CHEMICAL ENGINEERING TRANSACTIONS

VOL. 50, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Katharina Kohse-Höinghaus, Eliseo Ranzi

ISBN 978-88-95608-41-9; **ISSN** 2283-9216

DOI: 10.3303/CET1650070

The Effect of Magnetic and Electromagnetic Fields on the Morpho-Anatomical Characteristics of Corn (Zea mays L.) during Biomass Production

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There are several sources of raw material that have been identified worldwide with some potential to be used for the production of biofuels; for this reason hard work has been put into increasing the yields per unit area and increasing the sugar content (as in the case of corn). There are only a small number of studies that have analyzed the morpho-anatomical behaviour of crops modified for biomass production. For this reason, this work studied the morpho-anatomical, developmental and physiochemical changes in Zea mays L. plants when exposed to magnetic and electromagnetic fields with a view to the large-scale production of biomass for the generation of biofuels. Seeds were exposed to different fields for 21 days, with a control group of seeds that were not exposed. Sowing was carried out in 100 cm^3 trays using coconut fiber as a substrate. The substrate had been disinfected and moistened prior to use. The sowing trays were placed in a semi-controlled growth chamber at a light intensity of 3,000 lux, with light cycles of 12 hours and at a temperature of 23°C. The variables studied were the growth dynamics of coleoptiles and plants, the complete bromatological analysis and the anatomical structure. The bromatological analysis included the percentage variation of dry matter, crude protein, ether extract, ash content, organic matter, crude fibre, neutral detergent fibre (NDF), acid detergent fibre (ADF) and calcium, lignin and water activity. The anatomical structure was studied to identify relevant histological changes and mainly focused on the arrangement of parenchymatous tissue and the shape of the cells of which it is comprised. In addition, evaluations were conducted regarding the development of the crop based on the following indicators: relative growth rate, net assimilation rate, leaf area index, crop growth rate, absolute growth rate, leaf area duration and specific leaf area. The best results were obtained on plants whose seeds were treated with electromagnetic fields. A significant increase was seen in the majority of the indicators studied. This was most evident in the development of the parenchymal tissue and thus the chlorophyll content, as was clearly seen in the histological sections. It is important to emphasize that the histological technique allowed us to identify areas of the greatest concentrations of chlorophyll (shown by differing shades of green) in plants whose seeds had been subjected to electromagnetic fields. An increase in the chlorophyll level gives us an indirect measure of the high potential these plants offer for producing biomass.

1. Introduction

In recent years all countries have increased efforts to search for new energy sources that satisfy the demand of the people. In fact, the biomass production is important for the production of different products. This will gradually replace the usual energy supply just like that will reduce the environmental, economic and social impacts (Rosso et al., 2015). Among this diversification of sources, it's possible to find the biofuel production based on forest biomass, energy crops, and agricultural wastes among others. This allows to find a sustainable and lucrative source of energy (Quijano et al., 2012). Within the energy crops that are considered efficient for the biomass production is corn. Currently, the corn (Zea mays l.) is not only for the production

Please cite this article as: Suarez Rivero D., Ortiz Aguilar J., Marin Mahecha O., Velásquez Perilla P.E., Acevedo P., Santis Navarro A.M., 2016, The effect of magnetic and electromagnetic fields on the morpho-anatomical characteristics of corn (zea mays l.) during biomass production, Chemical Engineering Transactions, 50, 415-420 DOI: 10.3303/CET1650070

directed to the food chain, but also as a raw material in the bioethanol production. Additionally, the obtained fresh biomass can be used as for feeding of animals as a source of fiber and energy.
The search for improved energy crops (not just in terms of increased production and quality) does that they also increase the technological developments (Dvoretsky et al., 2015), whose aims are to obtain biomass yields in a quick and efficient way, fast vascular growths and with a few agricultural inputs (fertilisers, water, etc). Based on the above, this research aims to determine the effect on the morpho-anatomical characteristics, developmental and physiochemical changes in corn (Zea mays L.) when exposed to magnetic and electromagnetic fields. Histological techniques and bromatological analysis were used to determine the potential of plants subjected to stimulus, and get a promising amount of biomass energy as a renewable and environmental friendly raw material.

