techniques by providing a novel method and system for altering plant growth behavior.

It is a major object of the present invention to provide such a method and a system, which are suitable for mass production of plants.

It is a further object of the present invention to provide such a method for cuttings' treatment, which can be used in combination with the conventional hormone-based technique.

It is a still further object of the present invention to provide such a method and system, to accelerate the growth of young slow-growing trees and shrubs. The present invention utilizes the influence of a magnetic-field environment on the electro-physiological phenomenon taking place in plants. The main idea of the present invention is based on the following. One of the problems of vegetative propagation is associated with the fact that the root-development process depends on the firmness of the cortex (i.e. the tissue between the
epidermis and endodermis inclusive), and, consequently, the transport of a liquid phase through the cortex. In a plant already having roots, liquid is soaked into the root and flows through a cellular pathway, while in a root-free cutting the liquid, e.g., a hormonal substance, should flow through the apoplast pathway. The transport of the liquid through the apoplast pathway is impeded by the firmness of the cortex. It is known that pre-root cells, so-called "callus", are formed in a cambium, i.e. the layer of cells between the xylem and phloem. The more the callus developed in cambium after treatment, the more the possibility of successful root-development. Hence, by activating the cambium, the formation of callus can be stimulated.

The present invention utilizes the known phenomena of the existence of electric current loops (the directional movement of ions) formed in radial and longitudinal directions inside a plant. This phenomena is described, for example, in the article "Growth and Electric Current Loops in Plants", Biophysical Chemistry 33 (1989), 161-176. According to the invention, an alternating electromagnetic field is created and applied to a lower, foliage-free part (h₁) of a cutting stem. The alternating electromagnetic field may be a linear traveling field or a pulsating one. The term "linear traveling electromagnetic field" used herein signifies such a field that represents a movement of electromagnetic waves (system of poles) in a direction along the longitudinal axis of the stem. The interaction between the alternating magnetic field and radial electric current loops in a stem creates mechanical force effects, namely tensile and compressive stress in the epidermis and endodermis tissues, a so-called "electromagnetic stress". These effects are similar to vibrations, which, on the one hand, "massage" the cambium layer, thereby stimulating the callus formation, and, on the other hand, affect the friability of the cutting stem thereby increasing the liquid permeability therethrough. If such a liquid contains a hormonal substance, the quantity of the substance reaching the cambium is increased.
As to the further plant development from the rooted cutting, the main idea of the present invention is directed towards the altering of the rectilinear motion of ions within the phloem flows sap inside the stem to a spiral-like motion. To this end, an individual electromagnetic stimulator is attached to a young tree. The individual stimulator comprises a magnetic field source in the form of an elongated permanent magnet, which faces the stem by its one pole side. The magnet extends along a predetermined surface region of the stem, and produces the magnetic field that is characterized by a predetermined value of magnetic induction, and by magnetic force lines directed substantially perpendicular to the phloem flows sap inside the stem. This technique enables to speed up the growth of the stem’s diameter.

There is thus provided according to one aspect of the present invention a group electromagnetic stimulator for applying simultaneously to a group of cuttings during at least several seconds, the electromagnetic stimulator comprising a magnetic field source producing an alternating magnetic field and defining a slot-like space within said field for installing the group of cuttings by their predetermined stem portions in the space, wherein magnetic force lines of said alternating magnetic field are directed substantially perpendicular to the stem portions of the cuttings.

The magnetic field source comprises a pair of inductors accommodated at opposite sides of the space, respectively, and coupled to a predetermined electric current source. The electric current source may be constituted by at least two-phase network. The alternating magnetic field may be a linear traveling or pulsating. Each of the inductors comprises a predetermined number of windings supported on a packet of electric transformer steel that serves as the magnetic field concentrator.
The space may and may not be filled with liquid, which may be water or
may contain a hormone substance. Alternatively, the space may be filled with a
powder of hormone substance.

According to another embodiment of the invention, there is provided a
method for simultaneously processing a group of cuttings with a group
electromagnetic stimulator that comprises a magnetic field source producing an
alternating magnetic field and defining a slot-like space within said field for
installing the group of cuttings by their predetermined stem portions in the space,
wherein magnetic force lines of said alternating magnetic field are directed
substantially perpendicular to the stem portions of the cuttings, the method
comprising the steps of:

(a) providing said group of cuttings each having said lower stem portions
    substantially foliage-free;

(b) locating the lower stem portions of the cuttings in said space to be
    processed by said magnetic field for at least several seconds; and

(c) transplanting the processed cuttings into soil.

According to yet another embodiment of the invention, there is provided
an individual electromagnetic stimulator for attaching to the stem of a young
plant, the stimulator comprising a magnetic field source in the form of at least
one elongated permanent magnet that faces the stem by its one pole side, and
extends along a predetermined surface region of the stem, wherein the magnetic
field source produces the magnetic field that has a predetermined value of
magnetic induction and is directed substantially perpendicular to phloem mass
flows inside the stem.

Preferably, the stimulator comprises an elongated magnetic circuit coupled
to and extending along an opposite pole side of the elongated permanent magnet.
The magnetic circuit comprises at least a pair of spaced-apart symmetrically
identical projections extending along an axis substantially perpendicular to a
longitudinal axis of the stem, serving thereby as concentrators of the magnetic field. The at least one pair of projections may engage the surface of the stem, and may clamp the stem therebetween, thereby serving as fasten means for supporting the stimulator on the stem.

Preferably, the stimulator is substantially flexible along its length so as to engage the surface of the stem.

The at least one elongated permanent magnet may be formed by a plurality of separate permanent magnets, which have identical orientation of poles and are aligned along the magnetic circuit. Alternatively, the elongated permanent magnet may be in the form of a magnetic rubber.

