Kuwait J. Sci. 46 (1) pp 43-48, 2019

Stimulating ion flow in oil palm leaves and midribs applying electrical potential difference

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Abstract

Oil palms can live for >20 years. Crop yields are affected by fertilization (a chemical aspect), growthO rate and evolution (agricultural aspects), and plant health and genetic features (biological aspects). Electrical treatment (a physical aspect) can be used to enhance growth. We applied direct currents to accelerate ion flow in oil palms. Trees aged 1–4 years were subjected to potentials of 10, 16, 25, 35, or 50V. Leaf and midrib geometries and ion levels were evaluated in an attempt to optimize oil palm productivity.

Keywords: Direct current voltage; ion effect; nutrients for oil palms; productivity.

1. Introduction

Oil palms have many uses. Not only the fruit but also almost all parts of the tree are in demand. Scientific and technological advances have increased yields. Palm products now serve as raw materials for the manufacture of various synthetic, medicinal, and household materials. Relevant studies include those of Ducrey *et al.* 1996, Gil *et al.* 2009, Jacobs *et al.* 2005, and Kaiser *et al.* 2015. These researchers used electromagnetic approaches to optimize production. Oil palm production is strongly influenced by genetics and external factors such as soil, fertilizer, water, air, sunlight, and salinity (Temizel, 2015; Al-Arbash *et al.,* 2016). Good plant growth requires rapid metabolism (Manola *et al.*, 2005; Mancuso, 2000). Long-term nutrient inputs and outputs must always be considered (Marin *et al.*, 1981; Oyarce & Gurovich, 2011).

Oil palm productivity is measured over months and years. General considerations include appropriate fertilization (a chemical aspect), fast growth (an agricultural aspect), and the strain of tree (a biological aspect). However, physical aspects are also important. Electrical technology can support all of the above aspects. Such technology has been used in other countries to grow aloe vera (Volkov *et al.*, 2014), avocados (Gil *et al.*, 2009; Oyarce & Gurovich, 2011), and pine trees (Doucry *et al.*, 1996).

Application of an electrical direct current potential to the palm tree increases ion flow and optimizes growth and development. The tree requires high levels of nitrogen (N), phosphorus (P), potassium (K), and some other elements (Lingga & Marsono, 2002; Marschner, 1995; Al-Arbash *et al.*, 2016). N is indispensable for the growth of vegetative parts, such as the stems and roots and wide deep green foliage. It also increases plant protein levels and improves the growth of soil micro-organisms. However, an excess of N can inhibit flowering and fruiting, while N deficiency is associated with young yellow leaves.

Lingga & Marsono (2002) showed that P stimulated the root and seed growth of young plants. Additionally, P aids in the synthesis of specific proteins, promotes nutrient assimilation and respiration, and accelerates flowering, seed, and fruit ripening. P deficiency is associated with slow growth, dwarfism, and stunted roots. Leaf symptoms are very diverse. Some leaves turn an abnormal glossy dark green, inhibiting fruit ripening and compromising fruit shape and color.

K is present in roots, stems, and leaves in large amounts, acting as a catalyst to accelerate biochemical reactions. K is involved in photosynthesis, transpiration, and the biochemical pathways of leaves and growth points. K is present at high levels in palm fruit, especially the stalk, mesocarp, and shells. A lack of K reduces fruit production (Marschner, 1995). Other minor chemical elements are also required for plant growth and development.

Ions flow in water through plant capillaries. Fluid flow is affected by the pressure difference from the exterior to the interior of the capillary, facilitating entry of ions into the capillaries. An electrical potential difference can be created by placing electr odes at the tops and bottoms of plants. An applied (small) voltage of a current allows cations and anions to move toward equilibrium points. Here, we measured ion flow from the ground to the leaf midrib of the palm tree. We describe the flow pattern and how it is controlled by voltage in terms of conservative geometric growth.

2. Materials and methods

We used trees 1, 2, 3, 4, and 5 years of age to which 10, 16, 25, 35, and 50 V were applied for 1 month (Figure 1). The voltages and their orientation delivered to the leaf midrib were measured using a polar electrode for 2–8 h daily. The current in and resistivity of the midrib were assessed indirectly. Chemical levels in the stem and midrib were recorded. Samples were then dried, finely chopped, and heated at 105°C for 1 h. Afterwards, the samples were placed in a desiccator for about 1 h until the weight became constant. They were weighed again, placed in glass flasks, dissolved in 10-mL amounts of concentrated nitric acid (HNO_3), and filtered through Whatman no. 42 paper. The filtered samples were dissolved in 100mL of water and subjected to atomic absorption spectroscopy at specific wavelengths. Some of the predominant nutrients are listed in Table 1. The parameters of applied voltage are shown in Table 2.

