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On The Mathematical Model of the Biomechanics of Green Plants: Magnetic field effect

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ABSTRACT
This study considers the biomechanics in the stem of green plants where xylem flow occur. The fluid (soil mineral salt water) flow through the cylindrical vessel of the xylem is assumed to be viscous, incompressible, and the channel porous. The usual Navier stokes equations in cylindrical coordinate are utilized to formulate the governing system of equations for the flow. The resulting coupled non-linear partial differential equationsare non-dimensionlized and then transformed to nonlinear ordinary differential equations using the appropriate similarity variables. The transformed non-linear ordinary differential is then solved using the homotopy perturbation method. The effects of parameters such as soil nature (magnetic field), free convective forces embedded in the flow are examined on the velocity, temperature and concentration fields. Observation shows that the flow velocity, temperature and concentration decreases as the magnetic field strength increases; the free convective forces enhanced the flow velocity, temperature and concentration.
KEYWORDS: Biomechanics, xylem flow, homotopy perturbation method (HPM)

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I. INTRODUCTION

Green plants are the earth's primary solar energy collectors and are the ultimate source of food for both man and animals. Rand, [21].The ability to provide water and nutrients for all vital parts of green plants is very important for the survival of the plant. Water is primarily the basic solvent in all cells. It aids intercellular transport by diffusion. Speck, *et al.,[23*]. Plants also depends on water for transpiration, photosynthesis and for transport of photosynthates, mainly sugars. Since water is predominantly taken up in the roots and sugars are produced in the leaves, plants therefore undergo a long-distance transport of sap, water with solute and thus form a vascular system.

The vascular system of plants consists basically two parts, namely xylem and phloem Dolger *et al.*, [4]; Yu, [28]. The xylem is made up of the tracheids and vessel elements that die after reaching maturity while the phloem contains sieve elements that still lives after maturity Rand, [21].

The force that drives the upward flow in the xylem is enhanced by suction pressure generated in the leaves by evaporation of water vapor into the atmosphere Jensen, *et al.*, [8] and the environmental thermal differences resulting from free convective motion of the fluid Okuyade and Abbey, [11]. The downward phloem on the other hand is driven by concentration differences resulting from active transport Rand, [21].

it is observed from literature that fluid carrying vessels of green plants are porous and the flow naturally convective since they are not pumped by any physical means. Studies have also shown that flow through porous channels are affected by certain parameters such as, thermal gradient, concentration gradient, pressure gradient(for example suction and root pressure), the porosity, the physical properties of the fluid(for example, viscosity, density), body forces(for example, buoyancy, gravity, magnetic field)and bifurcation (Muskat, [10]; Zami-Pierre, et al., [29]; El-dabe, *et al.*, [5]; Okuyade and Abbey, [14]) etc. Several methods such as Laplace transform, finite fourier sine and cosine techniques, perturbation, direct numerical simulations have been used to examine the effects of these parameters on the flow structure.

The effect of small value of the aspect ratio and increasing values of the porosity were examined on the concentration field of a fully developed on the stem of a green plant by Bestman, [1] using Laplace transform method. Bestman, [3] went further to consider the case where the flow is not fully developed for larger value of the aspect ratio using perturbation and finite Fourier sine and cosine technique. Bestman,[2], also considered the Transient case of the problem due to daily changes in the stem diameters resulting from dehydration. The Laplace transform and Fourier sine and cosine transform method were used to investigate this. A low Reynolds number was assumed and environmental thermal differences were neglected. Hoad, [7] studied translocation of hormones in the phloem of higher plans. Problems associated with collection of sieve tube exudates and the analysis of samples were discussed. More so, possible functions of hormones were investigated. From the study, it was established that mobile hormones played a part in controlling the structure of the plant as their concentration in sieve tube have been shown to be influenced by the environment and developmental stage of the plant. Peuke*et al.,* [19] used the nuclear magnetic resonance (NMR) spectrometry to study the measurement of rates of flow in xylem and phloem. The effects of light regime on water flows on xylem phloem was monitored using this same method. It was observed that the presence of light did not change the flow of water in the phloem very much but rather, it increased the velocity of flow in the xylem. Transport of solute was mainly affected by the solute concentration during loading and thus resulting to changes in concentration.Rengel, [22] studied the transport of micronutrients (manganese and zinc) from leaves to roots, leaves and stems to developing grains and then from one root to another in the xylem and phloem of a developing plant species. Result showed that zinc solute was more mobile in phloem while manganese solute had poor mobility in the phloem and therefore occurred mainly on the xylem. Uka and Olisa, [26] studied the transport of sap in the stem of a of a non-bifurcating green plant using the homotopy perturbation method. The effects of varying values of the aspect ratio, porosity parameter, buoyancy forces and Schmidt number were examined on the concentration flow field.Uka, et al., [27] went further to examined the effects of varying values of the porosity parameter, aspect ratio, buoyancy forces and Schmidt number on the velocity and concentration fields using the homotopy perturbation method.

