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Alternating Electromagnetic Fields in Plantains

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ABSTRACT

Weak, static, varying and high electromagnetic fields (EMFs) and waves derive their origins from both natural and man-made sources. The proximity of biological systems to electrical transformers, high voltage transmission and distribution systems, which operate at low-frequencies (50/60 Hz) have been known to have differing biological responses on animals, plants, microorganisms, human beings and the surrounding environments. For some important agricultural crops, the effects of low-frequency EMFs increased germination, shoot and root lengths; fresh and dry weights; or the release of oxygen. While the above traits were inhibited in some other crops, yet there were no noticeable low-frequency EMFs effects in some other plants. Because of these conflicting results, coupled with the difficult and complicated evaluation of weak electromagnetic fields effects on plants, it was thought to be species-specific. Therefore, extensive literature search, review and plane waves mathematical analyses were used to model the effects of alternating electromagnetic fields in plantain pseudostems. The results show the determination of some important parameters like the Poynting power flow, conductance, conductivity, quality factor, penetration depth, propagation coefficient and Lamor radius for trapped ions of the thermic environment in plantains. Moreover, with suitable materials manufacture, modifications and mimicking, large amounts of power can be transmitted to the load using plantain pseudostems. In addition, the pico-farad capacitance values determined for plantains in this study; require very low voltages to drive digital circuits, reduce the signal-to-noise ratio when compared to analogue circuits and thus, enhance efficiency and performance characteristics in prime industries like energy, entertainment, recreation, transportation and telecommunications, which have become more and more digitalised.

Keywords: capacitance, conductivity, poynting power flow, pseudostems, quality factor
Abbreviations: AC, alternating current; **B**, magnetic flux; **D**, electric flux density; **DC**, direct current; **E**, electric field vector; **ECF**, electro-conjugate fluids; **EHD**, electrohydrodynamics; **ELF**, low-frequency electromagnetic fields; **EMF**, electromagnetic fields; **FSD**, foliar spiral direction; **H**, magnetic field vector; **ICR**, ion cyclotron resonance; **J**, current density; **MF**, magnetic fields; **PML**, perfectly matched layer; **Q**, quality factor; **S**, poynting mean power flow

INTRODUCTION

The processes of electrical energy production, transmission, utilisation, industrialisation and technological developments have brought with them the effects of electromagnetic fields on humans, animals, plants, inanimate objects and our surrounding environments. The electrical engineering devices and equipment which have become part and parcel of the everyday life of the modern man, and whose level of consumption has become the common denominator for measuring the quality of life and standards of living; produce low-frequency (50/60 Hz) electromagnetic fields (ELF), which especially affect biological systems (Dardeniz *et al*. 2006). In addition, biological systems in the proximity of electrical engineering transformers, high voltage transmission and distribution systems are known to specifically affect biological systems, with myriads of biological responses to ELF, when applied at varying frequencies, intensities and regions, as to be operative at the level of the cell (Segal 2010). Although static magnetic fields (MF) have been shown to affect normal cell metabolisms and also impacts cell division, the full evaluation of the effects on biological systems structures have been both difficult and complex. This complexity has been borne out of that fact that, investigations involving electromagnetic field (EMF) effects on organisms vary, depending on the intensities of the MF, frequencies, exposure durations of MF and EMF, genotypes of organisms and the biological systems under consideration (Dardeniz *et al*. 2006; Pazur and Rassadina 2009).

Weak magnetic and electromagnetic fields

Weak magnetic and electromagnetic fields influence the physiological processes in animals, plants and microorganisms, although the underlying perception methodologies and principles are not clearly understood (Pazur and Rassadina 2009). Natural and man-made sources generate electromagnetic energy in the form of electromagnetic waves, which consist of oscillating electric and magnetic fields that interact differently with biological systems like cells, plants, animals and human beings (Science Project 2010). Whereas there is conflicting evidence on the effects of EMF as an environmental hazard, there is link to cancer, leukemia and human melatonin denaturation (Science Project 2010). Weak MF and EMF effects have been studied in plants using the ion cyclotron resonance (ICR) approach for calcium in *Arabidopsis thaliana*, and the results show that there were transient cytosilic Ca^{2+} increases after switching the EMF on and off, with the latter decreasing with increasing duration of the EMF impact (Pazur and Rassadina 2009). Furthermore, MF and EMF effects can be observed with many organisms without proven ferrimagnetic particles and at field strengths far below those required for radical pair mechanisms (Pazur and Rassadina 2009). This radical pair mechanism is a consequence of the windows of opportunity, which were observed from a certain combination of field strengths and frequencies of the applied MF and EMF. Davies (1996) also studied the effects of 60 Hz ELF on barley (*Hordeum vulgare* L.), mustard (*Mustum ardens*), and radish (*Rapha-*

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nus sativus) using ICR, and found that dry stem weight, plant height, wet root weight, dry leaf weight, dry whole weight and stem diameter were greater in the EMF-exposed plants than in the control plants. The major significance of this study was that it is possible to independently replicate another laboratory and hence, validate bioelectromagnetic science.

Although positive rooting percentage effects and plant growth of ELF have been reported for *Komatsuda* (*Ablemoschus esculentus*), productivity and yield have also been positively affected by MF in sunflower (*Helianthus annuus*) and soybean (*Glycine soja*) (Dardeniz *et al*. 2006). Similarly, Bhatnagar and Deb (1977) as reported by Dardeniz *et al*. (2006), of implementing magnetic fields of 0.05 Tesla (T) to 0.30 T on the seeds of wheat (*Triticum aestinum*), barley and oat (*Avena sativa*), showed positive effects on germination rate, as well as, root and shoot lengths. However, Segal (2010) reports that spinach (*Spinacia oleracea*) subjected to the North Pole were smaller than the control, whereas those subjected to the South Pole were larger than the control. He further states that plants from seeds exposed to the southern pole fields gave off more oxygen and grew taller than those exposed to the North Pole. The explanation was that the South Pole fields encouraged the production of certain growth regulators like auxin and cytokinins, while the North Pole fields inhibited their production.

Moreover, weak EMFs are thought to suppress the growth of plants and arrest cells in the G1 phase-growth phase, leading up to cell division. Darwish (2006) states that the growth of wheat (*Triticum aestinum*), pea (*Pisum sativum*) and sugar beet (*Beta vulgaris*) roots was significantly inhibited by weak EMFs, but increased the germination of oak (*Quercus*) seeds, shoot length and dry weight. Similarly, onion (*Allium cepa*) and rice (*Oryza sativa*) seeds exposed to weak EMFs for 12 hours increased germination, shoot and root lengths and fresh and dry weights of their seedlings significantly. In contrast, Darwish (2006) quoting Govoroon *et al*. (1992) observed no effect of EMF on the growth of pea (*Pisum sativum*), flax (*Linum usitatissimum*), and lentil (*Lens culinaris*) seeds. Therefore, the above contradictory results seem to suggest that magnetic field effects on plants, is species-specific.

However, it is important to realise that self-generated electric fields and currents are important in the energetics and control of metabolism in plants. Equally, externally applied fields also have their effects in the above mechanisms. The non-polar effects of DC fields, where the effects are not related to the direction of the field, ranges from responses to massive electric fields like those found in thunderstorms, down to those of much weaker effects, which operate at the levels of the growth and differentiation of tissue culture (Goldsworthy 2006). For the polar effects of DC fields, the direction of plant response is related to the direction of the field and includes the effects of polar growth and tropisms. Coincidentally, the effects of time varying and alternating EMFs present evidence that a simple charge in membrane stability can account for virtually all of the previously unknown and unexpected biological effects of weak electromagnetic radiation (Goldsworthy 2006).

Time varying and oscillating electromagnetic fields

Alternating EMFs are constantly changing quantities that manifest simultaneously both magnetic and electric fields in tandem, during transport. As a result, different materials exhibit varying electromagnetic field effects mainly because of differences in their optical densities, loss factors, permittivity constants, dielectric or conductivity values. So, changes in MFs induce electromotive force in conductors, while changes in electric fields have associated MFs. It has also been shown that the electric field of a light wave is not a steady field, but alternating (Jenkins and White 1981).

Generalisations from experimental data obtained from electric charges, currents and magnets were used by Maxwell to develop equations for an EMF. As a result, the equations provide a basis for electromagnetic induction law, shows that an alternating electric field gives rise to the MF, absence of static electric field in vacuum and also the absence of magnetic charges (Akhmanov and Nikitin 1997).

Alternating electromagnetic waves derive from radiation occurring when atoms and molecules change from one energy level to another, with frequencies from microwave through visible light into X-ray regions of the spectrum. These natural radiations like from lightning and other natural variations are used in astronomy, telecommunications, navigational systems, radar and power transmission depending on the ability to generate, guide, store, radiate, receive and detect electromagnetic waves (Ramo *et al.* 2004).

Plants have been known to maintain a cytoplasmic free Ca^{2+}-ion concentration of 100-200 nM by ion-specific membrane channels, storage proteins and organelles like the vacuole. However, higher Ca^{2+}-levels are cytotoxic in the long term (Pazur and Rassadina 2009). Furthermore, the space needed for an undisturbed movement of an ion in an MF is governed by the Lamor radius, which predetermines the minimally required coherence length. Due to collisions with thermal moving solvent molecules, an undisturbed free distance λ for an ion circulating with the Lamor radius r_L and speed v, should not be possible in an aqueous phase (Pazur and Rassadina 2009). But, this paradox has been addressed with the suggestion that ion channels and ion-protein complexes guide ion orbits and hence, maintain the necessary coherence length $\lambda = 2 \bullet r_L$ of some 10^{-9} m free from thermic environmental influences (Pazur and Rassadina 2009).

The ion cyclotron resonance (ICR) effect (Davies 1996) can be observed in aqueous solutions of small molecules like glutamic acid without any additional biological components. Therefore, the existence of dielectric boundaries is common to any biological or *in vitro* systems probed for MF and EMF effects, where dielectric boundaries build up an electric double-layer (inner and outer, Helmholtz-layer) (Pazur and Rassadina 2009). The inner layer produces a potential trap for ions directly above the boundary plane between the two phases, and effects a sharp transition zone for relative dielectric permittivity ε_r, refraction number and entropy, between the two phases. These influence the adjacent diffuse outer layer, which in turn generates the measurable zeta potential (ζ). Consequently, the trapped ions should be able to provide an area with a local electric field E(d) and relative dielectric permittivity ε_r(d), at the distance d from the phase boundary (Pazur and Rassadina 2009).