The magnetic field source may comprise at least one additional elongated permanent magnet. In this case the at least two permanent magnets are spaced apart from each other in a plane perpendicular to the longitudinal axis of the stem, and face the stem by the same pole side.

The predetermined vale of the magnetic induction is determined in accordance with the following relationship:

\[
B \geq \frac{6 \cdot \pi \cdot d \cdot n \cdot \eta \cdot r \cdot L}{q \cdot V_0^2}
\]

wherein \(\pi \approx 3.14159\); \(d\) is the diameter of a phloem vessel; \(n\) is the number of loops passed by the phloem vessel ion during the spiral-like motion; \(\eta\) is the viscosity of the phloem sap; \(r\) is the ion radius; \(L\) is the length of said predetermined surface region of the stem; \(q\) is the electrical charge of ion; and \(V_0\) is the velocity of phloem mass flows in the stem.
BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

**Fig. 1** is a flow diagram illustrating the main principles of a conventional hormone-based treatment of cuttings;

**Fig. 2** is a schematic illustration of the main components of a device according to one embodiment of the invention associated with a plurality of cuttings for stimulating the rooting process;

**Fig. 3** is a flow diagram of a method according to the invention for stimulating the rooting process;

**Figs. 4a to 4c** illustrate the main principles underlying the implementation of the device of Fig. 2;

**Fig. 5a** is a cross-section of a stem in secondary growth;

**Fig. 5b** schematically illustrates the natural processes taking place in a stem;

**Fig. 6** is a diagram more specifically illustrating the operational principles of the device of Fig. 2;

**Fig. 7** schematically illustrates a device constructed according to another embodiment of the invention applied to a young tree for accelerating its development;

**Fig. 8a** illustrates one example of the construction suitable for the device of Fig. 7;

**Fig. 8b** illustrates another example of the construction suitable for the device of Fig. 7;

**Fig. 8c** more specifically illustrates the mounting of the device of either of Figs. 8a or 8b on the tree stem;
Figs. 9a and 9b are sections taken along lines A-A and B-B, respectively, in Fig. 8a, illustrating the main principles of operation of the device of either of Figs. 8a or 8b;

Fig. 10a and 10b illustrate another example of the construction suitable for the device of Fig. 7; and

Fig. 11 is a diagram more specifically illustrating the operational principles of the device of Fig. 7.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Fig. 1 illustrates a flow diagram of the main steps of a conventional hormone-based treatment of cuttings. The cuttings are taken from a tree for vegetative propagation thereof. Foliage is removed from a lower portion \( h_1 \) of the cutting stem. The foliage-free stem portion \( h_1 \) is typically relatively short in comparison to an upper foliaged portion \( h_2 \). This is associated with the fact that such a treatment by a hormone substance is actually applied to the end section of the cutting only, due to its relative friability in comparison to the firmness of the stem portion. Thus, the foliage-free portion \( h_2 \) of the cutting is dipped into a suitable hormone substance (powder or solution), and then transplanted into soil.

Referring to Fig. 2, there is illustrated a device, generally designated 1, for the simultaneous treatment of a group of cuttings, generally at 2, to stimulate further rooting therein. The device 1 represents a group electromagnetic stimulator (GEM-Stimulator) comprising a vessel 4 and a magnetic field source 6. The vessel 4 is elongated and has a substantially rectangular shape, so-called "slot-like vessel". The magnetic field source 6 has two parallel identical inductors 6a and 6b extending along opposite walls of the vessel 4. As shown, lower foliage-free stem portions of the cuttings, having the length \( h_1 \), are inserted into the slot-like vessel 4, being thereby enclosed between the inductors 6a and 6b so as to be within the electromagnetic environment produced by the magnetic field.
source 6. The foliaged stem portions, having the length $h_2$, are outside the vessel 4 and outside the electromagnetic environment. Hence, the foliage-free stem portion (constituting a root formation zone) is treated by the electromagnetic environment. It should be noted that the provision of the vessel 4 is optional, as such a slot-like space for installing the cuttings therein may be defined as the space between the indictors 6a and 6b. Hence, the vessel 4 constitutes the slot-like space within the magnetic field produced by the magnetic field source 6. The vessel (space) 4 may or may not be filled with water or a hormone substance, which is therefore not specifically shown. The GEM-Stimulator 1 having the dimensions of approximate 1m x 0.1m x 0.1m may be used for simultaneous treatment of about 200 cuttings.

Turning now to Fig. 3, the acceleration of the root-development process utilizing the device 1 is performed as follows. Cuttings are provided in a conventional manner, and the foliage is removed from a relatively increased stem portion $h_1$ in comparison to that of the hormone-based treatment. This is owing to the fact that the magnetic field environment is applied mainly to the stem, rather than to the end section of the cutting only, as will be described more specifically further below with reference to Figs. 4a-4c. As indicated above, a natural hormone (auxin) is typically produced in the foliaged portion $h_1$ of the cutting and transferred towards the lower portion $h_2$ through the phloem, favoring the root formation. The present invention enables an optimum ratio between the foliage-free and foliaged portions $h_1$ and $h_2$ to be established for increasing the time for root initiation, thereby accelerating the entire root-development process. The cuttings 2 are by their lower portions $h_1$ inserted into the vessel 4, where they are treated by the electromagnetic field over a relatively small period of time, from a few seconds to a few minutes. Optionally, the vessel 4 is previously filled with water or a hormone substance. The hormone substance may be in the form of a powder or solution. The electromagnetic field treatment is optionally
followed by the conventional hormone-based treatment. Thereafter, the cuttings undergo the conventional mass root-formation treatment in special cells filled with soil.