Flow of viscous, incompressible fluid through bifurcating porous channels have also been investigated. Okuyade*et al.,* (2015) examined the effects of variation in the amplitude of the pressure wave, height of constriction of the tube and Reynolds number on the temperature distribution and rate of heat transfer of the pulsatile blood flow in tubes (stenos artery) of varying cross section using the regular perturbation series solution. The heat flow behavior in the artery before and after the peak of the constriction was also examined. It was observed that; as the height of constriction, amplitude of the pulse and the Reynolds number increased, the flow temperature and rate of heat transfer of the flow also increased. Thus, as heat is generated in the system, the rise in its level led to hyperthermia situation which subjected the stenos patient's health at risk.Okuyade, [17] studied MHD blood flow through bifurcated porous fine capillaries of humans using perturbation method. Effects of magnetic field and environmental thermal parameters on the flow structure were examined. Okuyade and Abbey [13] examined the effects of variation in the pressure wave amplitude and height of constriction of oscillatory blood flow behavior in axis-symmetric convergent and divergent channel on the velocity, pressure and wall shear stress structure in the region before and after the peak of constriction using the perturbation series solution. Tadjfar and Smith [24] examined the effects of bifurcation angle on a 3-dimensional laminar steady flow of an incompressible viscous fluid through a straight mother tube bifurcating into two straight but divergent daughter tubes by direct numerical simulations. Liou, *et al.*, [9] studied the effect of bifurcation angles on the steady flow structure in a straight terminal aneurysm model with asymmetric outflow through the branches using the Laser-Doppler velocity and fluctuating intensity distribution.Okuyade and Abbey, [12] studied a steady MHD fluid flow in a bifurcating rectangular porous medium using perturbation method. The effects of bifurcation angle, magnetic field, thermal and concentration Grashof numbers on the flow were examined. Okuyade and Abbey,[15] investigated the oscillatory flow behavior of blood in bifurcating arteries under the influence of exposed magnetic field, temperature differentials, Pelect number Grashof numbers, Reynolds number, chemical reaction and bifurcation angle using the regular perturbation series expansion method. Okuyade and Abbey, [11] studied the flow through the xylem of a bifurcating green plant under a constant environmental thermal difference using the regular perturbation method. Okuyade and Abbey, [14] went further to investigate the effects of environmental temperature differentials on the xylem flow of a bifurcating green plant using the same method (perturbation).

Inthis study however, the effects of increasing values of the magnetic field strength and free convective forces (thermal and concentration Grashof number) on the velocity, temperature and concentration fieldswill be examined using the homotopy perturbation method.

II. MATERIALS AND METHOD

The mineral salt water in green plants is well describe as viscous, incompressible, fluid. The liquid carrying vessels are cylindrical and porous in nature and the flow itself naturally convective since they are not driven by any physical means. It is assumed that the flow is creepy with a very low Reynolds number. The velocity vectors with respect to the orthogonal coordinate directions (r', θ', z') are (u', v', w'). Assuming also that the flow is fully developed and the velocity is symmetrical about the θ' axis such that the variations about θ' is zero. The coordinate and velocity vectors becomes(r', z') and (u', w') respectively. By the usual Boussinesq approximation, the mathematical models describing the motion of the flow in cylindrical coordinates for the steady case are;

$$\frac{1}{r^*}\frac{\partial}{\partial r^*}(r^* u^*) + \frac{\partial w^*}{\partial z^*} = 0, \qquad (1)$$

$0 = -\frac{\partial p^*}{\partial r^*} + v\left(\frac{\partial^2 u^*}{\partial r^{*2}} + \frac{1}{r^*}\frac{\partial u^*}{\partial r^*} - \frac{u^*}{r^{*2}} + \frac{\partial^2 u^*}{\partial z^{*2}}\right) - \frac{v}{K}u^*$,(2)