2. Materials and methods

2.1 Seeds and plants

The experimental plants come from sprouted corn seeds (Zea mays L.). The seeds were supplied by the local company Semicol. The corn seeds that have been used in the experiments have a germination percentage around 92% (ICA–V–508).

2.2 Treatment and hydration of the seeds

The exposure of seeds and plants to the magnetic and electromagnetic fields was permanent for 21 days, using as a witness unexposed seeds. Sowing was carried out in 100 cm^3 trays using the coconut fibre (previously disinfected and dampened) as a substrate. The sowing trays were placed in a semi-controlled growth chamber at a light intensity of 3,000 lux, with light cycles of 12 hours and at a temperature of 23°C. A completely randomized design was used with the factorial arrangement of three replicates per treatment and 50 seeds per replicate. Statistical analysis was carried out using the single analysis of variance and, where needed, a multiple range test was used. The statistical package Statgraphics Centurion was used for the analysis

2.3 Watering sprouts and plants

An irrigation system was used. The system allowed an efficient use of the liquid and applications required for germination, growth and development. This guarantees that the seedlings can obtain the water and nutrients that they need.

2.4 Measurement of parameters of growth and development

During the germination process, growth and development the following morpho-physiological characteristics were measured:
a)Germination percentage: Expressed by the ratio between the number of seeds sown and germinated
b)Plant height (cm): The measure from the stem base to the apex of the totally formed leaf. It was taken with the help of a tape measure (or square)
c)Leaf Area (cm^2): The silhouette of all leaves was drawn on a bond paper. The silhouettes were cut out and weighed. After, (1) cm^2 of paper used was weighed and the leaf area was determined by the rule of three.
The bromatological analysis were determined according to the standard procedures (Cortés-Castillo et al., 2010). This analysis includes the percentage variation of dry matter, crude protein, ether extract, ash content, organic matter, crude fibre, neutral detergent fibre (NDF), acid detergent fibre (ADF) and calcium, lignin and water activity. The Chlorophyll content was described by Ortiz et al. (2015). The growth and development indices were described by Melgarejo (2010). These are showed in the table 1.

3. Results and discussion

3.1 Germination Percentage and Plant Height

The seminal dormancy of embryos was a major consequence of the low number of plants per unit area. It was observed that a high germination percentage was presented by the EMF treatment (85% of sprouted seeds), while the seed exposed with the MF and the control showed 70% and 67% respectively. This was an evidence that the EMF had influence directly on the dormancy reduction and therefore on the embryos stimulation. On the other hand, although there were little differences, the plants that more grew up during the study resulted to be those that were exposed by the EMF. The growth average rates were obtained: 24.95 cm for the EMF, 24.87 cm for the control and 23.94 cm for plants with the MF.

3.2 Leaf Area

Leaf area was mainly given by the expansion of the foliar laminae. This did not take into an account the thickness of mesophyll (space between the epidermis of both faces of the leaves). Figure 1 shows the behaviour of this variable in two stages. Initially, high values of LA occurred in plants which were exposed to the EMF. This behaviour had a variation at the end of the study, being the MF those that induced a high LA. This can be more related to expansion processes of the foliar laminae along with accumulation processes.

3.3 Fresh and Dry Matter

The fresh and dry matter values showed that these were more stimulated when they were applied on a vegetal material growing with the MF. When determining the ratio between the fresh matter and dry matter, it was evident that this is more significant for the EMF exposed plants and control plants. In addition, Figure 2 showed that the highest values of dry matter at the end of cycle were occurred in the plants which were exposed to the EMF

Table 1: Growth Indices used in the physiology of plant and crop, adapted of Santos et al. (2010)