Experimental tests of the method according to the invention applied to such cuttings as Juniper “Moonglow”, Juniper “Pathfinder”, Bougainvillia, having the diameter of 2-4mm and the length of 60-100mm, have shown the following results: the root initiation period of 1.5-2 months, and a percentage of rooting success of up to 60%-70% with high-quality root system (i.e. number of roots, their length and color, and lateral root-hairs). These results are much better than those of the conventional hormone-based treatment.

Reference is now made to Figs. 4a-4c, which more specifically illustrate the construction and operation of the magnetic field source 6. Each of the inducers 6a and 6b is composed of a certain number of windings, three windings 8a-8c in the present example, mounted on a packet of electrical transformer steel 10. The electrical transformer steel packet 10 has a “slots-and-teeth” design similar to that of a conventional asynchronous engine, i.e., is formed with a plurality of spaced-apart parallel slots 12, wherein each two adjacent slots are spaced by a corresponding one of a plurality of spaced-apart parallel teeth 14. The windings extend inside the slots 12. The teeth 14 serve as concentrators of the magnetic field, thereby creating a high-gradient magnetic field. The concentrators 14 may be made from a ferromagnetic shot or from thin sheets of the electrical transformer steel.

Figs. 4a and 4b show one example of the construction of the inducers 6a and 6b, producing a linear traveling magnetic field. To this end, each of the inducers 6a and 6b is composed of three windings 8a, 8b and 8c coupled to a three-phase electric current source, which is not specifically shown. Fig. 4c illustrates somewhat different construction of the inducers 6a and 6b capable of producing a pulsating magnetic field. In this case, each inductor comprises at
least one winding, a pair of windings 9a and 9b being illustrated in the present example, coupled to a one-phase electric current source (not shown). In the drawings, “+” and “-” show, respectively, the current directions from and towards an observer.

In the case of the traveling magnetic field (Figs. 4a and 4b), the three-phase electric circuit is provided in each of the inductors 6a and 6b, the electric currents passed through three windings 8a, 8b and 8c having three different phases A, B and C, respectively, which are displaced by 120 electrical degrees. Fig. 4a illustrates in a self-explanatory manner a rotary current vector diagram of the conventional commercial power network (for example, 50-60 Hz), and changes in the current directions in windings 8a, 8b and 8c. It should be noted, although not specifically shown that the traveling magnetic field may also be provided by means of two-phase windings, in which the phases are displaced by 90 electrical degrees.

As better seen in Fig. 4b, the electric current directions in the opposite windings of the inductors 6a and 6b are such (i.e., “+” - “-”) as to provide the opposite directions of magnetic force lines 16a and 16b, forming thereby the N-S orientation of poles. Alternatively, although not specifically shown, the directions of electric current in the opposite windings may be the same (e.g. “+” - “+”, or “-“ - “-“), forming the N-S orientation of poles.

Turning back to Fig. 4a, the phase rotation produces the effect of poles’ movement with the velocity V along an axis parallel to the longitudinal axis of the cutting stem. Hence, the magnetic-field environment formed by linear multi-poles windings creates a linear travelling magnetic field in a manner to cause a movement of waves (system of poles) along the cutting stem.

The linear travelling magnetic field has a semi-wave (λ/2), the length of which is defined by a distance between the conductors characterized by the same phase and opposite directions of electric currents, namely between A and X, B
and Y, C and Z. The velocity \( V \) of the travelling magnetic field is determined in accordance with the following relationship:

\[
V = \lambda \cdot f
\]

wherein \( \lambda \) is the wavelength of the traveling magnetic field; \( f \) is the frequency of the alternating electric current, for example of the commercial power network.

In the example of Fig. 4c, similar to that of Fig. 4b, electric currents in each pair of opposite windings 9a and 9b of the opposite inductors 16a and 16b flow in opposite directions. Consequently, so produced magnetic force lines 17a and 17b have opposite directions, forming thereby the N-N (or S-S) orientation of poles.

In order to facilitate the understanding of the effect of the group stimulator 1 onto the rooting process, it would be reasonable to consider the construction of a stem and natural processes occurring therein. Fig. 5a illustrates in a self-explanatory manner a cross-section of a stem, generally designated 20, in its secondary growth. As known, the pre-root cells, callus, is typically formed in the cambium cells layer. The formation of callus can be activated by the transport of liquid phase towards the cambium cells layer through the apoplast pathway, which depends on the firmness of cortex. In other words, the “substance-transport” parameter of a stem altering the growth behavior of the cutting is defined by the liquid permeability through the stem in a radial direction, i.e. from the stem’s surface to the cambium cells layer.

It was found that radial and longitudinal electric current (ions) loops take place inside a cutting stem. The interaction between the linear traveling (or pulsating) magnetic field and these radial electric current loops creates mechanical force effects, namely tensile and compressive stress in the epidermis and endodermis tissues. In both examples of Figs. 4a-4b and 4c, the magnetic
force lines are directed substantially perpendicular to the surface region of the cutting stem, namely perpendicular to the radial electric current (ions) loops inside the stem causing a so-called "pushing" of these loops. This is actually an "electromagnetic stress" that, similar to vibrations, "massages" the cambium cells layer, thereby stimulating the callus formation. Such vibrations increase friability of the stem cortex, thereby increasing the permeability of liquid therethrough in the radial direction, and decreasing the time for root initiation. If such a liquid contains a hormonal substance, the quantity of the substance reaching the cambium is increased, yet further accelerating the further root-development process. On the other hand, the linear travelling (or pulsating) magnetic field itself influences on the activity of the cambium cells layer.