$0 = -\frac{\partial p^*}{\partial z^*} + v\left(\frac{\partial^2 w^*}{\partial r^{*2}} + \frac{1}{r^*}\frac{\partial w^*}{\partial r^*} + \frac{\partial^2 w^*}{\partial z^{*2}}\right) - \frac{v}{K}w^* + \rho g\beta_t(T - T_\infty) + \rho g\beta_c(C^* - C_\infty) - \frac{\sigma B_0^2 u^*}{\rho}$, (3)

$\rho C_p\left(u^*\frac{\partial T}{\partial r^*} + w^*\frac{\partial T}{\partial z^*}\right) = \alpha_t\left(\frac{\partial^2 T}{\partial r^{*2}} + \frac{1}{r^*}\frac{\partial T}{\partial r^*} +\right.$
$\partial 2T\partial z*2+Q0\rho CpT-T\infty$, (4)

$\left(u^*\frac{\partial C^*}{\partial r^*} + w^*\frac{\partial C^*}{\partial z^*}\right) = D\left(\frac{\partial^2 C^*}{\partial r^{*2}} + \frac{1}{r^*}\frac{\partial C^*}{\partial r^*} + \frac{\partial^2 C^*}{\partial z^{*2}}\right) + K_r'(C^* - C_\infty)$, (5)

where p is the pressure, v is the viscosity, $T\ and\ C'$ are the fluid temperature and concentration respectively, $T_\infty\ and\ C_\infty$ are the temperature and concentration at equilibrium, K is the permeability, g is the gravitation which acts in opposite direction to the flow, ρ is the fluid density, $\beta_t\ and\ \beta_c$ are the coefficient of volume expansion for temperature and concentration respectively, C_p is the heat capacity, α_t is the thermal conductivity,k_0 is the thermal diffusivity and D is the mass diffusion coefficient.

$(u^*, w^*)(0, z) = (1,1)$; $T(0, z) = T_\infty C^*(0, z) = C_\infty$ at $r^* = 0$,
$(u^*, w^*)(1, z) = (0,0)$; $T(1, z) = T_w C^*(1, z) = C_w$ at $r^* = 1$. (6)

The following non-dimensional quantities are used to normalize our governing equations.

$$r = \frac{r^*}{r_0};\ z = \frac{z^*}{l};\ (u, w) = (u^*, w^*)\frac{r_0}{v};\ \theta = \frac{T - T_\infty}{T_w - T_\infty};\ \emptyset = \frac{C' - C_\infty}{C_w - C_\infty}; p = \frac{r_0^3(p' - p_\infty)}{\rho_\infty l v^2};\ R = \frac{r_0}{l},$$

$x^2 = \frac{r_0}{\sqrt{K}}$; $Gr = \frac{g\beta_t(T_w - T_\infty)r_0^3}{v^2}$; $Gc = \frac{g\beta_c(C_w - C_\infty)r_0^3}{v^2}$; $Sc = \frac{v}{D}$; $Pr = \frac{v}{k_0}$, $k_0 = \frac{\alpha}{\rho C_\rho}$. (7)

Thus, our normalized governing equations are;

$\frac{1}{r}\frac{\partial}{\partial r}(ru) + \frac{\partial w}{\partial z} = 0$, (8)

$0 = -\frac{\partial p}{\partial r} + \frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} - \frac{u}{r^2} - \alpha^2 u - R^2\frac{\partial^2 u}{\partial z^2}$, (9)

$0 = -R\frac{\partial p}{\partial z} + \frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r} - x^2 w + R^2\frac{\partial^2 w}{\partial z^2} + Gr\theta + Gc\emptyset$, (10)

$Pr\left(u\frac{\partial\theta}{\partial r} + Rw\frac{\partial\theta}{\partial z}\right) = \frac{\partial^2\theta}{\partial r^2} + \frac{1}{r}\frac{\partial\theta}{\partial r} + R^2\frac{\partial^2\theta}{\partial z^2}$ (11)

$Sc\left(u\frac{\partial\emptyset}{\partial r} + Rw\frac{\partial\emptyset}{\partial z}\right) = \frac{\partial^2\emptyset}{\partial r^2} + \frac{1}{r}\frac{\partial\emptyset}{\partial r} + R^2\frac{\partial^2\emptyset}{\partial z^2}$(12)