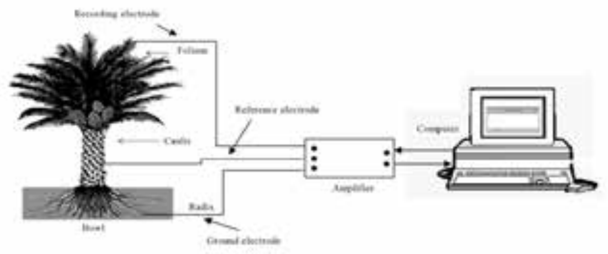

Fig. 1. Schematic of electrical voltage measurement of an oil palm tree.

Table 1. Several chemical elements of an oil palm tree*

Macro element	Ion species	Mostly found in	Deficiency	The good element source	Application for oil plants
Nitrogen (N)	NO_3^- NO_2^- NH_4^+	Leaf	2.3 % on young plant	$(NH_4)_2SO_4$	Size affects leaves, color, leaf production rate and photosynthesis
Phosphorus (P)	PO_4^{-3} HPO_2^- HPO_4^{-2} $H_2PO_4^-$	Root, Leaf	Occurs on plantations with overgrown reeds	Young plants: -TSP (Triple Super Phosphate) -DAP (Diammonium Phosphate) Adult plant: Phosphate Rock	Root growth and development of plants
Potassium (K)	K^+	Empty bunches	-	Potasium Chloride (KCl)	Affects the size and number of bunches, increases resistance to drought and disease
Magnesium (Mg)	Mg^{+2}	Leaf	Occurs in light textured soils, where acid and top soil have eroded	Kieserite ($MgSO_4 \cdot H_2O$)	Contributes to photosynthesis, phosphate metabolism, plant respiration and activation of the enzyme

Table 2. Treatment with applied voltage

Parameters*	**Oil palm tree age (year)**				
	1	2	3	4	5
V (V)	3	16	16	25	32
I (mA)	0,4	7,5	730	260	435
R (MΩ)	3.6-3.9	0.73-1	0.85-1.3	0.94-2.2	1.6-2.25

*Both treatment of electrode (+) (-) and of electrode (-) (+).

The electric potential difference was modeled using Poisson's equation. Ohm's law states that the electrical current reduces to

$$J = \sigma E \tag{1}$$

$$\nabla p(z) + J_a + J_p = \sigma E \tag{2}$$

where J, J_a, and J_p are the total current density, the treatment current density, and the natural current density, respectively. z is the ion mass, σ is the electrical conductivity; E is the electric ion flow field, and p refers to pressure. When the electric field is conservative (only one direction of motion), the electrical potential can be simplified to

$$\nabla \times \vec{E} \tag{3}$$

The potential gradient is then $\mathrm{U} = -\nabla \mathrm{V}$. is the electric potential energy and V the potential difference. V is affected by the resistance R and the electric current (I) as ΔV = RΔI. Poisson's equation was applied using Matlab. The boundary and initial conditions were the natural chemical and physical parameters of the tree.

3. Results

Nutrient levels differed between trees subjected to artificial potentials and those that were not. Figure 2 lists the values. At 1, 2, 3, and 4 years, the chlorine (Cl) and sulfur (S) levels declined significantly after treatment; those of P, calcium (Ca), and iron (Fe) increased, and those of N, magnesium (Mg), K, copper (Cu), and zinc (Zn) were unchanged.

Figures 2 and 3 show the results obtained with either voltage polarity. Cl, S, and Ca levels differed greatly, but those of N, P, and K did not. The fertilizer used was urea, perhaps affecting the results.

The electrical potential model was solved using the finite difference method. The boundary conditions of Figures 4 and 5 yield the mesh of Figure 6 and the electric potential distribution of Figure 7. In Figure 6, charge is distributed throughout the field but is more concentrated at particular points. The potential contours also exhibit regions of high charge concentration (violet in Figure 7).