Generally and from the above explanations, an electrical insulator like plantain can support an electric field in its interior without current flow. Electrons are not free to flow through the plantain under an applied electric field at the atomic level, but electrons and atomic nuclei are pulled to opposite directions by the field while responding to restricted movement by electrical polarisation (Cottingham and Greenwood 1995). Light can be described as an electromagnetic wave traveling through space. Thus, incident light will reflect and refract at an interface. This is especially so because Maxwell's equations must be satisfied when light interacts with a material which leads to boundary conditions at that interface (Woollam 2002). A dispersive medium could be defined as that within which harmonic waves move at wave speeds that are functions of their wavelengths, geometry of their boundary conditions or by the interactions of such waves with the transmitting medium. It can also be defined as that medium for which the phase velocity of an electromagnetic wave is a function of the frequency of propagation.

"Left-handed" media, which include the theoretical negative-index (ε, μ< 0) media and their metamaterial realisations, wavelength-scale periodic media that mimic some qualitative features of negative-index media while not having a strictly well-defined phase velocity (v_p), and certain uniform cross-section positive-index waveguides with "backward-wave" modes, that have their phase velocity and group velocity (v_g) of waves, antiparallel (Loh *et al.* 2009). For non-dispersive media (Loh *et al.* 2009), $v_g = v_p(f_t - f_z)$, where f_t and f_z are the fractions of the electromagnetic energy in the transverse (XY) and longitudinal (Z) directions, respectively. Consequently, backward-wave modes ($v_p, v_g < 0$) in non-dispersive media coincides with the fields being mostly in the longitudinal direction ($f_z > f_t$). Therefore, the situation of negative-index media involves material dispersion, which depicts a failure of perfectly matched layers (PMLs) that are often used as absorbing boundaries for simulating wave equations in backward-wave structures (Loh *et al.* 2009). In addition, a PML is an "anisotropic absorber" with gain in the longitudinal direction that dominates in backward-wave modes. Conversely, for inhomogeneous backward-wave media, unlike homogeneous negative index media, the recourse was to abandon PML in favour of adiabatic non-PML absorption tapers (Loh *et al.* 2009).

Therefore, the propagation of waves through dispersive media often leads to unexpected results and behaviour (Xu *et al.* 1997; Turukhin *et al.* 2001; Dolling *et al.* 2006). Similarly, the peak of a temporally long Gaussian pulse can appear at the rear side of a sample (i.e., opposite side to the region of the applied MF to the plantain pseudostem) before the peak Gaussian input pulse has entered the front side of the sample (i.e., the actual region and direction of the applied MF to the plantain pseudostem). A special example exists in negative-index metamaterials where both ε (electric permittivity) and μ (magnetic permeability) are negative in some frequency range with low loss in a dispersive medium and where energy density of the EMF suffers negligible loss. Therefore, in a dispersive negative index medium, a purely transverse field ($E_z = H_z = 0$) has opposite phase and group velocities. A nondispersive negative-index medium, on the other hand, is not physical especially as it violates the Kramers-Kronig consistency relations. In that case, v_g is somewhat artificial, mainly because the energy density is negative (Loh *et al.* 2009), and it is not discussed further here. A concentric dielectric cylinder that supports the backward-wave mode, was used to demonstrate in all-dielectric (positive-index non-dispersive) photonic-crystal Bragg and Holey fibres; can be explained as an avoided eigenvalue crossing from a forced degeneracy at β = 0 (where β is a propagation constant). Also, the backward-wave region coincides with fields that are mostly oriented in the Z (axial) direction (Loh *et al.* 2009). In cases where both the group and phase velocities are oriented in the same direction, the overall rate constant is negative and causes absorptive loss in the PML. Physically, the ratio v_g/v_p determines whether the fields are mostly transverse or mostly longitudinal and whether the PML loss (XY-axes) or gain (Z-axis), dominates (Loh *et al*. 2009).

Because of the above factors and the unexpected behaviour of dispersive media, doped- and/or meta-materials, experiments conducted to measure both the phase and group velocities in negative refractive index materials have yielded four conditions, namely: (a) Vphase > 0 and Vgroup < 0; (b) Vphase < 0 and Vgroup < 0; (c) Vphase < 0 and Vgroup > 0, and the usual (d) Vphase > 0 and Vgroup > 0. However, all four sign combinations have each produced a positive Poynting vector along the forward direction (Dolling *et al.* 2006).

Electromagnetic waves and the Poynting vector

Electromagnetic waves can be described as travelling waves that transport energy and momentum from one point to another, in time. This energy transfer is denoted by energy transferred per unit time per unit cross-sectional area or power per unit area, for an area perpendicular to the direction of wave travel (Young and Freedman 2005). This momentum, which corresponds to the momentum flow rate is responsible for the radiation pressure that is transferred to the absorbing surface as the average force per unit area of the wave (Young and Freedman 2005). Since **E** and **B** are perpendicular, the energy flow per unit area and per unit time through a cross-sectional area is perpendicular to the direction of propagation. For sinusoidal electromagnetic waves at high frequencies, the time variation of the Poynting vector is so rapid that, the average value of the radiation intensity is both admissible physically and more convenient to look at (Young and Freedman 2005). In addition, modifications are needed for the Poynting vector and energy intensity of sinusoidal waves travelling in dielectrics. Fortunately, it turns out that the modifications needed are to replace ε_o with the permittivity ε of the dielectric, replace μ_o with the permeability μ, and replace c with the speed v of electromagnetic waves in the dielectric. Interestingly, the energy densities in the **E** and **B** fields are equal in a dielectric. In addition, the ratio of the speed c in vacuum to the speed v in a material is known as the index of refraction, n of the material (Young and Freedman 2005).

Traditionally, the Poynting vector is the vector product of the **E** vector and the **H** vector and it is at right angles to the plane containing the **E** and **H** vectors. It is usually interpreted as the local power flow at right angles to the **EH** plane proportional to the area of the element of surface times the **E** field strength times the **H** field strength times sine (the angle between **E** and **H**) (Jefferies 2003). Incidentally, the above definition is suspect because a permanent magnet can be used to create a static **H** field and use a pair of charged stationary plates to set up a static **E** field not everywhere in the same direction as the magnetic field. Therefore, there would be no movement, no power supplied to maintain the charges or the magnetic field, and there will be no power dissipated anywhere. Yet, there would be local elemental Poynting vector, which can be interpreted as a local power flow. From the physics of the situation, the only plausible explanation would be that local power flow occurred during the period those fields were being set up, as energy stored in the fields. Similarly, Nordberg (2004) describes the Poynting vector as closest to the "Ball of Light Particle Model". Upon using the SI-derived and SI-basic units principle, Nordberg was able to show that the Poynting vector was a grand unification theory. He states that on one side of the equation, one has Electric cross Magnetic units, and on the other side of the equation, one has units of mass. Nordberg (2004) further pointed out that in order to simplify the Poynting vector uses in calculations, cylindrical spaces were usually considered and not spherical spaces.

This above fact was one of the justifications of applying the Poynting vector theorem to the almost cylindrically shaped plantain pseudostems. It should be emphasised that what probably stopped the further development of this rather promising theory was Albert Einstein's relativity theory. Another major weakness of the Poynting vector theorem results from the divergence of the electromagnetic fields. Fortunately, gravity has held the Poynting vector principle together. This earlier point is explained as such, because photons are known to pivot around and bend in the gravitational field (Nordberg 2004; Unnikrishnan 2005; Biswas and Mani 2008). While the covariant nature of electromagnetic fields is well documented, the Poynting theorem predicts radiation to infinity of electromagnetic power for accelerating charges. Using the linear coordinate system transformations, the power density flux of a uniformly moving charge in the frame of the moving charge is necessarily zero. Therefore, in the non-moving inertial system of the observer, the power balance on radiation, storage and dissipation does not have an outward radiation towards infinity (Giles 2009). Janhunen *et al.* (2005) studied wave-related (AC) and static (DC) parallel Poynting vector (Poynting energy flux) as a function of altitude in auroral field lines. Energy is dissipated in the auroral ionosphere through charged particle (mainly electrons) precipitation and resistive Joule heating. This auroral energy is seen to derive from the magnetosphere as electromagnetic energy flux (Poynting vector) and dissipates as Joule heating. Additionally, some part of the electromagnetic energy flux is transferred to electron energy flux (auroral acceleration) before reaching the ionosphere.

The non-trivial solutions to the paraxial wave equation have been generating much interest of late. These interests have arisen because the beams exhibit features like spin or orbital angular momentum, diffraction-free propagation, self reconstruction and acceleration. As a result, Sztul and Alfano (2008) have used the Airy solution of the paraxial wave equation to study the Poynting vector and angular momentum of the Airy beam as it propagates through space. Additionally and in theory, a non-dispersive beam like the Airy beam would have an infinite power. Conversely, and in practice, this above assertion cannot be the case, mainly because a beam cannot propagate infinite power (Giles 2009). Furthermore, the rate of electromagnetic energy flow per unit area or the Poynting vector is a usually known quantity in electrodynamics. Although the Poynting vector has usually been investigated for plane waves, it has also received considerable attention with regard to the Laguerre-Gaussian beams of light that have helical wavefronts (Sztul and Alfano 2008; Giles 2009). Zeppenfeld (2009) used oblate spheroidal coordinate wave functions to demonstrate the equivalence in the short wavelength limit to Gauss-Laguerre solutions to the paraxial wave equation.

However, in this study the plane waves approach shall be used in the analyses of alternating electromagnetic fields in plantains, mainly because of its mathematical simplicity. Observationally, quantitative analyses depicting the characteristics of plantains behaviour on the influence of covariant electromagnetic fields is either not commonly reported in the literature or the results are not clearly stated. For example, for the latter, the work by Blomme *et al.* (2004) on the "Relationship between electrical capacitance and root traits" recorded "Capacitance value" with respect to "Corm height" as "0.29" and "Capacitance value" with respect to "Corm width" as "0.38". Whereas the results table was captioned "Correlation coefficient between capacitance values and corm traits", the capacitance values reported had no units. It would appear that only the statistical "correlation" was measured in the Blomme *et al.* (2004) study and not the capacitance of bananas and plantain roots. The above assertion was made because there was no where in the body of the article in which the measured capacitance values, that were used for the statistical analyses, were ever stated. Therefore, this study has been structured such that the determination of electromagnetic fields, closely followed by divergence of current and displacement current effects, Faraday's law of induction and plane waves effects on plantains have been carried out in that sequence; for discussing alternating electromagnetic fields in plantains. Additionally, the Poynting power flow, conductance, capacitance, conductivity and quality factor values of plantains will also be evaluated and established in this study.