Growth rate	Symbol	Instantaneous value	Average value in a time interval (T2-T1)	Units
Relative Growth Rate	RGR	$\frac{1}{w}\frac{dw}{dt}$	$RGR = \frac{(Ln\,W2 - Ln\,W1)}{(T2 - T1)}$	g/gd
Net Assimilation Rate	NAR	$\frac{1}{LA}\frac{dw}{dt}$	$NAR = \frac{\frac{(W2 - W1)}{(T2 - T1)}}{\frac{(LnLA2 - LnLA1)}{(LA2 - LA1)}}$	g/cm^{2}d
Leaf Area Index	LAI	$\frac{LA}{FA}$	$LAI = \frac{\frac{(LA2 + LA1)}{2}}{\frac{1}{FA}}$	Dimensionless according to the units
Growth rate	**Symbol**	**Instantaneous value**	**Average value in a time interval (T2-T1)**	**Units**
Crop Growth Rate	CGR	$\frac{1}{FA}\frac{dw}{dt}$	$CGR = \frac{1}{FA} \times \frac{(W2 - W1)}{(T2 - T1)}$	g/cm^{2}d
Absolute Growth Rate	AGR	$\frac{dw}{dt}$	$AGR = \frac{W2 - W1}{T2 - T1}$	g/d
Leaf Area Duration	LAD	-	$LAD = \frac{(LA2 + LA1) \times (T2 - T1)}{2}$	cm/d
Specific Leaf Area	SLA	$\frac{LA}{DL}$	$SLA = \frac{\frac{LA2}{W2} + \frac{LA1}{W1}}{2}$	cm^2/g

(dw/dt= Derived of the function, LA=leaf area, FA= area of the floor, DL= dry mass foliar, T= time, W= dry mass).

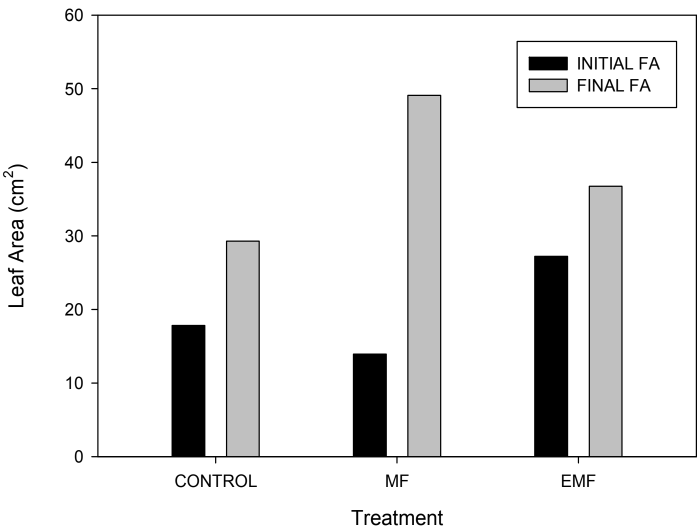

Figure 1: Expression of leaf area at two evaluation stage

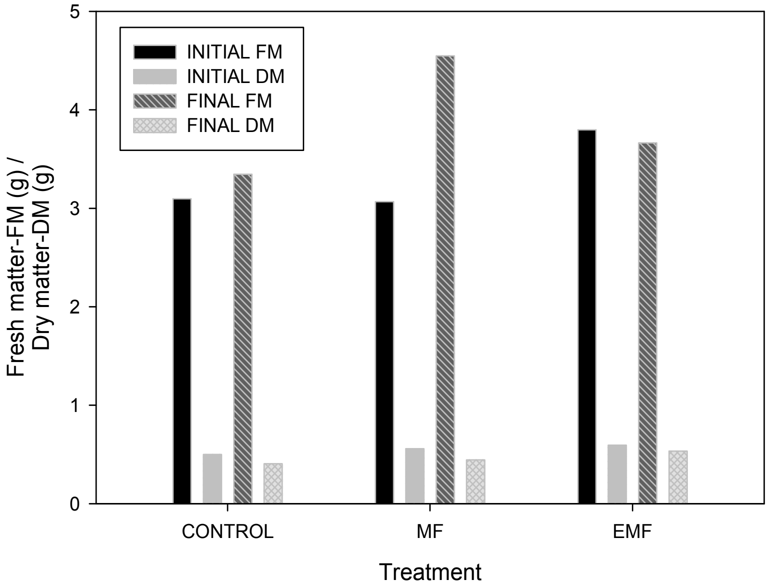

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Figure 2: Biomass behaviour during the study