The entire process of treatment by the travelling magnetic field is characterized by predetermined values of magnetic induction $B_c$ and treatment time $T_c$. These parameters could be determined in accordance with known polynom technique. According to prior-experimental data, the following empirical second degree polynom is used:

$$LR(b, F)S(b, F) = b_0 + \sum b_i F_i + \sum b_j F_j F_i + \sum b_u F_i^2$$

$$1 \leq i \leq n$$
$$1 \leq i \leq j \leq n$$
$$1 \leq i \leq n$$

wherein $LR$ is the length of roots measured through treatment by the above method; $S$ is the ratio of the number of "successfully processed cuttings", namely the cuttings formed with the roots, to the total number of treated cuttings; $F$ are the process initial factors such as the magnetic induction $B_c$, treatment time $T_c$, hormone substance concentration $K_h$, ratio $h_2/h_1$ between the upper out-of-treatment portion $h_2$ of the cutting and the lower treated portion $h_1$ thereof; $n$ is the number of such initial factors; $b$ are polynomial coefficients.
Suitable mathematical models could be used for optimizing the process. Such process optimization techniques are known *per se*, and do not form a part of the present invention.

Reference is now made to Fig. 6, illustrating a diagram summarizing the main principles of the above-described technique for altering the growth behavior of the cuttings that leads to the acceleration of further root-development process. The GEM-Stimulator 1 is applied to the plurality of cuttings 2. The Gem-Stimulator 1 is constructed so as to provide *N*-N (S-S) or *N*-S poles' orientation by the opposite indictors 6a and 6b. The magnetic force lines are directed substantially perpendicular to the stem's surface, namely to the radial electric current loops inside the stem within the zone of electromagnetic environment. The Gem-Stimulator 1 provides alternating magnetic field, which is either linear traveling or pulsating. The provision of such a magnetic field in the vicinity of the cutting stem causes the electromagnetic interaction of the magnetic field with the radial electric current loops inside the stem. This, in turn, causes the mechanical force effects on the epidermis and endodermis tissues, thereby leading to the increase of the liquid permeability through the stem in the radial direction. The quantity of hormone substance that reaches the cambium layer could be therefore increased. This results, on the one hand, in the decrease of time for root initiation, and, on the other hand, in the increase of the percentage of successful rooting.

Reference is now made to Fig. 7, illustrating a device, generally designated 20, constructed according to another embodiment of the invention. The device 20 is attached to young tree 22 extending along a surface region 24 of its stem, while the lower, root portion of the tree is dipped in soil. The device 20 represents an individual electromagnetic stimulator (IEM-Stimulator) for accelerating the tree growth.
Fig. 8a illustrates one example of the construction of the IEM-Stimulator 20, comprising an elongated permanent magnet 26 in the form of a magnetic rubber band. The magnet 26 faces the stem region 24 by its one pole side 26a, for example N-pole. The opposite pole side 26b (S-pole) is coupled to a magnetic circuit 28 having a thin elongated portion 28a, extending along the S-pole side 26a of the magnet, and a plurality of spaced-apart pairs of projections 29a-29b (only one projection in each pair 29a being seen in Fig. 8a). The projections 29a and 29b are symmetrically identical and extend substantially transverse to the longitudinal axis of the stem. The projections 29a and 29b in at least some pairs are coupled to one another by brackets 30 or the like, to support the entire stimulator 20 on the stem region 24.

Fig. 8b illustrates somewhat different construction of the IEM-Stimulator 20. Here, the elongated permanent magnet 26 is formed by a plurality of disk-shaped permanent magnets 32 aligned along the portion 28a of the magnetic circuit 28. The magnets 32 are identically oriented, facing the stem portion 24 by the same pole (e.g. N-pole). The magnets 32 are coupled to the magnetic circuit 28 by means of the projections 29a-29b. As clearly seen in the drawing, each pair of projection 29a-29b is located between two adjacent magnets 32. The projections 29a and 29b are substantially C-shaped, thereby circumferentially engaging the stem surface.

In both of the above examples, namely in the case of a magnetic rubber band or a plurality of magnets, the magnetic circuit is made of a flexible material (e.g. steel). This allows for attaching the entire device to the tree stem, which becomes clamped by the projections 29a-29b.

As shown in Fig. 8c, the flexibility of the magnetic circuit 28, in combination with the elongated permanent magnet 26, constituted by either a flexible magnetic rubber or a plurality of disk-shaped magnets, provides the
flexibility of the entire device 20. This facilitates the mounting of the device 20 onto the tree stem.

To understand the main operational principles of the device 20, it would be reasonable to consider the physiological processes that take place inside the tree stem. Turning to Fig. 5b, there are shown xylem and phloem mass flows. These phloem mass flows (PMF) represent a rectilinear motion of ions, such as K\(^+\), Ca\(^{++}\), Mg\(^{++}\), SO\(_4\)\(^-\), auxin ion\(^-\) (typically a natural amino acid), etc., which favor the growth of the tree. In other words, the "substance-transport" parameter affecting the growth behavior of the tree is defined by the motion of ions within the PMF region inside the stem.