MATERIALS AND METHODS

The main objective for this study is to theoretically analyse plantain pseudostems as they are influenced and affected by constantly changing electromagnetic fields. The sample size used for this study was one (1) representative plantain pseudostem among a group of twenty (20) plantain pseudostems. The main aim of that representation was, to obtain a 5% or 0.05 statistical power. The main materials used for this study are the cylindrical shaped pseudostems of plantains. Extensive literature search, review and quantitative analyses will similarly be used by exploiting the plantain cylindrical surface (Nordberg 2004) as the most amenable to simplified solutions of the boundary conditions that are normally associated with Maxwell's equations.

Furthermore, the divergence relationships between electric and MFs; displacement currents; distributed currents for **H** and **J** vectors; Faraday's law; plane sinusoidal waves effects, Poynting vector power flow equations in consonance with varying alternating fields will be used to determine the conductance, capacitance, wave impedance, Poynting power flow, conductivity and quality factor in plantains. Upon determination of the aforesaid quantities for plantains, possible application areas with suitable modifications and manufacture would be suggested.

Divergence in electric fields

The physics of divergence of a vector field shows the rate at which the density of a vector field leaves a certain space. Therefore, without the creation or destruction of matter, the density can only change by the amount flowing into or out of that region of space (Weisstein 2009), which represents the continuity principle of a scalar field.

Consider an electric field represented by an electric flux density **D** existing in space. For an elemental cube $\delta x\delta y\delta z$ (**Fig. 1**) and charge density ρ coulombs per metre, the total charge enclosed by the cube element is $\rho\delta x\delta y\delta z$. This is also the outward net normal electric flux from the element (Morton 1971; Jordan and Balmain 1998; Naidu and Kamaraju 2007). If D_x is the normal component of electric flux density on face EF, the value over face GH becomes (Morton 1971):

$$D_{xp} + \frac{\partial D_{xp}}{\partial x}\delta x \quad (1)$$

The inward normal flux on face (Morton 1971):

$$\text{EF} = D_{xp}\delta y\delta z \quad (2)$$

The outward normal flux from face (Morton 1971):

$$\text{GH} = \left(D_{xp} + \frac{\partial D_{xp}}{\partial x}\delta x\right)\delta y\delta z \quad (3)$$

Therefore, the net normal outward flux in the X-direction gives (Morton 1971):

$$\frac{\partial D_{xp}}{\partial x}\delta x\delta y\delta z \quad (4)$$

Using the same above arguments for both the Y- and Z-directions, yields (Morton 1971):

$$\text{Normal outward total flux} = \left(\frac{\partial D_{xp}}{\partial x} + \frac{\partial D_{yp}}{\partial y} + \frac{\partial D_{zp}}{\partial z}\right)\delta x\delta y\delta z \quad (5)$$

Equation (5) is the divergence of the electric flux density vector $\mathbf{D_p}$, or div $\mathbf{D_p}$. Therefore, (Naidu and Karamaju 2007):

div $\mathbf{D_p}$ $\delta x\delta y\delta z = \rho_p\delta x\delta y\delta z$ (6)
or div $\mathbf{D_p} = \rho_p$ (7).

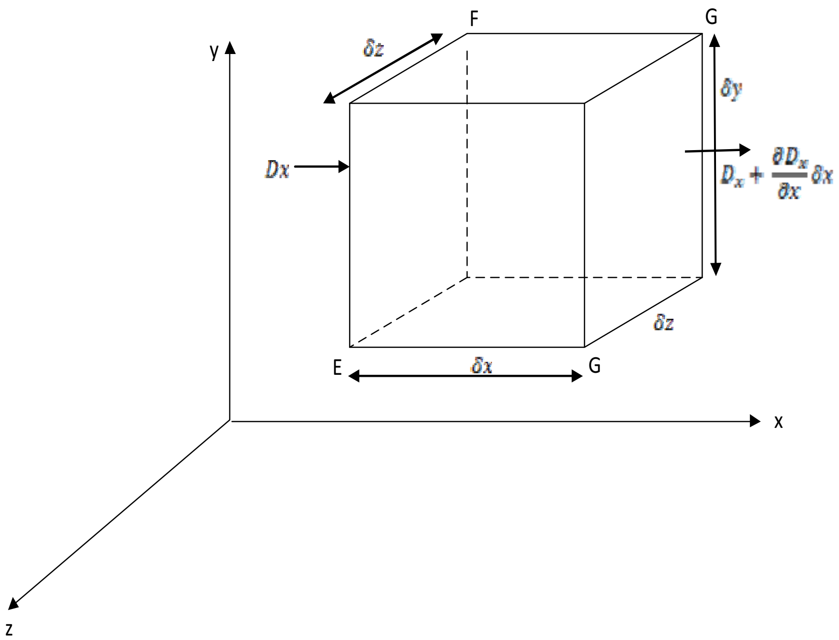

Fig. 1 Divergence of electric flux density. The positive X-direction shows an increase in the electric flux density

Hence, div $\mathbf{D_p}$ is the net flux outflow from a unit volume of field (Morton 1971; Jordan and Balmain 1998; Naidu and Kamaraju 2007). The electric field potential in the X-direction in terms of equation (7) can be written as (Naidu and Karamaju 2007):

$E_{xp} = -\partial V/\partial x$, such that

$$\frac{\partial D_{xp}}{\partial x} = \varepsilon \frac{\partial E_{xp}}{\partial x} = -\varepsilon \frac{\partial^2 V_{xp}}{\partial x^2} \tag{8}$$

Using similar arguments of equation (8) for both Y- and Z-directions, gives (Naidu and Karamaju 2007):

$$divD_p = -\left(\frac{\partial^2 V_p}{\partial x^2} + \frac{\partial^2 V_p}{\partial y^2} + \frac{\partial^2 V_p}{\partial z^2} \right) \tag{9}$$

So (Naidu and Karamaju 2007):

$$\left(\frac{\partial^2 V_p}{\partial x^2} + \frac{\partial^2 V_p}{\partial y^2} + \frac{\partial^2 V_p}{\partial z^2} \right) = -\frac{\rho}{\varepsilon} \tag{10}$$

Equation (10) is the Poisson's equation. If, however, there is no distributed charge for the space under consideration, that is, $\rho = 0$, equation (10) reduces to the following Laplace equation (Morton 1971; Jordan and Balmain 1998; Naidu and Kamaraju 2007):

$$\left(\frac{\partial^2 V_p}{\partial x^2} + \frac{\partial^2 V_p}{\partial y^2} + \frac{\partial^2 V_p}{\partial z^2} \right) = 0 \qquad (11).$$

Divergence of magnetic flux

For the MF produced by a current, the flux paths form closed loops with no net magnetic flux outflow (the rate of flow of energy) from any element of the volume (Morton 1971; Cottingham and Greenwood 1995). From the foregoing analyses, therefore, and by extension, the net magnetic flux outflow from the volume element δxδyδz, becomes (Morton 1971):

$$\text{div } \mathbf{B_p}\, \delta x \delta y \delta z = 0 \tag{12}$$

Since the elemental volume $\delta x \delta y \delta z \neq 0$, then the divergence of the magnetic field must be identically equal to zero. Hence (Cottingham and Greenwood 1995):

$$\text{div } \mathbf{B_p} = 0 \tag{13}$$

Equation (13) shows that the magnetic field must have zero divergence everywhere in plantains, and possibly, bananas and ensette, which was the main focus of this study. This means that if the magnetic fields are due to currents, there are no magnetic flux sources that correspond to electric flux (flow of electric charge) sources. Hence, the search for isolated magnetic poles by physicists and engineers, continue (Ramo *et al.* 1984).

Divergence of current

Whenever current flows in a coordinate space as shown in **Fig. 1**, the current density on face EF is J_x. The outward total current from elemental cube δxδyδz in the x-direction is (Morton 1971; Cottingham and Greenwood 1995; Jordan and Balmain 1998; Naidu and Kamaraju 2007).

$(\partial J_{xp}/\partial x)\ \delta x\delta y\delta z$ (Morton 1971) (14a)

Similarly, the outward total currents for both the Y- and Z-directions are respectively (Morton 1971):

$(\partial J_{yp}/\partial y)\ \delta x\delta y\delta z$ (14b)

$(\partial J_{zp}/\partial z)\ \delta x\delta y\delta z$ (14c)

Therefore, the total outward current in all three directions becomes (Morton 1971):

$(\partial J_{xp}/\partial x + \partial J_{yp}/\partial y + \partial J_{zp}/\partial z)\ \delta x\delta y\delta z = \text{div}\ \mathbf{J_p}\ \delta x\delta y\delta z$ (15).

It is known that the outward current is equal to the rate of change of enclosed charge, so (Morton 1971):

$$divJ_p\delta x\delta y\delta z = \frac{d}{dt}\left(\rho_p\delta x\delta y\delta z\right) \quad (16)$$

where ρ is the charge density of the enclosed charges. Consequently (Jordan and Balmain 1998):

$$divJ_p = \frac{d}{dt}\left(\rho_p\right) \quad (17).$$

Displacement current

By a stretch of the imagination, a fictitious current or pseudocurrent, called the displacement current (i_D), which was invented by James Clerk Maxwell. That means, by imagining that the changing flux through a curved surface, is equivalent in Ampere's law to a conduction current (i_C) passing through that surface. As this fictitious displacement current is included along with the real current (i_C), in Ampere's law, thus makes Ampere's law to be obeyed no matter which surface is used. Therefore, for a flat surface, i_D is zero; for the curved surface, i_C is zero; and i_C for the flat surface equals i_D for the curved surface (Young and Freedman 2005). The generalised Ampere's law is valid in a magnetic material, provided the magnetisation is proportional to the external field and replacing μ_o by μ. Other benefits of the displacement current are that it helps one to generalise Kirchhoff's junction rule and also, confirms directly the role of displacement current as a source of a magnetic field (Young and Freedman 2005).

The introduction of displacement current makes electromagnetic waves possible, and represents the great contribution of James Clerk Maxwell to electromagnetic theory (Reitz *et al.* 1993).

An ammeter connected to a capacitor measures current if an alternating voltage is applied between its terminals. For a perfect dielectric, no conduction current flows through the dielectric between the plates. Maxwell explains that alternating fields cause displacement current as a consequence of the rate of change of charge on the capacitor, which is equal to the rate of change of electric flux between them (Morton 1971; Cottingham and Greenwood 1995; Jordan and Balmain 1998; Maxwell 1998; Naidu and Kamaraju 2007).