For convenience, we assume a solution of the form

$\theta^{(0)} = \theta(r) - \gamma z,\ \emptyset = \emptyset^{(0)}(r) - \gamma z,\ p = Kz - \frac{\gamma}{R}z^2$, (13)

as given by Bestman, [1]. Substituting the assumed solution (13) into equations (8) - (12), we have

$K = w'' + \frac{1}{r}w' - \alpha^2 w + Gr\theta^{(0)} + Gc\emptyset^{(0)}$, (14)

$-P_r R\gamma w = \theta^{(0)''} + \frac{1}{r}\theta^{(0)'}$ (15)

$-S_c R\gamma w = \emptyset^{(0)''} + \frac{1}{r}\emptyset^{(0)'}$ (16)

where γ is a constant, R is the aspect ratio, α is sum of the magnetic field parameter and the porosity parameter $(M + x)$, Gr is the thermal Grashof number, Gc is the concentration Grashof number, Sc is the Schmidt number, Pr is the Prandtl number. The transformed boundary conditions are

$\emptyset^{(0)}(0) = 0$; $\emptyset^{(0)}(1) = 1$,
$w(0) = 1$; $w(1) = 0$,
$\theta^{(0)}(0) = 0$; $\theta^{(0)}(1) = 1$. (17)

According to the HPM of He, [6] , the homotopy form of (14), (15) and (16) are constructed as follows

$(1 - p)\{w''\} + p\left[w'' + \frac{1}{r}w' - \alpha^2 w + Gr\theta^{(0)} + Gc\emptyset^{(0)} - K\right] = 0$, (18)

$(1 - p)\left[\theta^{(0)''}\right] + p\left[\theta^{(0)''} + \frac{1}{r}\theta^{(0)'} + P_r R\gamma w\right] = 0$, (19)

$(1 - p)\left[\emptyset^{(0)''}\right] + p\left[\emptyset^{(0)''} + \frac{1}{r}\emptyset^{(0)'} + S_c R\gamma w\right] = 0$. (20)

We assume w, $\theta^{(0)}$ and $\emptyset^{(0)}$ as

$w = w_0 + pw_1 + p^2 w_2 + \cdots$, (21)

$\theta^{(0)} = \theta^{(0)}{}_0 + p\theta^{(0)}{}_1 + p^2\theta^{(0)}{}_2 + \cdots$, (22)

$\emptyset^{(0)} = \emptyset^{(0)}{}_0 + p\emptyset^{(0)}{}_1 + p^2\emptyset^{(0)}{}_2 + \cdots$, (23)

Substituting equations (21)- (23), into equations (18)-(20), simplifying and rearranging equations based on the powers of p-terms together with its boundary conditions, we have

p^0; $w_0'' = 0$; $w_0(0) = 1;\ w_0(1) = 0$,

$\theta^{(0)}{}_0'' = 0\ \theta^{(0)}{}_0(0) = 1; \theta^{(0)}{}_0(1) = 1$,

$\emptyset^{(0)}{}_0'' = 0 \emptyset^{(0)}{}_0(0) = 1; \emptyset^{(0)}{}_0(1) = 1,$ (24)

$$P^1; \quad w_1'' = -\frac{1}{r}w_0' + \alpha^2 w_0 - Gr\theta^{(0)}{}_0 - Gc\emptyset^{(0)}{}_0 + K \quad ; \quad w_1(0) = 0; \; w_1(0) = 0,$$

$$\theta^{(0)}{}_1'' = -\frac{1}{r}\theta^{(0)}{}_0' - PrR\gamma w_0 \theta^{(0)}{}_1(0) = 0; \theta^{(0)}{}_1(1) = 0,$$

$\emptyset^{(0)}{}_1'' = -\frac{1}{r}\emptyset^{(0)}{}_0' - ScR\gamma w_0 \emptyset^{(0)}{}_0(0) = 0; \emptyset^{(0)}{}_1(1) = 0,$ (25)

$P^2; \; w_2''' = -\frac{1}{r}w_1' + \alpha^2 f_1 - Gr\theta^{(0)}{}_1 - Gc\emptyset^{(0)}{}_1 \quad ; \quad w_2(0) = 0; \; w_0(1) = 0,$

$\theta^{(0)}{}_2'' = -\frac{1}{r}\theta^{(0)}{}_1' - PrR\gamma w_1 \theta^{(0)}{}_2(0) = 0; \theta^{(0)}{}_2(1) = 0,$