The device 20 is applied to the PMF region of the stem, so as to change the rectilinear motion of these ions to a substantially spiral-like motion. The phloem vessels are located substantially within a periphery region of the stem, namely near the stem's surface, while the xylem vessels are located close to the central region of the stem. Therefore, the magnetic force lines, produced by the electromagnetic environment formed by the elongated magnet 26, are substantially perpendicular to the direction of the phloem mass flow, and are substantially parallel to the direction of the xylem mass flows which define a Xylem Mass Flow (XMF) region. Such a magnetic field, whose magnetic force lines are substantially parallel to the xylem mass flows, makes no influence on the movement of nutrient ions substances in the xylem mass flows. By changing (prolonging) the trajectory of movement of ions at least within the PSF region, the passage time of these ions along the electromagnetic environment could be increased. Additionally, this increases the time, during which the ions are absorbed by the vascular cambium located along the electromagnetic environment region. These effects lead to the additional increase of the stem diameter, and to the additional decrease of hydrodynamic resistance to the
movement of xylem and phloem sap flows from the foliage towards the stem. In other words, roots', stem' and leaves' sap mass flows are increased, and the plant growth is accelerated. The device 20 produces a so-called "magnetotropic stimulus" altering the growth behavior of a tree, which results in unequal lateral distribution of auxin (and other ions) inside the stem, namely higher ions' concentration in the longitudinal and radial directions. The entire movement of ions within the stem is slowed down, thereby retarding the ions in the stem region and speeding on the growth of the stem diameter.

The above is implemented in the following manner. Turning back to Fig. 8b (or Fig. 8a), it is shown that, owing to the fact that the magnetic circuit 28 is associated with the S-pole side of the magnet 32, each pair of projection 29a-29b represents S-pole magnets. The projections 29a-29b thus serve as concentrators of the magnetic field. Due to the displacement between the disk-shaped magnet 32 and its neighbor pair of projections 29a-29b along the axis parallel to the longitudinal axis of the stem, the magnet and the pair of projections are actually applied to different, spaced-apart along this axis regions of the stem. These regions are characterized by the existence therein of a substantially unipolar magnetic field.

Referring to Figs. 9a and 9b, there is illustrated that, due to the extension of the projections 28a-28b away from the magnet 32, each disk-shaped magnet 32 and its neighboring pair of projections 28a-28b are applied to different radial zones of the stem, designated Z₁ and Z₂, respectively. These regions Z₁ and Z₂ are also characterized by different unipolar magnetic field, namely N- and S-pole fields, respectively.

Thus, the electromagnetic field environment is formed by repeatedly localized unipolar (N-N-N-... and S-S-S-...) magnetic field along the stem region within the location of the device 20. Therefore, the magnetic force lines are configured to be substantially perpendicular to the stem within the PMF
region and substantially parallel to the stem within the XMF region. This affects
the motion of ions within the PMF region by changing it from a substantially
rectilinear to substantially spiral-like.

The magnetic field induction $B_1$, produced by the disk-shaped magnet 32,
is a function of the magnet radius $r$ and the stem radius $R$, that is $B_1(r, R)$. The
magnetic induction $B_1$ reaches its maximum value at the center of the magnet 32,
and decreases from the center of the magnet towards its peripheral region and
from the peripheral region of the stem towards its axis. The extent of this
decrease depends mainly on the stem diameter $R$. Consequently, the device 20
when applied to young trees or shrubs having relatively small diameter (2-10mm)
will provide successful results even at relatively small values of the magnetic
field induction.

The magnetic field induction $B_2$, produced by the pair of projections
28a-28b is characterized by its maximum value within the surface layers of the
stem (proximate the projection), and decreases up to zero at the paraxial area of
the stem’s axis.

To estimate the optimum value of the magnetic induction $B$ to be achieved
by the electromagnetic environment, known principles of plasma physics and
theories of liquid electrolytes are used. These principles relate to the changing of
ions' movement trajectory from rectilinear to spiral-like under the influence of a
magnetic field having magnetic force lines perpendicular to the ions' stream. In
our case, this stream of ions is the phloem sap flows inside the phloem vessels
(Figs. 5a and 5b). The magnetic induction $B$ is determined according to the
following relationship:

$$B \geq \frac{6 \cdot \pi \cdot d \cdot n \cdot \eta \cdot r \cdot L}{q \cdot V_0^2}$$
wherein \( \pi = 3.14159 \); \( d \) is the diameter of a phloem vessel; \( n \) is the number of loops passed by the phloem vessel ion during the spiral-like motion; \( \eta \) is the viscosity of the phloem sap; \( r \) is the ion radius; \( L \) is the length of said predetermined surface region of the stem; \( q \) is the electrical charge of ion; and \( V_0 \) is the velocity of the PMF.

Reference is now made to Figs. 10a and 10b illustrating two more examples of the construction suitable for the device 20. Fig. 10a shows a device, generally designated 120. Same reference numbers are used for identifying those components, which are identical in the device 20 (Figs. 8a and 8b) and 120. The device 120 is actually composed of two devices 20, located so as to face each and enclose the stem region 24 therebetween. A pair of brackets 30 couples the devices 20 to each other, and supports the entire device 120 on the stem. As shown here, the provision of the projections 29a-29b is generally optional.

Fig. 10b shows a device 220 having a spiral-like shape. The device comprises an elongated magnet 26 that may and may not be provided with a magnetic circuit, which is therefore not shown here.

It should be noted, although not specifically shown, that more than two devices 20 may be mounted on the stem, provided they faces the stem by the same pole-side. It should also be noted that asymmetric accommodation of several devices 20 relative to the circumference of the stem does not lead to asymmetric development of the stem along its radius. Indeed, it is known that the phloem and xylem vessels are communicating (through their side openings) by means of liquid phase. This causes the radial redistribution of the liquid phases in the stem along the transverse direction. Accordingly, the influence of the IEM-Stimulator on the physiological processes occurring in a plant has evolution character only, during the operation of the stimulator. Thus, the IEM-Stimulator combines the advantageous features of the magnetic field treatment with a
convenient way for mounting the stimulator on the tree, and does not impede
natural evaporation from the surface of the tree.