Using the surfaces shown in **Fig. 2**, S_{1p} and S_{2p}, carry the conduction currents I_{1p} and I_{2p}. The rate of increase of charge of the enclosed plate becomes (Reitz *et al.* 1993):

$dq_p/dt = I_{2p} - I_{1p}$ (18)

When the electric fluxes across S_{1p} and S_{2p}, are ψ_{1p} and ψ_{2p}, then by Gauss's theorem (Reitz *et al.* 1993):

$q_p = \psi_{1p} - \psi_{2p}$ (19)

Therefore (Reitz *et al.* 1993):

$dq_p/dt = d\psi_{1p}/dt - d\psi_{2p}/dt$ (20)

So (Reitz *et al.* 1993),

$I_{2p} - I_{1p} = d\psi_{1p}/dt - d\psi_{2p}/dt$ (21)

and (Reitz *et al.* 1993),

$I_{1p} + d\psi_{1p}/dt = I_{2p} + d\psi_{2p}/dt = I_{Tp}$ (22)

I_{1p} and I_{2p} are the normal conduction currents. $d\psi_{1p}/dt$ and $d\psi_{2p}/dt$ are the displacement currents, while I_{Tp} is the total current, which is the sum of both the conduction and displacement currents (Morton 1971; Cottingham and Greenwood 1995; Jordan and Balmain 1998; Maxwell 1998; Naidu and Kamaraju 2007). Conduction current through any surface is the integral of the normal component of the conduction current density over that surface. The displacement current through any surface is the integral of the normal component of the displacement current density over that surface (Beaty 2000).

Equation (22) can be expressed in the form of current densities, by dividing through by the area A, as (Reitz *et al.* 1993),

$$J_{Tp} = \frac{I_{Tp}}{A} = \frac{I_{cp}}{A} = \frac{d\left(\psi_p/A\right)}{dt} = J_{cp} + \frac{dD_p}{dt} \quad (23)$$

where I_{cp} is the conduction current, J_{cp} is the conduction current density and $\mathbf{D_p}$ is the electric flux density. For an alternating electric flux, $D_p = D_{mp}\sin\omega t$, then (Reitz *et al.* 1993):

$$\begin{aligned}\frac{dD_p}{dt} &= \omega D_{mp}\cos\omega t\\ &= \omega\varepsilon_p E_{mp}\cos\omega t\\ &= \omega\varepsilon_p\rho_p J_{cp}\cos\omega t\end{aligned} \quad (24)$$

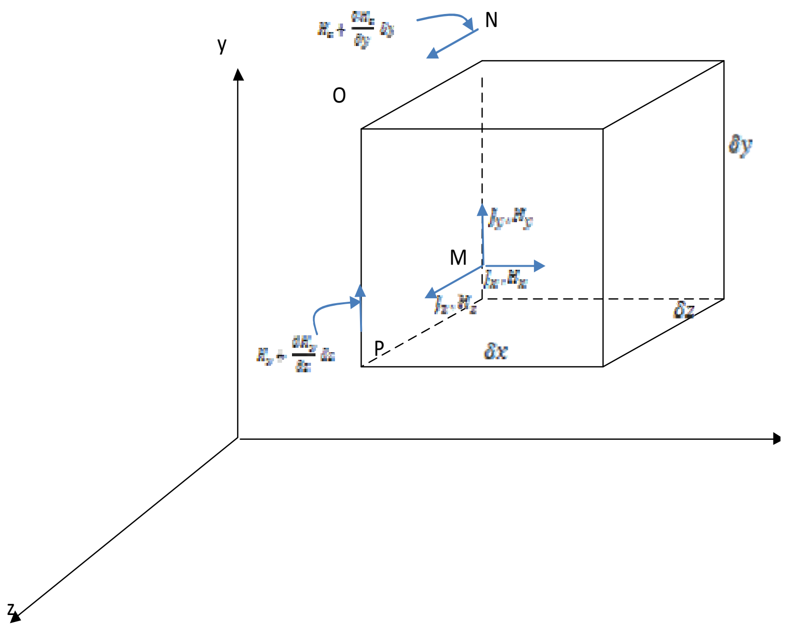

Fig. 2 Distributed fields and currents. The figure shows the different current density and magnetic field components of selected points in the X-, Y-, and Z-axes, respectively. Orthogonality conditions for these current densities, magnetic fields and their increases were also fulfilled, at such points.

From Ohm's law, $R_p = V_p/I_p = \rho_p l/A_p$, where ρ_p is the resistivity of plantain (resistivity is the capacity for resisting the flow of electric current per unit length).

Therefore (Reitz *et al.* 1993),

$$E_p = V_p/l_p = \rho_p\, I_p/A_p = \rho_p J_p \tag{25}$$

By a little stretch of the introduction of displacement current, the magnetic circuit law is now modified to (Boast *et al*. 2000):

$$\int H_p ds = I_{Tp} = I_{cp} + d\psi_p/dt \tag{26}$$

Additionally, Arbab (2009) uses New guage transformations for Maxwell's equations found that total momentum and energy of electrodynamics systems (fields and particles), as well as the total current of the system are conserved. Therefore, three currents were noticed, namely: (a) electromagnetic current (b) electronic current and (c) vacuum current (with a negative sign). Also, Maxwell's equations, Lorentz force and continuity equations were shown to be invariant under New guage transformations.

Relationship between H and J for distributed currents

Considering a point M in space on a cuboid; the total current density J_{Tp}, with components J_{Txp}, J_{Typ}, and J_{Tzp} in their perpendicular X-, Y-, and Z-directions, respectively. The magnetising force has associated magnetic field components H_{xp}, H_{yp} and H_{zp}. Using a constructed elemental cube with sides δx, δy, and δz at one corner, M, gives from loop MNOP and by equation (26), (Morton 1971):

$$\int \mathbf{H_p} \mathbf{ds} = I_{Tp} = J_{Txp}\delta y\delta z \tag{27}$$

By considering each side of the cube, we have (Morton 1971)

(a) For side MN, $\int \mathbf{H_p}\mathbf{ds} = H_{yp}\,\delta y$ (28a)

(b) For side NO, $\int \mathbf{H_p}\mathbf{ds} = \left(H_{zp} + \dfrac{\partial H_{zp}}{\partial y}\delta y\right)\delta z$ (28b)

(c) For side OP, $\int \mathbf{H_p}\mathbf{ds} = -\left(H_{yp} + \dfrac{\partial H_{yp}}{\partial y}\delta z\right)\delta y$ (28c)

(d) For side PM, $\int \mathbf{H_p}\mathbf{ds} = -\,H_{zp}\,\delta z$ (28d).

This is so because the magnetising force on side NO is, $[H_{zp} + (\partial H_{zp}/\partial y)\delta z]$ and on side OP, is $-\,[H_{yp} + (\partial H_{yp}/\partial z)\,\delta z]$.
By adding components round the loop in equations (28), give (Morton 1971):

$$\begin{aligned}\int_{MNOP} \mathbf{H_p}\mathbf{ds} &= (a) + (b) + (c) + (d) = \frac{\partial H_{zp}}{\partial y}\delta y\delta z - \frac{\partial H_{y}}{\partial z}\delta y\delta z \\ &= \left(\frac{\partial H_{zp}}{\partial y} - \frac{\partial H_{yp}}{\partial z}\right)\delta y\delta z \\ &= J_{Txp}\,\delta y\delta z \end{aligned} \tag{29}$$

Equation (29) becomes (Morton 1971):

$$J_{Txp} = \frac{\partial H_{zp}}{\partial y} - \frac{\partial H_{yp}}{\partial z} \tag{30a}$$

Using the same line of argumentation and considering the line integral of $\mathbf{H_p ds}$ around the rectangles in both the XY- and XZ-planes, give respectively

$$J_{Typ} = \frac{\partial H_{xp}}{\partial z} - \frac{\partial H_{zp}}{\partial x} \tag{30b}$$

$$J_{Tzp} = \frac{\partial H_{yp}}{\partial x} - \frac{\partial H_{xp}}{\partial y} \tag{30c}$$

In free space, there is no conduction density and the equations (30) become (Jackson 2001)

$$\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = \frac{dD_x}{dt} = \varepsilon_0 \frac{dE_x}{dt} \tag{31a}$$

$$\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = \frac{dD_y}{dt} = \varepsilon_0 \frac{dE_y}{dt} \tag{31b}$$

$$\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = \frac{dD_z}{dt} = \varepsilon_0 \frac{dE_z}{dt} \tag{31c}$$

By replacing the permittivity of free space with the dielectric constant for plantains, equations (31) become (Jackson 2001):

$$\frac{\partial H_{zp}}{\partial y} - \frac{\partial H_{yp}}{\partial z} = \frac{dD_{xp}}{dt} = \varepsilon_p \frac{dE_{xp}}{dt} \tag{32a}$$

$$\frac{\partial H_{xp}}{\partial z} - \frac{\partial H_{zp}}{\partial x} = \frac{dD_{yp}}{dt} = \varepsilon_p \frac{dE_{yp}}{dt} \tag{32b}$$

$$\frac{\partial H_{yp}}{\partial x} - \frac{\partial H_{xp}}{\partial y} = \frac{dD_{zp}}{dt} = \varepsilon_p \frac{dE_{zp}}{dt} \tag{32c}$$

The above equations show that the rate of change of magnetic field at a point depends on the time rate of change of the electric field for that same point (Morton 1971; Cottingham and Greenwood 1995; Jordan and Balmain 1998; Maxwell 1998; Beaty 2000; Boast *et al*. 2000; Naidu and Kamaraju 2007).

Faraday's Law

Faraday's law represents the first quantitative expressions of experimental observations for circuits behaviour in time-dependent alternating electromagnetic fields. As a result, transient current is induced in a circuit if: (a) steady state current flow in an adjacent circuit is switched on or off, (b) adjacent circuit with steady state current flow is moved relative to the first circuit and (c) a permanent magnet is put into or out of the circuit (Jackson 2001).

For a single turn conductor linked by a changing magnetic field, the induced electromotive force (e. m. f.), is (Jackson 2001):

$$\nu = d\Phi/dt \tag{33}$$

where ν is the induced e. m. f. , Φ is the magnetic flux and the direction of the induced e.m.f., is opposite the direction of the flux causing it according to Lenz's law (Morton 1971; Jackson 2001).