$\emptyset^{(0)}{}_2'' = -\frac{1}{r}\emptyset^{(0)}{}_1' - ScR\gamma w_1 \emptyset^{(0)}{}_2(0) = 0; \emptyset^{(0)}{}_2(1) = 0,$ (26)

Solving (24) - (26) we have

$w_0 = L1r + L2,$(27)

$w_1 = -L1(r\, In\, r - r) + \frac{1}{6}(\alpha^2 L1 - GrL3 - GcL5)r^3 + \frac{1}{2}(\alpha^2 L2 - GrL4 - GcL6 + K)r^2 + L7r + L8,$(28)

$w_2 = \frac{L1}{2}(r(In\, r)^2 - 2r) - L7(r\, In\, r - r) - \frac{\alpha^2 L1}{2}\left(\frac{r^3 In\, r}{3} - \frac{r^3}{9}\right) + \frac{Gr\, L3}{2}\left(\frac{r^3 In\, r}{3} - \frac{r^3}{9}\right) - \frac{Gr\, L3}{12}r^3 + \frac{Gc\, L5}{2}\left(\frac{r^3 In\, r}{3} -\right.$
r39− Gc
L512r3+1120α2L1− α2GrL3− α2GcL5+GrPrRγL1+GcScRγL1r5+124α2L2− α2GrL4− α2GcL6+α2K+GrPrRγL2+GcScRγL2r4− 112α2L1− GrL3− GcL5r3+16α2L1− α2L7− GrL3− GrL9− GcL5− GcL11r3− 12α2L2− GrL4− GcL6− α2L8+GrL10+GcL12+Kr2+L13r+L14, (29)

$\theta^{(0)}{}_0 = L3r + L4,$ (30)

$\theta^{(0)}{}_1 = -L3(r\, In\, r - r) - \frac{PrR\gamma L1}{6}r^3 - \frac{PrR\gamma L2}{2}r^2 + L9r + L10,$ (31)

$\theta^{(0)}{}_2 = \frac{L3}{2}(r(In\, r)^2 - 2r) - L9(r\, In\, r - r) + \frac{PrR\gamma L1}{2}\left(\frac{r^3 In\, r}{3} - \frac{r^3}{9}\right) - \frac{1}{120}(PrR\gamma\alpha^2 L1 - PrR\gamma GrL3 -$
PrRγGcL5r5− 124PrRγα2L2− PrRγGrL4− PrRγGcL6+PrRγKr4− 16PrRγL1+PrRγL7r3+12PrRγL2+PrRγL8r2+L15r+L16, (32)

$\emptyset^{(0)}{}_0 = L5r + L6,$(33)

$\emptyset^{(0)}{}_1 = -L5(r\, In\, r - r) - \frac{ScR\gamma L1}{6}r^3 - \frac{ScR\gamma L2}{2}r^2 + L11r + L12,$ (34)

$\emptyset^{(0)}{}_2 = \frac{L5}{2}(r(In\, r)^2 - 2\, r) - L11(r\, In\, r - r) + \frac{ScR\gamma L1}{2}\left(\frac{r^3 In\, r}{3} - \frac{r^3}{9}\right) - \frac{1}{120}(ScR\gamma\alpha^2 L1 - ScR\gamma GrL3 -$
ScRγGcL5r5− 124ScRγα2L2− ScRγGrL4− PrRγGcL6+ScRγKr4− 16ScRγL1+ScRγL7r3+12ScRγL2− ScRγL8r2+L17r+L18, (35)

III. RESULTS AND DISCUSSION

The effects of varying values of themagnetic field parameter and buoyancy forces (Thermal and Concentration Grashof number, (Gr/Gc))embedded in the fully developed flow at a very low Reynolds number are examined on the velocity, temperature and concentration fields. The results obtained are examined at a fixed value of $Pr = 0.71$, $K = \eta = 0.5$. and varying values of $M = 0.1, 0.5, 0.7, 1.0, Gc = Gr = 1.0, 5.0, 10.0, 15.0$, as shown in figures (1) –(9). Nusselt number and Sherwood number effects on Gr/Gc are also shown;