Additionally, the IEM-Stimulator may be applied to the young tree either
continuously or periodically (discrete). Thus, the above-described static magnetic
field, which is substantially perpendicular to the direction of phloem mass flows,
has predetermined values of the magnetic induction $B$ and of the plant treatment
time $T$. These values could be determined using the known polynomial technique
and the following empirical (experimental) second degree polynom:

$$H(b, F), D(b, F), L(b, F), G(b, F) = b_0 + \sum b_i F_i + \sum b_{ij} F_i F_j + \sum b_{ii} F_i^2$$

$1 \leq i \leq n$
$1 \leq i \leq j \leq n$
$1 \leq i \leq n$

wherein $H$, $D$, $L$ and $G$ are measured parameters of the plant’s growth response,
- namely $H$ is the plant height, $D$ is the stem diameter, $L$ is the length of twigs, $G$
is the plant mass; $F$ are the initial factors such as $B$, $T$, $K_f$, $M$, where $K_f$ is a
fertilizer substance concentration and $M$ is the watering mass; $n$ is the number of
initial factors; and $b$ are polynomial coefficients.

Reference is made to Fig. 11, illustrating a diagram summarizing the
above-described principles of the individual treatment of a plant (young tree or
shrub) by the IEM-Stimulator to accelerate the plant-development process. The
stimulator is designed and operated in accordance with the predetermined value
of magnetic field induction, predetermined configuration of the magnetic force
lines and predetermined length of the stem zone under treatment. The
predetermined values of the magnetic field induction $B$ and of the length of the
stem zone $L$ are determined in accordance with the above-proposed mathematical
relationship. As for the predetermined configuration of the magnetic force lines, they are such as to be perpendicular to the stem within the PMF region.

The predetermined values of the above parameters and predetermined configuration of the magnetic force lines prolong the trajectory of the ions’ movement at least within the PMF region. The presence of these ions within the magnetic field environment is thereby desirably delayed. As a result, such process characteristics as the time of absorbing the ions by the vascular cambium, dynamic ions concentration and ion cell membrane permeability are increased, favoring the additional increase of the stem diameter.

Experimental testing of IEM-Stimulator, designed as shown in Fig. 8b and applied to Bougainvilia, Juniper “Pathfinder”, Pomegranate having the diameter of 2-10mm and height of 120-300mm) have shown the real possibility of decreasing the secondary growth period (up to desired plant’s dimensions) up to 50%.

Those skilled in the art will readily appreciate that various modifications and changes may be applied to the preferred embodiments of the invention as hereinbefore exemplified without departing from its scope as defined in and by the appended claims.
CLAIMS:

1. An individual electromagnetic stimulator for attaching to the stem of a young plant, the stimulator comprising a magnetic field source in the form of at least one elongated permanent magnet that faces the stem by its one pole side, and extends along a predetermined surface region of the stem, wherein the magnetic field source produces the magnetic field that has a predetermined value of magnetic induction and is directed substantially perpendicular to phloem mass flows inside the stem.

2. The stimulator according to Claim 1, and also comprising an elongated magnetic circuit coupled to and extending along an opposite pole side of said elongated permanent magnet.

3. The stimulator according to Claim 2, wherein said magnetic circuit comprises at least a pair of spaced-apart symmetrically-identical projections extending towards the stem along an axis substantially perpendicular to a longitudinal axis of the stem, serving thereby as concentrators of the magnetic field.

4. The stimulator according to Claim 3, wherein said at least one pair of projections engage the circumference of the stem.

5. The stimulator according to Claim 4, wherein said at least one pair of the projections clamps the stem therebetween, thereby serving as fasten means for supporting the stimulator on the stem.

6. The stimulator according to Claim 1, which is substantially flexible along its length so as to engage the surface of the stem.

7. The stimulator according to Claim 2, wherein said at least one elongated permanent magnet is formed by a plurality of separate permanent magnets, which have identical orientation of poles and are aligned along said magnetic circuit.

8. The stimulator according to Claim 7, wherein said magnetic circuit comprises a plurality of pairs of projections aligned along the magnetic circuit in a
spaced-apart parallel relationship, each pair of projections being located between
two adjacent separate permanent magnets, the projections of each pair being
symmetrically identical and extending towards the stem along an axis
substantially perpendicular to a longitudinal axis of the stem.

9. The stimulator according to Claim 1, wherein said elongated permanent
magnet is in the form of a magnetic rubber band.

10. The stimulator according to Claim 1, wherein said magnetic field source
comprises at least one additional elongated permanent magnet, the at least two
permanent magnets being spaced apart from each other in a plane perpendicular
to the longitudinal axis of the stem, and facing the stem by the same pole side.

11. The stimulator according to Claim 1, wherein said predetermined value
of the magnetic induction, B, is determined in accordance with the following
relationship:

\[ B \geq \frac{6 \cdot \pi \cdot d \cdot n \cdot \eta \cdot r \cdot L}{q \cdot V_0^2} \]

wherein
\( \pi = 3.14159; \)

\( d \) is the diameter of a phloem vessel;

\( n \) is the number of loops passed by the phloem vessel ion during the
spiral-like motion;

\( \eta \) is the viscosity of the phloem sap;

\( r \) is the ion radius;

\( L \) is the length of said predetermined surface region of the stem;

\( q \) is the electrical charge of ion; and

\( V_0 \) is the velocity of phloem mass flows.
12. The stimulator according to Claim 1, when attached to the tree, has a spiral like shape engaging the circumference of the stem along the predetermined region.

13. A group electromagnetic stimulator for applying simultaneously to a group of cuttings during at least several seconds, the electromagnetic stimulator comprising a magnetic field source producing an alternating magnetic field and defining a slot-like space within said field for installing the group of cuttings by their predetermined stem portions in the space, wherein magnetic force lines of said alternating magnetic field are directed substantially perpendicular to the stem portions of the cuttings.