In the absence of a conductor, the changing flux still sets up a potential gradient, E, in a way that makes ∫**Eds** round the closed loop equal to ν. Vectorially, the positive directions of an axis and its rotations are governed by the right-hand screw rule. Hence, a negative sign is included in the vector relation, as (Naidu and Karamaju 2007):

$$\int \mathbf{E ds} = -d\Phi/dt \tag{34}$$

For point M of three mutually perpendicular varying magnetic flux components B_x, B_y, and B_z, the associated potential gradient components are respectively, E_x, E_y, and E_z (**Fig. 3**). Considering the elemental cube at point M, the total flux through face MNOP is $B_x\delta y\delta z$ and the total induced voltage round the loop becomes (Morton 1971):

$$\nu = -E_{yp}.MN - \left(E_{zp} + \frac{\partial E_{zp}}{\partial y}\delta y\right).NO + \left(E_{yp} + \frac{\partial E_{yp}}{\partial z}\delta z\right).OP + E_{zp}.PM$$

$$= -\frac{\partial E_{zp}}{\partial y}\delta y\delta z + \frac{\partial E_{yp}}{\partial z}\delta y\delta z \tag{35}$$

From the foregoing, $\nu = \frac{\partial \Phi_{xp}}{\partial t} = \frac{\partial B_{xp}}{\partial t}\delta y\delta z$, for the loop MNOP.

Therefore, for plantains considered in this study

$$\frac{\partial E_{zp}}{\partial y} - \frac{\partial E_{yp}}{\partial z} = \frac{\partial B_{xp}}{\partial t} \tag{36a}$$

By similar arguments and reasoning, it can be shown that

$$\frac{\partial E_{xp}}{\partial z} - \frac{\partial E_{zp}}{\partial x} = -\frac{\partial B_{yp}}{\partial t} \tag{36b}$$

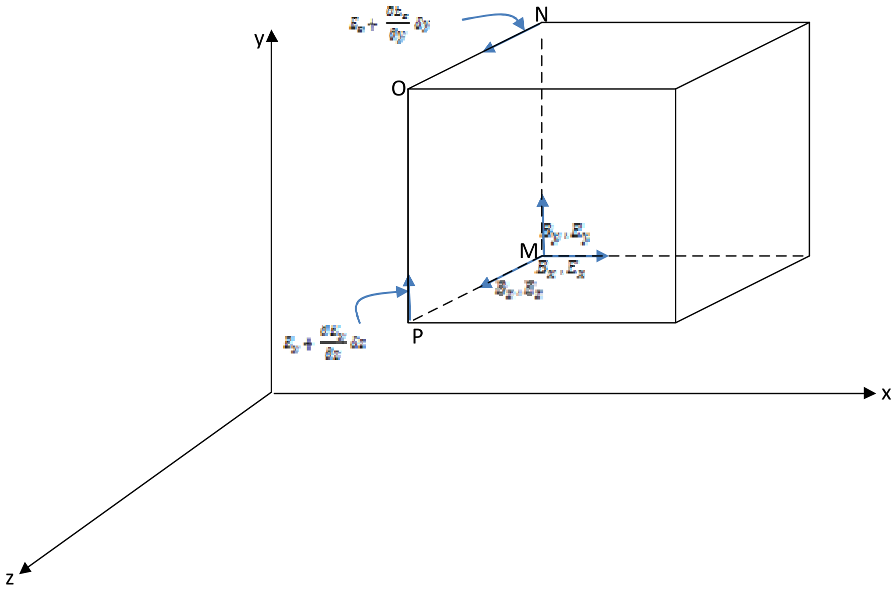

Fig. 3 Alternating electric and magnetic fields in space. The above diagram shows a general representation of magnetic field and electric field components as well as electric fields component increases along the Y- and Z-axes, respectively.

and

$$\frac{\partial E_{yp}}{\partial x} - \frac{\partial E_{xp}}{\partial y} = -\frac{\partial B_{zp}}{\partial t} \qquad (36c).$$

The above equations give both the time variation of magnetic fields and space variation of associated electric fields in plantains. Equations (7), (13), (30) and (36) are called Maxwell's equations (Morton 1971; Mathews and Venkatesan 1977; Gautreau and Savin 1978; Spiegel 1980; Cottingham and Greenwood 1995; Maxwell 1998; Boast *et al*. 2000; Jackson 2001).

Plane sinusoidal waves in plantains

Even in non-dispersive media, a three-dimensional wave in general changes its profile as it propagates. But, there is, fortunately, plane waves which can propagate in three dimensions without change. That is the main reason it is used here to reduce the complexity of the mathematics in plantains analyses (Lipson *et al.* 1995), which is the main focus of this study.

The sinusoidal forward wave of the time variation of plane electric field in free space is written as (Lipson *et al.* 1995):

$$E_{x1} = E_{xm} \cos \omega (t - z/c) = E_{xm} \cos (\omega t - \omega z/c) \qquad (37)$$

It is realised that time variation E_x for a value of z is a space variation of E_x for a given t.

Also, $f\lambda = c$, where λ is the wavelength. The relation becomes (Morton 1971),

$$\omega/c = 2\pi/\lambda \qquad (38)$$

This is the phase change coefficient β, in radians per metre. Thus (Morton 1971),

$$\beta = \omega/c = \omega\sqrt{(\mu_o\varepsilon_o)} \text{ rad/m} \qquad (38a)$$

The magnetic field given by the above magnetic field becomes, if (Morton 1971):

$$\int\partial E_x/\partial z = -\mu_o\partial H_y/\partial t \qquad (39)$$

Then (Morton 1971),

$$H_y = -1/\mu_o \int\partial E_x/\partial z \, dt \qquad (40)$$

Because there is no d.c. component, the constant of integration is zero. Therefore (Morton 1971),

$$H_y = -1/\mu_o \int E_{xm} \, \omega/c \sin (\omega t - \omega z/c)dt$$

$$= 1/\mu_o c \, E_{xm} \cos (\omega t - \omega z/c) \qquad (41)$$

This is a retarded magnetic field wave function traveling on the z-axis at the velocity of light. Also, both the peak values of E_x and H_y occur at the same values of z (Morton 1971).

The peak electric and magnetic field strengths, expressed in terms of the other, become (Morton 1971):

$$H_{ym} = 1/\mu_o c \, E_{xm}$$

or (Morton 1971):

$E_{xm} = cB_{ym}$ (42)

The quotient E_x/H_y has the dimensions of impedance (ohms) and it is called wave impedance, Z_w. For free space (Morton 1971):

$Z_w = E_x/H_y = \mu_o c = \sqrt{(\mu_o/\varepsilon_o)} \approx 4\pi\times10^{-7}\times3\times10^8 \approx 120\pi\ \Omega$ (43)

Because $c = 1/\sqrt{(\mu_o\varepsilon_o)}$ (43a)

For the backward electric field wave function (Morton 1971):

$E_{xb} = E_{xm} \cos \omega (t + z/c)$ (44)

and (Morton 1971):

$H_{yb} = -1/\mu_o\int\partial E_x/\partial z\, dt = -E_{xm}/\mu_o c \cos(\omega t + \omega z/c)$ (45)

The wave impedance for the backward wave becomes (Morton 1971):

$E_{xb}/H_{yb} = -Z_w$ (46)

With plantain as the medium for the electromagnetic wave propagation, and relative permittivity ε_p, the velocity of propagation reduces to

$u_p = 1/\sqrt{(\mu_o\varepsilon_o\varepsilon_p)} = c/\sqrt{\varepsilon_p}$ m/s (47)

Deriving H_y from E_x gives,

$H_{ym} = E_{xm}/(\mu_o u_p) = \sqrt{(\varepsilon_o\varepsilon_p/\mu_o)}\, E_{xm} = E_{xm}\sqrt{\varepsilon_p}/\mu_o c$ (48)

The wave impedance expression for plantains becomes

$Z_{wp} = E_{xm}/H_{ym} = \mu_o c/\sqrt{\varepsilon_p} = \sqrt{(\mu_o/\varepsilon_o\varepsilon_p)} = 120\pi/\sqrt{\varepsilon_p}$ Ohms (49)

where ε_p is the relative permittivity of plantains.

Poynting power flow in plantains

The Poynting theorem represents the conservation of energy and momentum for electromagnetic fields, which involves the movement of charges and the rate of doing work within a certain volume as a result of external alternating electromagnetic fields of **E** and **B** (Jackson 2001; Subrahmanyam and Lal 2005).

Alternating electromagnetic fields of plane waves travel with velocity u, and the associated stored energy through the plantain also travels at the same velocity. Upon using a square metre wavefront in a plane wave in the z-direction, with components E_x and H_y, the energy stored in the plantain element δz thick, becomes (**Fig. 4A**) (Naidu and Karamaju 2007):

$\delta W = ½\varepsilon_p E_x^2\delta z + ½\mu_p H_y^2\delta z$ J/m^2 (50)

The energy passing through the plantain per second becomes

$\delta W/\delta t = ½\varepsilon_p E_x^2\, \delta z/\delta t + ½\mu_p H_y^2\, \delta z/\delta t$ W/m^2

where δt is the time taken for the wave to travel a distance δz in the plantain. This is equivalent to the instantaneous power flow S_i, through one square metre inside the plantain (Morton 1971; Cottingham and Greenwood 1995; Jordan and Balmain 1998; Jackson 2001). Therefore (Padley 2005):

$S_i = ½\varepsilon_p E_x^2\, \delta z/\delta t + ½\mu_p H_y^2\, \delta z/\delta t$ W/m

$S_i = ½\varepsilon_p E_x^2\, u_p + ½\mu_p H_y^2\, u_p$ W/m (51)

$= (½u_p\varepsilon_p E_x \times H_y\sqrt{(\mu_p/\varepsilon_p)}) + (½\mu_p u_p H_y \times E_x\sqrt{(\varepsilon_p/\mu_p)})$ (from Eqn 43a) (52)

where μ_p is the relative permeability of plantains and u_p is the velocity of light in plantains. It is also assumed for most dielectric materials, that their relative permeabilities are approximately equal to that of free space or vacuum. So, Boast *et al.* (2000): $\mu_p \approx \mu_o$.