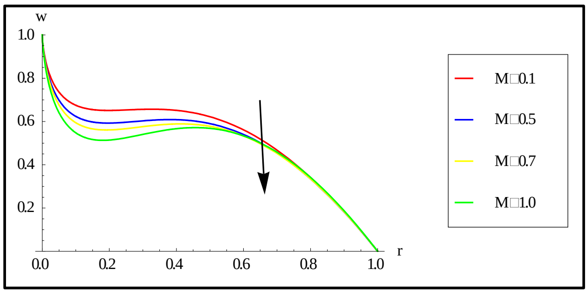

Figure 1: Effects of Mon velocity at $Pr = 0.71, \eta = 5.0, R = K = 0.5, Sc = Gr = Gc = x = 1.0.$

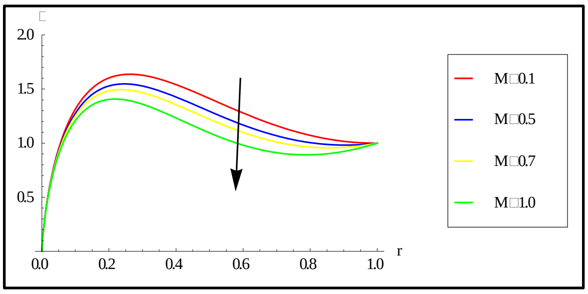

Figure 2: Effects of Mon temperature at $Pr = 0.71, \eta = 5.0, R = K = 0.5, Sc = Gr = Gc = x = 1.0.$

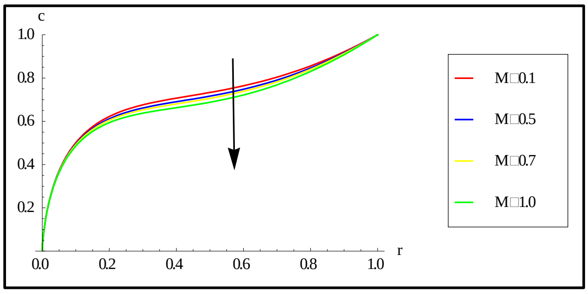

Figure 3: Effects of M**on concentration at** $Pr = 0.71, \eta = 5.0, R = K = 0.5, Sc = Gr = Gc = x = 1.0$.

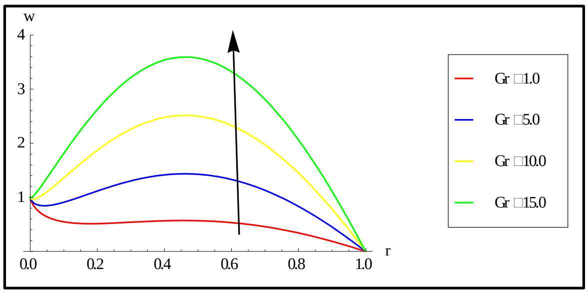

Figure 4: Effects of Gr**on velocity at** $Pr = 0.71, \eta = 5.0, R = M = K = 0.5, Sc = Gc = x = 1.0$.

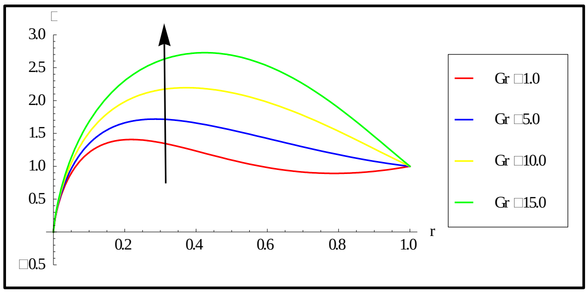

Figure 5: Effects of Gr**on temperature at** $Pr = 0.71, \eta = 5.0, R = M = K = 0.5, Sc = Gc = x = 1.0$

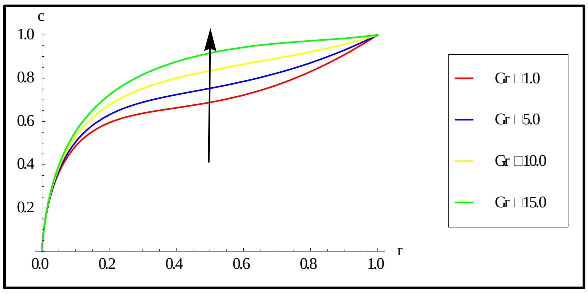

Figure 6: Effects of Gr**on concentration at** $Pr = 0.71, \eta = 5.0, R = M = K = 0.5, Sc = Gc = x = 1.0$.