3.4 Chlorophyll content and carotenoids

When analysing the figure 3, one can see that the plants treated with the EFM had a high content of chlorophyll and carotenoids. This may be related with a high efficiency of pigments synthesis processes. When there is a high content of active pigments, it establishes a direct relation with the development of the photosynthesis. This allows the formation of macromolecules such as the polysaccharides and the strengthening of cellular structures.

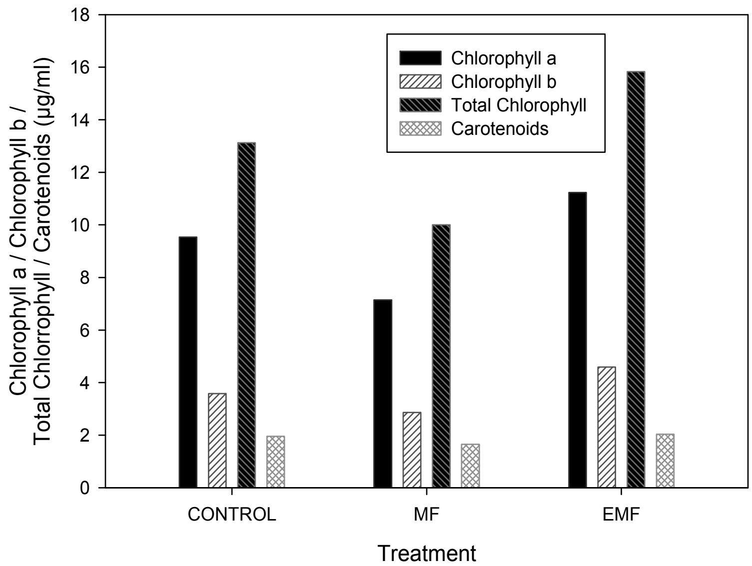

Figure 3: Content of photosynthetic pigments and carotenoids

3.5 Analysis of growth and development indices

The table 2 presents a quantitative approximation based on indicators that allow both the description and interpretation of the behaviour of plants that grew under controlled environment. These measures showed a significant difference between different treatments. The electromagnetic fields have had the highest values. It should be noted that the NAR was the variable with the highest difference with regard to the control and the magnetic field. The maximum values of NAR were translated in a higher photosynthetic efficiency and therefore a high biomass accumulation

Table 2: Physiological indices

Growth rate	Units	Control	Magnetic Field	Electromagnetic Field
RGR	g/gd	0.030	0.032	0.088
NAR	g/cm^2d	0.420	0.179	2.047
LAI	Dimensionless according to the units	147.26	196.96	199.90
CGR	g/cm^2d	0.0021	0.0026	0.0062
AGR	g/d	0.013	0.016	0.039
LAD	cm/d	164.93	220.60	223.88
SLA	cm^2/g	51.25	59.53	73.15

3.6 Preliminary chemical composition

The dry matter content values were reported 90% in control plants, 88.52% in the EMF and 86.95% in the MF. Everything seems to indicate that this variable is closely related to the genetic expression of the species under study or with the growth phase of the crop. Figure 4 allowed evidence the contents of the cellular wall, mainly in cellulose, hemicellulose and lignin. It seems that the treated plants with MF and EMF were deposited with low lignin contents of the cellular wall structure, which is reflected in the presence of high value of FDA (cellulose + lignin) in control plants. Similar result was obtained for the analysis FDN as its FDA fraction contains more hemicellulose.