Therefore, Padley (2005):

$S_i = 1/2E_xH_y + 1/2E_xH_y = E_xH_y$ (53)

Since $u_p = 1/\sqrt{(\mu_p\varepsilon_p)}$ (Morton 1971) (54)

The Poynting mean power flow in plantains becomes (Padley 2005):

$S = E_{rms} \times H_{rms}$ W/m^2 (55)

It is a known fact that plantain pseudostems are made up of air in the vacuolar spaces, liquids and solid fibres and that the breakdown strength would be determined by the air in the vacuolar spaces (Mehta and Mehta 2007; Naidu and Karamaju 2007). Therefore, the plantains breakdown strength would be limited by the rate determining step which is air contained in the vacuolar spaces of the pseudostem. In addition, the peak breakdown strength for air is approximately 30 kV/cm (Mehta and Mehta 2007; Naidu and Karamaju

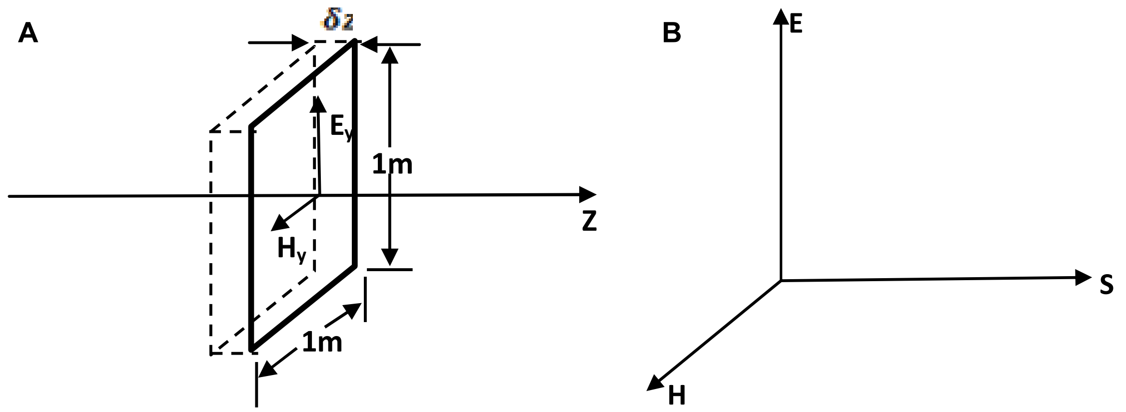

Fig. 4 Poynting power flow. (**A**) An electromagnetic wave front moving to the right with velocity *v*. The **E** and **H** fields are at right angles and the corresponding Poynting vector is also perpendicular and it is also in the direction of the Z-axis. For a plane polarized wave the wave is traveling in the positive Z-direction, which is the same as the direction of **E** × **H**. (**B**) Orthogonal relationship between **E**, **H** and **S** (the Poynting power flow vector).

2007). Therefore, the maximum Poynting power flow density for plantains becomes (Since $Z_{wp} = 120\ \pi/\sqrt{\varepsilon_p} = 120\ \pi/\sqrt{3}$);

$S_p = E_{rms} \times H_{rms} = E^2_{rms}/Z_{wp} = (9 \times 10^8)/(2 \times 120\ \pi/\sqrt{3})$

$= 2.0675$ MW/cm^2

$= 20.675$ GW/m^2

Also, the associated peak value magnetising force, becomes

$H_{max} = (E_{peak}/(120\ \pi/\sqrt{3})) = 0.138$ A/cm

$= 13.8$ A/m

This Poynting vector is in the direction of the velocity u_p, such that **S**, **E**, and **H** form a right-handed orthogonal system (**Fig. 4A**).

Plane waves in lossy plantains

Plane waves, which are travelling transverse electromagnetic waves carry energy from one point to another as they do so. The travelling wave solutions of Maxwell's equations for plantain nonconducting media can be obtained through spatially constant permeability and susceptibility (Jackson 2001). Upon considering the plantain dielectric to be sandwiched between wide strips of conductors, which is analogous to a transmission line, the capacitance per unit width and length of line becomes (**Fig. 5**) (Boast *et al.* 2000):

$C = \varepsilon_o\varepsilon_p/d$ F/m^2 (56)

where d is the separation thickness of plantain between the conductor strips in metres (Morton 1971).

By substituting standard values, the capacitance determined in this study for plantains becomes (Beaty 2000) (where $\varepsilon_o = 8.854187827 \times 10^{-12}$ F m^{-1})

$C_p = 8.854187827 \times 10^{-12} \times \sqrt{3}/1$ m

$= 15.3359 \times 10^{-12}$ F/ m^2 (56a)

If the current per metre width of line is A (linear current density), the inductance becomes (Morton 1971):

$L = \Phi/A = B(1 \times d)/A = \mu Hd/A$ (57)

Since H = A, then (Morton 1971):

$L = \mu d$ Henrys (58)

By substituting both standard and calculated values for plantains, the inductance of 1 metre thick plantain pseudostem can be determined, thus

$L_p = 4\pi \times 10^{-7} \times 1$ m

$= 1.25662$ μH (58a)

If the conductivity of plantain between the lines is σ_p, then the conductance between the two conductors per metre length and breadth (unit area) becomes (Morton 1971):

$G = \sigma_p/d$ (59)

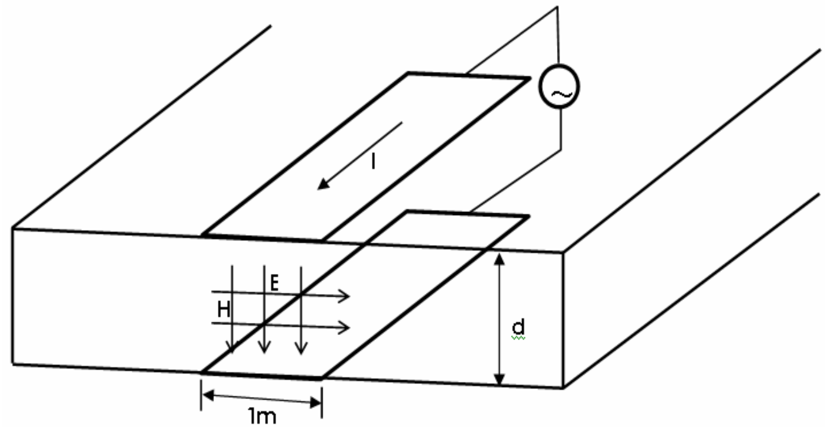

Fig. 5 Fields between conductors of a line strip.

Similarly, the conductance of plantains assuming 1 metre thickness (d = 1 m), becomes

$G_p = 3.74333955 \times 10^3$ siemens/m × 1/1 m = 3.74333955×10^3 siemens/m^2 (59a)

If the resistance is zero (R = 0), the characteristic impedance per unit breadth becomes (Morton 1971):

$Z_o = \sqrt{(j\omega\mu d/(\sigma_p/d + j\omega\varepsilon_p/d))} = d\sqrt{(j\omega\mu/(\sigma_p + j\omega\varepsilon_p))}$ Ohms (60)

Continuing with the same arguments of R = 0, the propagation coefficient becomes (Morton 1971):

$\gamma_p = \sqrt{[j\omega\mu d(\sigma_p/d + j\omega\varepsilon_p/d)]} = \sqrt{[j\omega\mu(\sigma_p + j\omega\varepsilon_p)]}$ per metre (61)

If $\sigma_p << \omega\varepsilon_p$, the binomial expansion can be used to evaluate the plantains propagation coefficient γ_p, as (Morton 1971):

$\gamma_p \approx j\omega\sqrt{(\mu\varepsilon_p)}\,[1 + \sigma_p/j2\omega\varepsilon_p]$

$= \sigma_p/2\sqrt{(\mu/\varepsilon_p)} + j\omega\sqrt{(\mu\varepsilon_p)}$ (62)

By substituting values into equation (62) above gives

$\gamma_p = 3743.33955/2\,\sqrt{(4\pi \times 10^{-7}/3)} + j\,2\pi \times 50\sqrt{(4\pi \times 10^{-7} \times 3)}$

$= 3.8307 + j\,1.9289$ per metre (62a)

Therefore, the attenuation coefficient for plantains becomes (Morton 1971):

$\alpha_p = \sigma_p/2\sqrt{(\mu/\varepsilon_p)} = Z_{wp}\sigma_p/2$ nepers/m (63)

Similarly, by substituting values into equation (63) for plantains, becomes

$\alpha_p = \sqrt{(4\pi \times 10^{-7}/3)} \times 3743.33955/2$

$= 3.8307$ nepers/m (63a)

Also, the plantains phase change coefficient becomes (Morton 1971):

$\beta_p = \omega\sqrt{(\mu\varepsilon_p)}$ rad/m (64)

By substituting values into equation (64) for plantains, the phase change coefficient becomes,

$\beta_p = 2\pi \times 50\sqrt{(4\pi \times 10^{-7} \times 3)}$

$= 1.9289$ rad/m (64a)

Additionally, Asemota (2008) has found that $\varepsilon_p = 3\varepsilon_o$ and $Z_{wp} = 217.656\ \Omega$ (approximately).
The quality factor of a circuit is defined as (Morton 1971):

$$Q = 2\pi \frac{\text{Energy stored in electric or magnetic field}}{\text{Energy dissipated per cycle}} \quad (65a)$$

$$Q = 2\pi \frac{\text{Peak energy stored in electric field}}{\text{Mean power dissipation}} \quad (65b)$$

Because equal energies are stored in the electric and magnetic fields, the mean power or energy dissipated per second is the same as the energy dissipated per cycle multiplied by the number of cycles per second (Morton 1971). Consequently, the peak stored energy density in the electric field is $½D_mE_m$ J/m^3, and D_m is the peak electric flux density, while E_m is the peak electric field strength. So, the peak stored energy per metre width and length of plantain dielectric of thickness d, becomes (Naidu and Karamaju 2007):

$$W = ½D_mE_md \text{ Joules} \quad (66)$$

For a conductor, the mean power dissipated for peak sinusoidal voltage V_m (= E_md), applied to a conductor of conductance G, becomes (Naidu and Karamaju 2007):

$$P = ½GV_m^2 = ½G(E_md)^2$$

$$= ½\sigma_p/dE_m^2d^2 = ½\sigma_pdE_m^2 \quad (67)$$

The quality factor becomes, (Naidu and Karamaju 2007):

$$Q = 2\pi f\frac{W}{P} = 2\pi f\frac{D_mE_md}{\sigma_pdE_m^2}$$

$$= 2\pi f\frac{\varepsilon_pE_m^2}{\sigma_pE_m^2} = 2\pi f\frac{\varepsilon_p}{\sigma_p}$$

$$= \omega\varepsilon_p / \sigma_p \quad (68)$$

Upon substituting values, the quality factor for plantains becomes

$$Q_p = 2.517745942 \times 10^{-2}$$

Equation (68) corresponds to the quality factor of a circuit with capacitance C and in parallel with a conductance G ($Q = \omega C/G$), (Naidu and Karamaju 2007). Physically, the quality factor (Q factor) is a dimensionless quantity that compares the time constant for the decay of the alternating electromagnetic fields amplitude to its oscillation period or frequency. In other words, it compares the frequency at which a system oscillates (alternating electromagnetic fields) to the rate at which it dissipates its energy. A higher Q-factor indicates a lower rate of energy dissipation relative to the oscillation frequency, so the oscillations die out more slowly and vice versa (Alley and Atwood 1973; Brophy 1977).