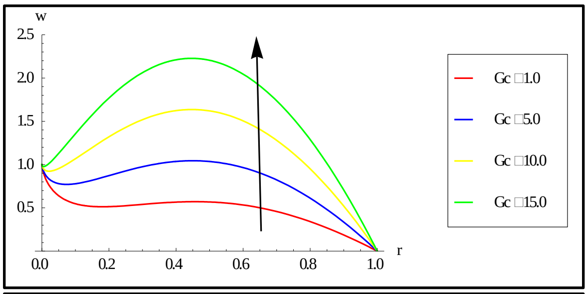

Figure 7: Effects of Gc**on velocity at** $Pr = 0.71, \eta = 5.0, R = M = K = 0.5, Sc = Gr = x = 1.0$.

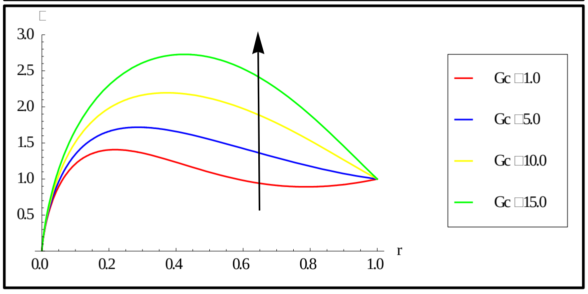

Figure 8: Effects of Gc**on temperature at** $Pr = 0.71, \eta = 5.0, R = M = K = 0.5, Sc = Gr = x = 1.0$.

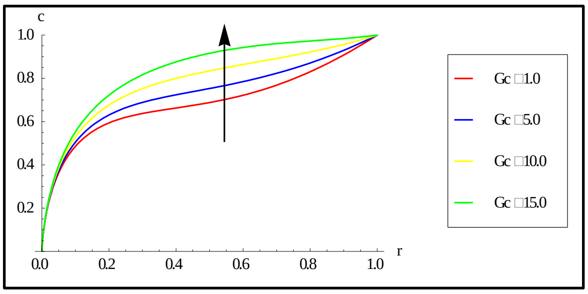

Figure 9: Effects of Gc**on concentration at** $Pr = 0.71, \eta = 5.0, R = M = K = 0.5, Sc = Gr = x = 1.0$.

Table 1: The effect of Gr variation on Nusselt number (Nu)

Gr	M	Pr	Nu
1.0	**0.5**	**7.0**	**-8.96181**
5.0	**0.5**	**7.0**	**-7.60069**
10.0	**0.5**	**7.0**	**-5.89931**
15.0	**0.5**	**7.0**	**-4.19792**

Table 2: The effect of Gc variation On Sherwood number (Sh)

Gc	M	Pr	Sh
1.0	**0.5**	**7.0**	**0.43403**
5.0	**0.5**	**7.0**	**0.62847**
10.0	**0.5**	**7.0**	**0.87153**
15.0	**0.5**	**7.0**	**1.114583**

It is observed from figures $(1)-(3)$, that the flow velocity, temperature and concentration increase with increasing values of the magnetic field parameter. This agrees with the result obtained by Okuyade and Abbey [11] Figures $(4)-(9)$ show that as the free convective forces increases, the flow velocity, temperature and concentration also increase. This agrees with the result obtained by Okuyade and Abbey [14]. From tables (1) and (2), the Nusselt and Sherwood number increases with increasing values of the thermal/concentration Grashof numbers respectively.

The soil mineral salt water is magnetically susceptible and so the water particle exists as charges. In the presence of the earth's magnetic field, they generate electric currents. The current acts on the magnetic field to produce a mechanical force which freeze up the fluid velocity thereby reducing its kinetic energy as well as its velocity. The increase in the free convective forces on the other hand reduces the viscous force of the fluid particle and thus makes the fluid particle more buoyant. This positively affects the effective growth and yield in plant.

IV. CONCLUSION

A steady, incompressible, two-dimensional flow model on the biomechanics of green plants has just been analyzed. The coupled non-linear governing equations of the flow were non-dimensionalized and then solved by homotopy perturbation method. Analytical results for various parametric conditions of the fully developed flow were presented on the velocity, temperature and concentration field. Results showed thatmagnetic fieldhad an inhibitive effect on flow fields as it slowed down thevelocity, temperature and concentration fields whereas increase in the free convective forces had a positive effect on the flow velocity, temperature and concentration. That is to say, as the rate and quantity of the fluid transported within the plant increases, more nutrients are absorbed into the plant thereby enhancing its growth and productivity.

COMPETING INTEREST

No competing interest exist.

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