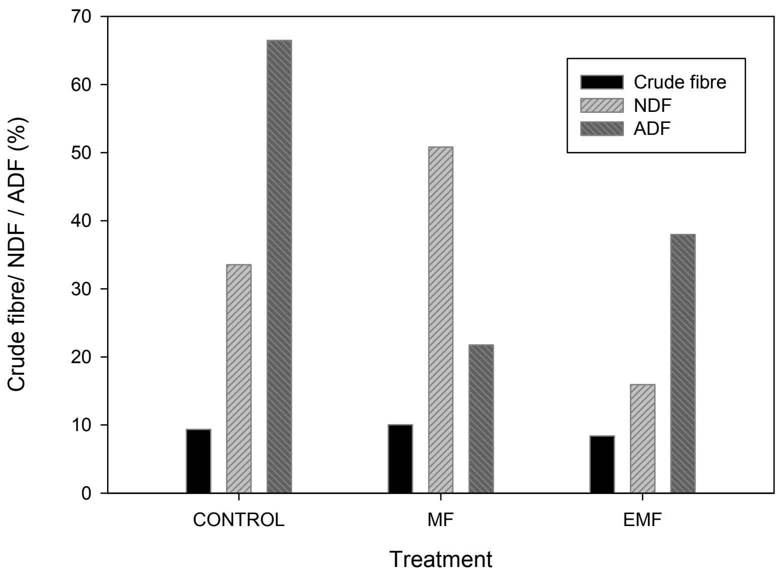

Figure 4: Crude fibre content (CF), neutral detergent fibre (NDF), and acid detergent fibre (FDA)

When making the analysis of the aqueous activity (Aw) in the figure 5 it is certain that the values are similar for different treatments and the control (0.95 for the CEM, 0.93 in CM and 0.92 for plant them Control). The rest of variables showed in the same figure also show similar behaviours, standing out the content of protein that tends to be high in the plants treated with the CEM and that can increase the nutritional value of the produced biomass.

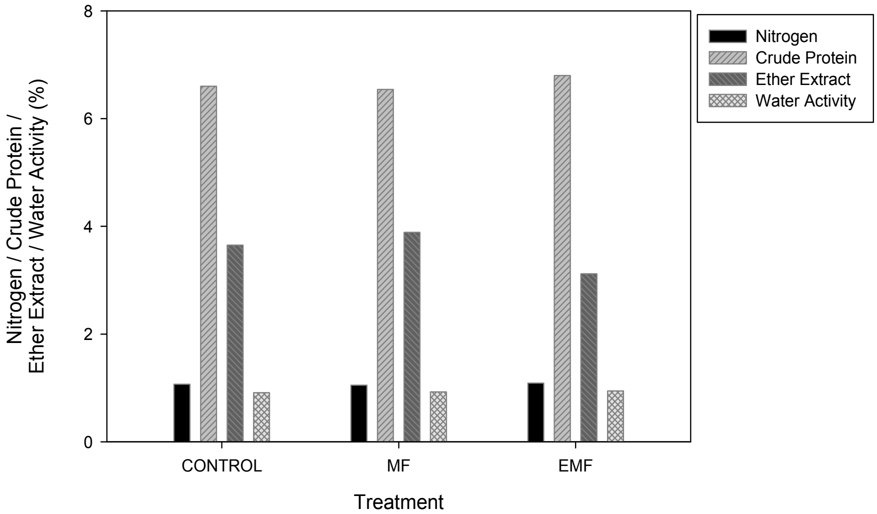

Figure 5. Composition in additional nutritional elements in the material under study

4. Conclusions

During the experiment has been found that plants exposed to EMF produced more biomass quantity together with high quality. All this was based on the bromatological analysis, especially for by the low obtained contents of NDF and ADF. The NDF and ADF contain lignin and this is associated with the quality of the biomass used mainly for animal feeding.

High contents of chlorophylls and carotenoids were obtained in plants exposed to the EMF. Chlorophylls are responsible for the synthesis processes. And this, it seems to be related to the increased production of biomass and protein synthesis obtained in the bromatological analysis.

From the performed analysis it is possible to observe the benefits (especially in the biomass production) that a large scale application of the EMF during the growth and development of corn offers.

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