Supposing the medium that the plane alternating waves travels is a good conductor, then $\sigma_p >> \omega\varepsilon_p$, and the propagation coefficient becomes (Morton 1971, Naidu and Karamaju 2007)):

$$\gamma_p \approx \sqrt{(j\omega\mu\sigma_p)}$$

$$= \sqrt{(\omega\mu\sigma_p/2)} + j\sqrt{(\omega\mu\sigma_p/2)} \text{ per metre} \quad (69)$$

The length δ, which causes the plane alternating waves to be attenuated to 1/e of its initial value is $\delta\sqrt{(\omega\mu\sigma_p/2)} = 1$, so that (Morton 1971; Naidu and Karamaju 2007):

$$\delta = \sqrt{(2/\omega\mu\sigma_p)} \quad (70)$$

where e is the Napierian (natural) logarithm base value.

Equation (70) represents the penetration depth or skin depth of alternating currents into conductors and by extension plantains (Halbach 2006; Ng and Bane 2006; Schnell 2006; Tigner 2006; Zotter 2006).

From equations (69) and (70); and upon substituting values becomes,

$$\sigma_p = \frac{2}{(1/e)^2\omega\mu} = \frac{2}{(1/e)^2 \times 2\pi \times 50 \times 4\pi \times 10^{-7}}$$

$$= 3.74333955 \times 10^3 \text{ siemens/m} \quad (71)$$

where σ_p is the determined conductivity of plantains in this study.

Upon substituting standard values and those of equation (71) into equation (70), gives the penetration depth or skin depth of alternating currents into plantains

$$\delta_p = \sqrt{(2/(2\pi \times 50 \times 4\pi \times 10^{-7} \times 3.74333955 \times 10^3))}$$

$$= 0.1162 \text{ metre} = 11.62 \text{ cm} \quad (72)$$

The skin depth for plantains calculated in equation (72) is valid when $\sigma_p >> \omega\varepsilon_p$

Similarly, upon substituting standard and calculated values into equation (69), the propagation coefficient becomes,

$$\gamma_p = \sqrt{(2\pi \times 50 \times 4\pi \times 10^{-7} \times 3.74333955 \times 10^3/2)} + j\sqrt{(2\pi \times 50 \times 4\pi \times 10^{-7} \times 3.74333955 \times 10^3/2)}$$

$$= 2.71828 + j2.71828 \text{ m}^{-1}$$

The existence of dielectric boundaries is common to any biological or *in vitro* system probed by MF and EMF effects. Because of collisions with thermal moving solvents molecules, an undisturbed free distance λ for an ion circulating with the Lamor radius r_L and speed v, should not be possible in an aqueous phase. But this paradox was explained that ion channels and ion-protein complexes guide the ion orbits and can thus, maintain the necessary coherent length $\lambda = 2 \cdot r_L$ of some 10^{-9} m free from thermic environmental influence (Pazur and Rassadina 2009). A typical electric double layer for cytoplasmic membrane of λ~4.7 nm was obtained for Ca^{2+} and the MF strengths used, which was sufficient for the expected Lamor radii r_L of < 2 nm in a plane parallel and close to the dielectric surface (Pazur and Rassadina 2009).

Substituting values into the Lamor radius for plantains becomes (Pazur and Rassadina 2009):

$r_{Lp} = \lambda/2$ (73)

$= (4.7/2)$ nm

$= 2.35$ nm.

RESULTS AND DISCUSSION

The wave impedance for plantains was evaluated using the reciprocal relationship that exists between the transverse components of the electric field strength, and the magnetising force coupled with the dielectric permittivity of plantains pseudostems. By that reciprocal relationship only the availability of the dielectric permittivity constant as determined by Asemota (2008) was the only quantity required for the complete evaluation of the wave impedance of plantain pseudostems. For lumped resistors, inductors and capacitors, as assumed in this study, the wave impedance or characteristic impedance of the plantain pseudostem transmission medium involves the propagation constant. In reality, the concept of wave impedance manifests in the transport of maximum energy whether to a load with reflection and dissipates losses or simply to passing it on. In addition, electromagnetic waves are considered "true waves" because the energy-momentum relationship is linear, thus allowing a wave packet to be maintained at all times and in any reference frame (Tsu and Datta 2008).

It has been observed that high voltage natural fields and the rise and fall of electroculture caused trees in the artic to be very green and healthy because of the weak electric currents carried through the atmosphere by air ions from the aurora borealis despite the low light and temperature intensities (Goldsworthy 2006). Pazur and Rassadina (2009) used transient effects of weak EMFs to induce changes in the Ca^{2+} concentrations in *Arabidopsis thaliana* through a combination of MFs and EMFs that matched Ca^{2+}-ICR conditions. Darwish (2006) explains that while magnetic fields effects on plants have been explored by scientists and physicists especially as a consequence of power lines and other associated technologies, weak EMFs have been thought to suppress plant growth by reducing cell division. Further, Ca^{2+} levels have been known to increase in plants cells from exposure to MFs. Ca^{2+} take part in many plant growth processes and responses like wounding, heat and salt stresses. Franco (2010) reports that bean (*Vicia faba*) plants exposed to MFs grew faster at warmer temperatures than those without MFs. She further states that komatsuna (*Ablemoschus esculentus*) plants exposed to MFs higher than 10 Hz influenced the plant growth in terms of leaf area, even after the MF exposure was removed. Davies (1996) using 60 Hz EMFs on radish (*Raphanus sativus*), mustard (*Mustum ardens*) and barley (*Hordeum vulgare*) was able to replicate an earlier laboratory works and also demonstrated different levels of successes with regard to root and shoots lengths; dry root, wet leaf, and wet whole weights, stem diameter and dry seed weights.

Dardeniz *et al.* (2006) used ELF to show significant developmental changes on the vegetative growth of *Uslu* grape (*Vitis vinifera*) in terms of mean rooting percentage, mean root development, mean root number, mean shoot weight and mean shoot + root weight. Darwish (2006) reporting Carbonell *et al.* (2000) confirmed that weak EMFs increased the germination rate and percentage of rice (*Oryza sativa*) seeds. Similarly, he reported Alexander and Doijode (1995) by stating that onions (*Allium cepa*) and rice exposed to weak EMFs increased in germination; shoot and root lengths, and fresh and dry weights of seedlings. Moreover, spinach (*Spinacia oleracea*) exposed to the South Pole was found to grow taller and bigger as well as released more oxygen, than those subjected to the North Pole. One of the plausible explanations advanced for these processes and responses was that the South Pole encouraged the growth of certain growth regulators like, auxin and cytokinins, while the North Pole inhibited such growth regulators (Segal 2010). Because of these rather conflicting, contradictory and complicated different plants responses to the varying intensities, frequencies, regions of action, modes and levels of operation of EMFs, are thought to be species-specific.

Goldsworthy (2007) reports that weak EMFs remove calcium ions bound to the membranes of living cells, making them more likely to tear, develop temporary pores and leak. DNAase (an enzyme that destroys DNA) leaking through membranes of lysosomes (small bodies living in cells packed with digestive enzymes) explains the fragmentation of DNA seen in cells exposed to mobile phone signals. In addition, Ca^{2+} leakage into the cytosol (the main part of the cell) acts as a metabolic stimulant that accounts for accelerated growths and healing, which also promotes tumor growths. He further opines that, Ca^{2+} leakage into neurons (brain cells) generates spurious action potentials (nerve impulses), which cause pain and other neurological conditions in electro-sensitive individuals. ELFs are ubiquitous in the earth's environment and electric current is involved in graviperception and root growth. Wawrecki and Zagórska-Marek (2007), suggest that the internal EMFs of plants are used to determine and control plants physiological polarities and also, set their biological rhythms. Similarly, plants exposure to external EMFs cause changes in growth direction, rates of cell division, enhancement or inhibition of flowering, and stimulation of embryogenesis. They showed that DC fields changed the cellular pattern of root apical meristem of maize (*Zea mays*) by activating the quiescent centre, which penetrated the root cap junction, disturbed the organisation of the closed meristem and can damage its root cap initials by terminating its cell division. Minorsky and Bronstein (2007) say foliar spiral direction (FSD) in coconut palms (*Cocos nucifera*) is not genetically determined. This is so because the morphological asymmetry, which is due to both dextral (right side) and sinistral (left side) forms are not inherited and are equally common within species. They further report that asymmetries in FSD was evident in coconut palm populations on opposite sides of islands and that these asymmetries between cohorts vary with an 11-year periodicity arising from geomagnetic (geographical magnetic) variations that underpin asymmetries in coconut palm FSD. The foregoing was so because seawater is more electrically conductive than land. The induced earth currents tend to divide and stream past an island in a pattern determined by surrounding bathymetry (the science of sounding seas and lakes). This geomagnetic island effect is characterised by complete reversal of the vertical Z component of short-period geomagnetic field variations at observation points on opposite sides of islands (Minorsky and Bronstein 2007).

Belyavskaya (2004) indicates that the proliferation activities, cell reproduction in meristem of plant roots and functional genome activity at early pre-replicate period are decreased in weak MFs. Also, changes in condensed chromatin distribution, nucleolus compactisation in nuclei, accumulation of lipid bodies, lytic compartment development (vacuoles, cytosegresomes and paramural bodies), and reduction of phytoferritin in plastids of meristem cells were observed in pea (*Pisum sativum*) roots exposed to weak MFs. Maharramov (2007) reports that stable static MF operating at different temperature microenvironments was used to increase the growth rates of chickpeas (*Cicer arietinum*), beans (*Vicia faba*) and lentils (*Lens culinaris*). This effect was created using magnetic bars of intensity **H** equal to that of the earth and at a distance of about 23 cm from a pole of the bar magnet, on the line passing along both its poles. Similarly, Köse (2007) used DC electric current effects to investigate adventitious root formation of the grapevine rootstock *Vitis champini* cv. 'Ramsey' and found significantly high increases in rooting rates and root growth, especially because grapevine rootstocks are rather difficult to root through cuttings. The main advantage and contribution of DC electric current effects to this plant is that it can be used to enhance the roots propagation efficiency and effectiveness of grapevine rootstock *V. champini* cv. 'Ramsey'.