4. Discussion

4.1. Experimental results

Electrical potential affects ion motion in plants (Shomer, 2003). The flow of negative ions from the soil to the leaves and midribs is electrically accelerated. In addition, the fundamental catalytic ions N, P, and K react with many other ions and elements when travelling through tissues (Shomer, 2003). Therefore, ion motion that is more rapid than under natural conditions cannot be interpreted as being composed of different streams flowing toward an electrode. Prior to application of the electrical potential, all of the ions are distributed throughout the plant. When a potential is applied and current flows, the ion flow changes for 2–8 h and natural conditions are re-established after electrical treatment ceases (for 2 × 2–8 h periods daily for 1 month). Thus, the ions cannot always be localized to particular places; diffusion may increase or decrease ion concentrations between the electrodes. After treatment, the ions will return to equilibrium, although

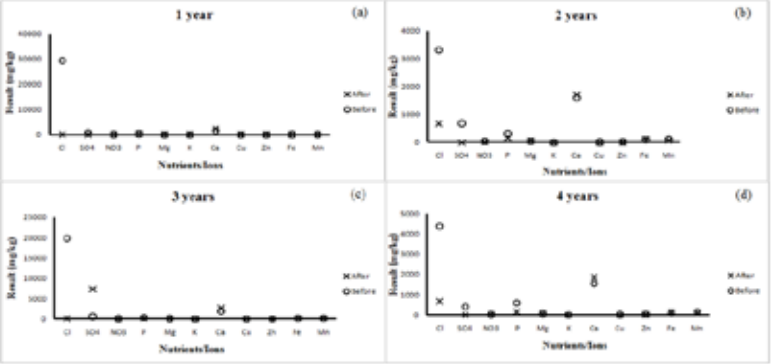

Fig. 2. Nutrients/ions in leaf for oil palm trees with age of (a) 1 year, (b) 2 years, (c) 3 years and (d) 4 years. Note: (o) indicates nutrients before treatment and (×) indicates after treatment.

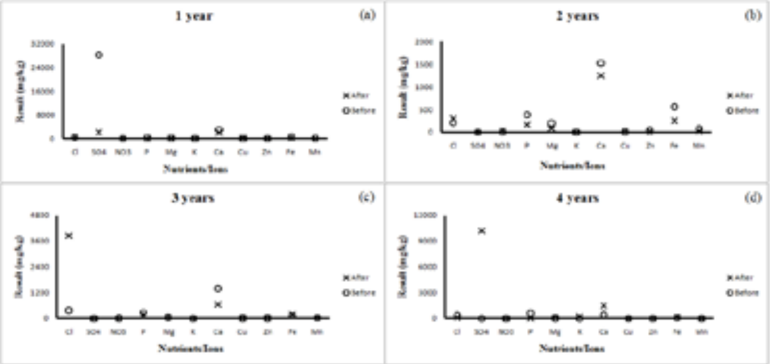

Fig. 3. Nutrients/ions in midrib for oil palm tree with age of (a) 1 year, (b) 2 years, (c) 3 years and (d) 4 years. Note: (o) indicates nutrients before treatment and (×) indicates after treatment.

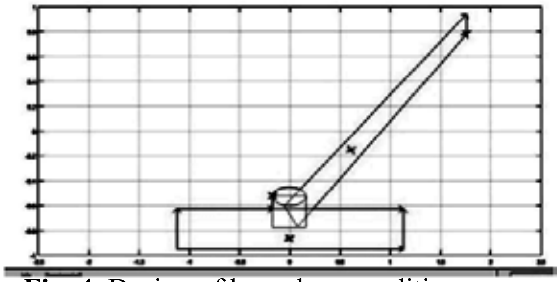

Fig. 4. Design of boundary conditions.

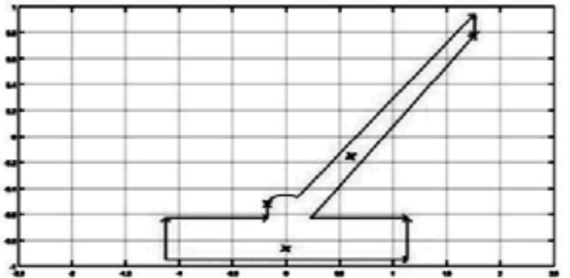

Fig. 5. Determination of boundary conditions.

Table 3. Geometrical data of midrib and leaf of oil palm tree

		Oil Palm Tree Age (in years)					
		1	2	3	4	5	
Midrib	P (mm)	1120	1340	1690	1700	2150	Treatment A
	L (mm)	15-28	16-30	17-46	68	82	
Leaf	P (mm)	297	325	310	340	560	
	L (mm)	3-28	4-30	3-26	3-27	5-36	
Midrib	P (mm)	1100	1560	1820	1640	2360	Treatment B
	L (mm)	29	32	63	65	69	
Leaf	P (mm)	295	360	365	355	560	
	L (mm)	2-27	4-30	3-26	2-26	5-39	
Midrib	P (mm)	900	1350	1500	1510	2300	Natural*
	L (mm)	15-29	15-30	18-48	17-50	23-65	
Leaf	P (mm)	290	320	340	390	550	
	L (mm)	2-28	4-32	3-25	3-26	5-36	

*Natural parameters are obtained by directly measuring length (P) and width (L) of the midrib and leaf with no applied voltage. The measured natural voltage and current of the soil are 8 to 53mV and 0.23 to 1.5mA, respectively.

some will not change in terms of position or motion.