14. The group stimulator according to Claim 13, wherein said space is elongated having a substantially rectangular cross section.

15. The group stimulator according to Claim 13, wherein a slot-like vessel is mounted in said space defined by the magnetic field source.

16. The group stimulator according to Claim 13, wherein said magnetic field source comprises a pair of inductors accommodated at opposite sides of the space, respectively, coupled to a predetermined electric current source.

17. The group stimulator according to Claim 16, wherein said electric current source is at least two-phase network.

18. The group stimulator according to Claim 17, wherein the alternating magnetic field is a linear traveling field.

19. The group stimulator according to Claim 17, wherein the alternating magnetic field is a pulsating field.

20. The group stimulator according to Claim 16, wherein each of the inductors comprises a predetermined number of windings supported on a packet of electric transformer steel that serves as the magnetic field concentrator.

21. The group stimulator according to Claim 13, wherein said space is filled with liquid.
22. The group stimulator according to Claim 21, wherein said liquid is water.

23. The group stimulator according to Claim 22, wherein said liquid contains a hormone substance.

24. The group stimulator according to Claim 13, wherein said space is filled with a hormone substance.

25. The group stimulator according to Claim 24, wherein said hormone substance is a powder.

26. A method for simultaneous processing a group of cuttings with a group electromagnetic stimulator that comprises a magnetic field source producing an alternating magnetic field and defining a slot-like space within said field for installing the group of cuttings by their predetermined stem portions in the space, wherein magnetic force lines of said alternating magnetic field are directed substantially perpendicular to the stem portions of the cuttings, the method comprising the steps of:

(a) providing said group of cuttings each having said lower stem portions substantially foliage-free;

(b) locating the lower stem portions of the cuttings in said space to be processed by said magnetic field for at least several seconds; and

(c) transplanting the processed cuttings into soil.

27. The method according to Claim 26, and also comprising the step of:

(d) filling the space with liquid prior to placing the cuttings therein.

28. The method according to Claim 27, wherein said liquid contains a hormone substance.

29. The method according to Claim 27, wherein said liquid is water.

30. The method according to Claim 26, and also comprising the step of:

(e) filling the space with a hormone substance prior to placing the cuttings therein.
31. The method according to Claim 26, and also comprising the step of:
(f) treating the processed cuttings by a hormone substance prior to transplanting
them into soil.
AMENDED CLAIMS
[received by the International Bureau on 17 June 1999 (17.06.99); original claims 1-31 amended; new claims 32-35 added; (5 pages)]

CLAIMS:
1. An individual electromagnetic stimulator for attaching to the stem of a young plant, the stimulator comprising a magnetic field source in the form of at least one permanent magnet that faces the stem by its one pole side and extends along a predetermined surface region of the stem, wherein the magnetic field source produces the magnetic field that has a predetermined value of magnetic induction and magnetic force lines directed substantially perpendicular to phloem mass flows inside the stem.
2. The stimulator according to Claim 1, wherein said magnetic field source is elongated and extends along a portion of the stem at either side thereof.
3. The stimulator according to Claim 1, and also comprising a magnetic circuit coupled to and extending along an opposite pole side of said at least one permanent magnet.
4. The stimulator according to Claim 3, wherein said magnetic circuit comprises at least a pair of spaced-apart projections extending towards the stem along an axis substantially perpendicular to a longitudinal axis of the stem, serving thereby as concentrators of the magnetic field.
5. The stimulator according to Claim 4, wherein the at least two projections are made of a substantially flexible material so as to engage two circumferential portions of the stem.
6. The stimulator according to Claim 5, wherein said at least one pair of the projections clamps the stem therebetween, thereby serving as fasten means for supporting the stimulator on the stem.
7. The stimulator according to Claim 1, wherein said magnetic field source is supported on the stem by at least a pair of projections which extend towards the stem along an axis substantially perpendicular to a longitudinal axis of the stem, and are made of a substantially flexible material so as to engage at least two
circumferential portions of the stem, respectively, thereby clamping the stamp therebetweem.

8. The stimulator according to Claim 1, which is substantially flexible along its length so as to engage the surface of the stem along the axis thereof.

9. The stimulator according to Claim 1, wherein said at least one permanent magnet is formed by a plurality of separate magnetic elements which have identical orientation of poles with respect to the stem.

10. The stimulator according to Claim 9, wherein the separate magnetic elements are aligned along a magnetic circuit which is coupled to and extends along pole sides of the magnetic elements opposite to the pole sides facing the stem.

11. The stimulator according to Claim 10, wherein said magnetic circuit comprises a plurality of pairs of projections aligned along the magnetic circuit in a spaced-apart parallel relationship, each pair of projections being located between two adjacent separate magnetic elements, the projections of each pair being symmetrically identical and extending towards the stem along an axis substantially perpendicular to a longitudinal axis of the stem.

12. The stimulator according to Claim 1, wherein said at least one permanent magnet is in the form of an elongated magnetic rubber band.

13. The stimulator according to Claim 1, wherein said magnetic field source comprises at least one additional permanent magnet, the at least two permanent magnets being spaced apart from each other in a plane perpendicular to the longitudinal axis of the stem, and facing the stem by the same pole side.

14. The stimulator according to Claim 1, wherein said predetermined value of the magnetic induction, B, is determined in accordance with the following relationship:
\[ B \geq \frac{6 \cdot \pi \cdot d \cdot n \cdot \eta \cdot r \cdot L}{q \cdot V_0^2} \]

wherein \( \pi = 3.14159; \)
- \( d \) is the diameter of a phloem vessel;
- \( n \) is the number of loops passed by the phloem vessel ion during the spiral-like motion;
- \( \eta \) is the viscosity of the phloem sap;
- \( r \) is the ion radius;
- \( L \) is the length of said predetermined surface region of the stem;
- \( q \) is the electrical charge of ion; and
- \( V_0 \) is the velocity of phloem mass flows.