The breakdown mechanism of impure liquids depends on several factors like the nature and condition of electrodes, the physical properties of the liquid, the sizes of solid impurities and the gases present. The value of breakdown strength depends strongly on the applied hydrostatic pressure, change of phase of the medium, impurity particles and vapour bubbles arising from gas pockets at electrode surfaces, electrostatic repulsive forces between space charges, liquid dissociation by electron collisions and corona-type discharge from sharp points and irregular surfaces in the plantain pseudostem vacuoles (Naidu and Karamaju 2007). It was the above factors, which necessitated the use of the breakdown strength for air in determining the Poynting power flow in plantains. The Poynting power flow shows an enormous amount of power transmitted per unit area by considering the power to be circulating such that the outwards flow across a local region of any closed surface is balanced by an equal flow inwards somewhere else on the same surface (Jefferies 2003). The emphasis is that the Poynting vector is normal to the real part of a dispersion surface in the total reflection region, even when the contribution of the imaginary part of the scattering factor to the diffraction is negligible (Xu *et al.* 1997). Similarly, in the Airy beam case, the spatial angular momentum distribution is changing, but the angular momentum has non-zero values, locally (Sztul and Alfano 2008). In the same vein, Janhunen *et al.* (2005) statistically considered AC (wave-related Poynting vector) and DC (parallel) Poynting vector in the auroral zone as a function of altitude and conclude that: (a) about 30% of the energy input was due to particle precipitation and 70% was due to Joule heating (b) a slight decreasing trend was noticed in the midnight sector, while in the evenings the DC flux was almost independent of altitude (c) the AC Poynting vector alone could not power auroral electron precipitation, mainly because the highest AC Poynting vector values were less than the observed electron energy (d) the waves carrying significant Poynting vectors were storm-related and could be rightly called, Alfven waves and (e) both the AC and DC Poynting vectors were in agreement with the midnight auroral zone. As a result of the foregoing arguments, the AC Poynting vector power flow for plantain pseudostems deduced in this study seem in good agreement with the plane waves analyses of covariant electromagnetic fields, while the DC (parallel) Poynting vector for plantains should be addressed in the future.

Moreover, EMFs must be able to generate electrical 'eddy currents' flowing in and around the cell or tissues before they can produce biological effects. As a result, both the electrical and magnetic components of the fields can induce eddy currents, which tend to follow low impedance pathways. For instance, the usually soft and wet plantain pseudostem forms an excellent low resistance pathway for DC and low frequency AC signals. Because the tissues and cells of a plantain pseudostem is a maze of tubes and fibres filled with highly conductive and polarised fluids, they can carry signals at high frequencies across their membranes very easily due to their capacitance (Goldsworthy 2007). Therefore, the whole plantain pseudostem becomes an efficient and effective antenna for picking up electromagnetic radiation. Incidentally, most biological membranes are negatively charged so as to make them attract and adsorb positive ions. The amounts and types of ions attached to these membranes at any point in time depends on their availability, number of positive charges each carries, their chemical affinity and abundance. Although calcium predominates and binds firmly to the negative membrane, potassium which is about ten thousand times the number of calcium (in virtually all living cells and in the cytosol) is a strong contender for any displaceable Ca^{2+} (Goldsworthy 2007). Whenever an alternating electric field from eddy current strikes the membrane, it pulls the cations away during the negative half cycle and drives them back in the positive half cycle. This process tends to preferentially dislodge Ca^{2+} in weak fields and the less affected K^+, which were essentially in their positions try to replace the lost Ca^{2+}. Consequently, weak MFs and EMFs increase the proportion of K^+ bound to the membrane and hence, release the Ca^{2+} into the surrounding environments of the plantain pseudostem (Goldsworthy 2007). These rather simple and seemingly harmless activities of eddy currents in the plantain pseudostem membranes cause internal weakening, leakage, wear and tear in the vacuoles, cells and tissues, thereby undermining the integrity of the whole plantain and banana crop to withstand external stresses like wind; leading to heavy losses from wind-throws and blow-downs.

Robinson *et al.* (2003) reviewed dielectric permittivity and electrical conductivity measurements of water bearing porous materials, and affirmed that the permittivity of such materials is strongly influenced by their water content. Additionally, the origin of this real permittivity part derives from the asymmetry of charge in the water molecules (a small displacement of the positive and negative charge centres that creates a permanent dipole of about 6.216×10^{-30} C m). Once a material is placed in an alternating electric field, the molecules overcome their random thermal motion and align with the field. This alignment process stores electrical energy, which can be released whenever the application of field has stopped. Because of actual charge carriers (ions) existing in the materials, energy is lost due to ionic conductivity. This energy loss which is dissipated as heat, results whenever the aligned molecules can no longer keep up with the speed of field alternation (Janhunen *et al.* 2005; Sztul and Alfano 2008). Electrohydrodynamic (EHD) flow actuation of dielectric flows was studied by Raghavan *et al.* (2009). They found out that the electric pressure gradients were due to induced polarisation. But for low conductivity dielectric fluids (Electro-conjugate fluids-ECF), they exhibit EHD when subjected to non-uniform fields of low intensities (< 1 kV/cm). Under such low field intensities, it does not lead to the presence of threshold voltages, which can bring about flow, quadratic scaling of flow velocity (turbulence) with applied voltage and flow from high to low field regions.

But for plantains pseudostems under study, the alternating fields present very high intensities of the order of 30 kV/cm (Mehta and Mehta 2007; Naidu and Karamaju 2007). The Frequentist approach to inference was chosen for this study since the Bayes rule allows probabilities to have an interpretation that represents the researcher's belief that the given values of parameters are true (Moore and McCabe 1993; Montgomery *et al*. 1998).

As a result, such intensities can lead to the presence of threshold voltages, which can lead to the onset of corona, fluid and charge flow, turbulent flow velocities with applied voltage and electric pressure gradient flows from high to low field regions by the processes of diffusion, Brownian motion and random walk. Furthermore, the electrical conductivity evaluated for plantains in this study is large. This result shows that the conductive parts of the plantain pseudostems mainly consist of ions and electrolytes.

Grudinin *et al.* (2007) have demonstrated that with proper manufacture and mechanical polishing of cavity resonators; surface scattering and surface absorptions difficulties can almost be eliminated. Presently, the only obstacle to obtaining that ultimate quality factor in dielectric materials lie with eliminating both linear and nonlinear attenuation effects. While it has been shown that the scattering loss mechanism determines the optical attenuation, both the linear and nonlinear absorption mechanisms are equally known to have very strong frequency dependence. Hsu *et al.* (2008) found out that carbon nanotubes produce electrothermal effect that results in low quality factor. This low quality factor showed strong damping and strong coupling effects of the main mass. Because of the low voltage requirements, it would be very useful in digital technology, they opined. To produce a device with low quality power factor, the capacitor with a low equivalent series resistance would be required. This is so because the quality factor is that number which is closely related to the dissipation factor and determines how long a resonant circuit would ring (Johnson 2005). For low voltages, capacitance that guarantees a low quality factor (a minimum equivalent series resistance value) as determined in this study is something from which we will all benefit. This is especially so because we are in the digital age and anything that advances digital technology, moves the world at least one step forward in technological development.

CONCLUSIONS

The three dimensional coordinate system has been used to analyse the effects of time-varying electric and magnetic field effects in plantains. The results show that it is possible to have electric charges in plantains because of the likely presence of electrolytes in the conductive paths of the pseudostem. The divergence of the magnetic field, is, however, zero (Ramo *et al.* 1984, 2004) as in other substances.

Calcium loss in membranes as a result of varying and alternating EMFs and eddy currents, make holes that cause leakage and consequently weaken plantain pseudostem tissues, through more tears, slower repair capacities and more overall solute leakage (Goldsworthy 2007). Because it is known that, 16 Hz is the ICR frequency for potassium in the earth's magnetic field, and when exposed to EMF at this frequency resonate, absorb the field's energy and convert it to energy of motion. This increases their ability to replace calcium ions in cell membranes (Goldsworthy 2007). Whereas the extra energy gained by each K^+ may be small, that fact that, there are about ten thousand of them competing with just one Ca^{2+} for each place on the membrane means that a slight increase in their energies due to resonance is enough to overwhelm those calcium ions, as their sympathetic and synergistic support for each other can easily produce more than twice the work function (that is the energy required to dislodge the Ca^{2+} from the surface of the cell membrane) to replace and substitute K^+ for Ca^{2+}, which is a binding or cementing agent for the cell membranes and thereby undermine the overall quality and integrity of such plantain or banana crop (Goldsworthy 2007; Naidu and Karamaju 2007).

Interestingly, it is only low frequency EMFs that will allow Ca^{2+} have time to be pulled clear of the plantain or banana membranes and replaced by K^+ before the field reverses and drives them back to their former positions. In addition, pulses and square waves from digital and telecommunications equipment that have become preponderant and used to transfer signals, voice and other data all over the globe, work best because they give rapid changes in voltage that pushes the Ca^{2+} far away from their original plantain membranes and then, allow more time for K^+ to fill the vacated sites (Goldsworthy 2007).

The divergence of the current density in plantains was also found to be equal to the time rate of change of charge. The time rate of change of displacement in plantains is proportional to the electric field as well as the total current. Both the Poynting vector energy and capacitance values for plantains were also obtained in this study.

The conductance, attenuation coefficients and penetration depth were also determined. The relatively low quality factor determined in this study, ensure the charging and discharging of voltages at very short intervals of time. This pulse switching mechanism is very useful for signal processing and transmission. It would be of great benefit to the digital technology, mainly because the shorter the switching times between maximum and minimum levels, the better it is for data and signal exchange capabilities. While large amounts of power can be transmitted from the source or transmission system to the load (Johnson 2005), the small pico-farad capacitance value from plantains, demand the use of smaller voltages in the digital circuits range while requiring the minimum equivalent series resistance for best achieveable efficiency and performance. The above is especially beneficial to digital technology and the world at large, mainly because of the reduced signal-to-noise ratio when compared to analogue devices, coupled with that fact that we are in the digital age where almost all use for our work, play, recreation, transportation, communication and all other human endeavours are becoming more and more digitalised.

Therefore, it is strongly recommended that, with suitable modifications or other materials manufacture, which can mimic the properties of plantains obtained from this research, can be applied to such industrial sectors as telecommunications, computers and computing technologies, navigation systems, radar, defence and power systems engineering, for the overall benefit of mankind.

However, the above technological benefits can only be available to mankind if it is able to exploit to advantage the myriads of properties obtainable from plantains electrodynamics as determined in this study. It must be emphasised that the foregoing benefits are different from the enhanced and improved food security provided to the world, especially because plantains and bananas occupy the fourth position as a major world food crop, as pointed out by Schoofs *et al.* (1999) and CGIAR (2005).

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