The data do not reveal the ions that predominantly control and accelerate overall ion movement to leaves and midribs, but such movement stimulates growth of geometrically appropriate leaves. The voltage both increases and reduces the levels of various ions. The motions of ions on the root surface are inhibited or stimulated. The ions are absorbed by the roots and move to the leaves and midribs.

The geometrical parameters of the midrib and leaf are listed in Table 3, according to the electrode arrangement: (i) ground (+) and leaf/midrib (–) (namely treatment A) and (ii) ground (–) and leaf/stem (+) (namely treatment B). For some treatments the voltage treatment varied according to plant age, electrode location, and resistance value (R value).

However, these alterations do not change the behavior of the system because the electric current can be controlled. The sizes of leaves and midribs increased after treatment, yet these changes were not affected by electrode polarity. Although some leaves and midribs did not increase or decreased in size, these tissues remained the same. This shows that small changes in nutrient levels are important. Changes in the levels of N, P, K, and S were in play. The current-mediated acceleration of positive and negative ions is complicated due to the presence of macronutrients (Wargo & Skutt, 1975; Walsh & Tuckwell, 1985). The accelerated growth evident cannot be predicted by tree age, but rather by the sum of tree height and width (Table 3). Tree age, current fluctuation, current level, or resistance were particularly significant variables. The data show that artificial current affected leaf and midrib length.

4.2 Modeling of the electrical potential difference

The electrical potential distribution on two points of the palm trunk was modeled using Poisson's equation: $\nabla^2 V + q/\varepsilon = 0$. The idealized model is shown in Figures 4 to 7. The boundary conditions used in Figure 4 are distant, the potential is zero, and V = 0 (the Dirichlet condition). On the trunk, the potential gradient was zero where $\partial V/\partial n = 0$ (the Neumann boundary condition).

In Figures 6 and 7, the ions are concentrated at certain points and the leading ions do not move freely. Thus, in the natural state, ions move toward the electrodes to produce charge buildups (positive at one point and negative at another), compromising regular ion movement. Ion motion is induced by the potential (Wargo & Skutt, 1975; Walsh & Tuckwell, 1985). In effect, the ions accelerate faster than normal. However, although the model incorporates the simulation, the potential is not constantly applied in the field. When the current ceases, ion motion will increase until equilibrium is reached.

5. Conclusion

We successfully applied a direct current voltage potential to the palm leaf and midrib and measured the effects thereof on nutrient levels; the potential was applied in either orientation. The changes in nutrient levels were attributable to the electrical currents. We did not consider ion flow induced by chamber pressure or the ion cross-sections. Therefore, the particular ions involved remain unknown. The simulation shows that ions tend to flow toward the negative electrode; the positive electrode attracts negatively charged ions, distributing ion charges around electrodes of opposite charges. The addition of capacitors to polar electrodes would allow nutrient ion flows to follow the natural motion in oil palm trees.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Riau, Indonesia and the Ministry of Research, Technology and Higher Education for financial support in Research Grant in 2018.

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Submitted:13-02-2018
Revised: 27-02-2018
Accepted: 09-04-2018

تحفيز التدفق الأيوني في نخيل الزيت والعروق الوسطة في الأوراق باستخدام فرق الجهد الكهربائي

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الملخص

يمكن أن تُعمر أشجار نخيل الزيت لمدة تزيد عن 20 عاماً. وتتأثر عائدات المحاصيل بعملية التسميد (جانب كيميائي)، معدل النمو والتطور (جوانب زراعية)، وصحة النبات والسمات الوراثية (جوانب بيولوجية). يمكن استخدام المعالجة الكهربائية (كجانب فيزيائي) لتعزيز النمو. لقد قمنا باستخدام تيارات كهربائية مباشرة لتسريع التدفق الأيوني في أشجار نخيل الزيت. وقد تعرضت الأشجار التي تتراوح أعمارها من 1 – 4 سنوات إلى تيارات كهربائية بمقدار 10، 16، 25، 35 أو 50 فولت. تم تقييم هندسيات الورقة والعروق الوسطى ومستويات الأيون كمحاولة لتحسين انتاجية نخيل الزيت.