15. The stimulator according to Claim 1, which, when attached to the tree, has a spiral like shape engaging the circumference of the stem along the predetermined region.

16. A group electromagnetic stimulator for applying simultaneously to a group of cuttings during at least several seconds, the electromagnetic stimulator comprising a magnetic field source producing an alternating magnetic field and defining a slot-like space within said field for installing the group of cuttings by their predetermined stem portions in the space, wherein magnetic force lines of said alternating magnetic field are directed substantially perpendicular to the stem portions of the cuttings.

17. The group stimulator according to Claim 16, wherein said space is elongated having a substantially rectangular cross section.

18. The group stimulator according to Claim 16, wherein a slot-like vessel is mounted in said space defined by the magnetic field source.
19. The group stimulator according to Claim 16, wherein said magnetic field source comprises a pair of inductors accommodated at opposite sides of the space, respectively, coupled to a predetermined electric current source.

20. The group stimulator according to Claim 19, wherein said electric current source is at least one-phase network.

21. The group stimulator according to Claim 19, wherein the alternating magnetic field is a linear traveling field.

22. The group stimulator according to Claim 20, wherein the alternating magnetic field is a pulsating field.

23. The group stimulator according to Claim 19, wherein each of the inductors comprises a predetermined number of windings supported on a packet of electric transformer steel that serves as the magnetic field concentrator.

24. The group stimulator according to Claim 16, wherein said space is filled with liquid.

25. The group stimulator according to Claim 24, wherein said liquid is water.

26. The group stimulator according to Claim 24, wherein said liquid contain a hormone substance.

27. The group stimulator according to Claim 16, wherein said space is filled with a hormone substance.

28. The group stimulator according to Claim 27, wherein said hormone substance is a powder.

29. A method for simultaneous processing a group of cuttings with a group electromagnetic stimulator that comprises a magnetic field source producing an alternating magnetic field and defining a slot-like space within said field for installing the group of cuttings by their predetermined stem portions in the space, wherein magnetic force lines of said alternating magnetic field are directed
substantially perpendicular to the stem portions of the cuttings, the method comprising the steps of:

(a) providing said group of cuttings each having said lower stem portions substantially foliage-free;

(b) locating the lower stem portions of the cuttings in said space to be processed by said magnetic field for at least several seconds; and

(c) transplanting the processed cuttings into soil.

30. The method according to Claim 29, wherein said alternating magnetic field is a linear traveling field.

31. The method according to Claim 29, and also comprising the step of:

(d) filling the space with liquid prior to placing the cuttings therein.

32. The method according to Claim 31, wherein said liquid contains a hormone substance.

33. The method according to Claim 31, wherein said liquid is water.

34. The method according to Claim 29, and also comprising the step of:

(e) filling the space with a hormone substance prior to placing the cuttings therein.

35. The method according to Claim 29, and also comprising the step of:

(f) treating the processed cuttings by a hormone substance prior to transplanting them into soil.
GROUP TREATMENT of CUTTINGS by MAGNETIC-FIELD ENVIRONMENT

(GEM-Stimulator)

PERPENDICULAR DIRECTION of MAGNETIC FORCE LINES to SURFACE LAYERS of CUTTINGS' STEMS

ALTERNATING MAGNETIC FIELD

LINEAR TRAVELLING MAGNETIC FIELD or PULSATING MAGNETIC FIELD

INITIATION of the MECHANICAL FORCE EFFECTS within STEM CORTEX

ELECTROMAGNETIC INTERACTION between the MAGNETIC FIELD and RADIAL ELECTRIC CURRENT LOOPS in STEM

INCREASING the CUTTING STEM RADIAL LIQUID PERMEABILITY

INCREASING the QUANTITY of HORMONAL SUBSTANCE REACHED to CAMBIUM SELLS LAYER

DECREASING the TIME for ROOT INITIATION

INCREASING PERCENTAGE of ROOTING SUCCESS

FIG. 6
INDIVIDUAL TREATMENT of TLGEE (SHRUB) STEM by MAGNETIC-FIELD ENVIRONMENT (IEM-Stimulator)

- DESIRED VALUE of MAGNETIC INDUCTION
- PREDETERMINED LENGTH of TREATMENT STEM REGION
- PREDETERMINED MAGNETIC FIELD CONFIGURATION

- PROPOSED MATHEMATICAL RELATIONSHIP (B)
- PERPENDICULAR DIRECTION of MAGNETIC FORCE LINES to PHLOEM MASS FLOWS

- CHANGING (PROLONGING) of IONS MOVEMENT TRAJECTORY AT LEAST WITHIN PHLOEM MASS FLOWS

- INCREASING the FLUCTUATION TIME of IONS at MAGNETIC FIELD ENVIRONMENT

- INCREASING of ABSORPTION TIME of IONS by VASCULAR CAMBium

- INCREASING the DYNAMICAL IONS' CONCENTRATION and ION CELL MEMBRANE PERMEABILITY

- ADDITIONAL INCREASING the STEM DIAMETER

FIG. 11
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC 6 A01G7/04

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 A01G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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X  Further documents are listed in the continuation of box C.

X  Patent family members are listed in annex.

**Date of the actual completion of the international search**

9 April 1999

**Date of mailing of the international search report**

21/04/1999

**Name and mailing address of the ISA**

European Patent Office, P.B. 5018 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016

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### INTERNATIONAL SEARCH REPORT

**Int. Application No:** PCT/IL 99/00033

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