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Simulation of Time Independent Schrödinger Equation for Finite Potential Well Using the Graphical Solution Method

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ABSTRACT

This paper investigates applying the approximate method; Graphical Solution Method (GSM), to theoretically solve the Time Independent Schrödinger Equation (TISE) in one dimension for a finite square well using MATLAB. With just few lines of MATLAB coding, calculating and plotting accurate eigenvalues (energy), eigenvectors (wave functions) and the bound eigenstates are possible for the finite square well of a negative potential (depth of the well) of -400 eV and a well width of 0.1 nm for an electron confined to this quantum well. These eigenvalues, eigenvectors and eigenstates are obtained and discussed. The found energy eigenvalues and states are discrete and yield physical acceptable solutions. The even and odd solutions of the TISE are also considered. The graphical solutions for the finite potential well are shown. The locations of discrete eigenvalues for even and odd solutions are also presented. These eigenvalues are tested confirming the correct eigenfunctions. The precision of these solutions depend on well width L and on the interval dx used to integrate the equation. Exact analytical solutions for this case are obtained and compared with results from the GSM. The accuracy and the convergence of the numerical results are easily checked. The results showed that the GSM can be considered as a suitable mean for determining the one dimensional solutions for the finite square well.

محاكاة معادلة شرودنجر غير معتمدة على الزمن لبئر الجهد المحدود باستخدام طريقة الحل البياني

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الكلمات المفتاحية:
معادلة شرودنجر غير معتمدة على الزمن
بئر مربع محدود
طريقة الحل البياني
القيم الذاتية للطاقة
دوال ذاتية

الملخص

هذا الورقة تتحقق نظريا من تطبيق طريقة التقريب، طريقة الحل البياني(GSM) ، لحل معادلة شرودنجر غير معتمدة على الزمن (TISE) في بعد واحد لبئر الجهد المحدود باستخدام الماث لاب (MATLAB). بفقط عدد قليل من برامج الماث لاب، كان من الممكن حساب ورسم القيم الذاتية الصحيحة (طاقة) ، المتجهات الذاتية (دوال الموجه)، والحالات الذاتية المقيدة لبئر مربع محدود لجهد سالب (عمق البئر) بقيمة -400 eV وعرض البئر بقيمة 0.1 nm لإلكترون محصور في هذا البئر الكمي. تم مناقشة هذه القيم الذاتية، المتجهات الذاتية والحالات الذاتية المتحصل عليها. القيم الذاتية وحالات طاقة المتحصل عليها منفصلة وتنتج حلول فيزيائية مقبولة. ايضا تم حساب الحلول الزوجيه والفردية لمعادلة شرودنجر غير معتمدة على الزمن. تم توضيح الحلول البيانية للبئر محدود الجهد. مواقع القيم الذاتية المنفصلة للحلول الزوجية والفردية ايضا تم عرضها. تم اختبار هذه القيم الذاتية لتأكيد الدوال الذاتية الصحيحة. دقة هذه الحلول يعتمد على عرض البئر L والفترة dx المستخدمة لتكامل المعادلة. تم ايجاد الحلول التحليلية الدقيقة لهذه الحالة ومقارنتها مع نتائج طريقة الحل البياني. (GSM) دقة وتقارب النتائج العددية يمكن فحصها بسهولة. النتائج بينت ان طريقة الحل البياني يمكن اعتبارها وسيلة مناسبة لحساب حلول البعد الواحد للبئر المربع المحدود.

Introduction

Peanut (*Arachis hypogaea* L.) is an annual legume crop that provides food and helps maintain soil fertility through nitrogen fixation [1]

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The symbiotic relationship between leguminous crops and rhizobium bacteria is becoming increasingly important in the agriculture world, as this potentially leads to more sustainable agricultural systems, reducing requirements for chemical fertilizer, enhancing residual benefits to subsequent crops and increasing crop yields [2]. Globally, the consumption of peanuts is increasing at a rate of around 3 % per annum. In 2011/12, peanut production in the world was 35 million (*United States Department of Agriculture)*. China, India, and the USA are the main producers, growing 16.0, 5.5, and 1.7 million tons, respectively, accounting for 45 %, 16 % and 5 % of the world's total respectively [3].

Biochar is a carbon-rich product of burning biomass in the absence of oxygen (pyrolysis), and its potential to improve soil fertility and mitigate climate change has been recognized globally [4][5]. Biochar has a high proportion of recalcitrant C with hundreds to thousands of years of durability, making it a potentially effective soil C sink [6]. Biochar also has unique properties to improve soil productivity [7][8]. The porous physical structure of biochar induces a greater sorption capacity to conserve soil moisture and nutrients. The alkaline nature of many biochars makes such materials especially suitable for improving acidic soil [9]. Biochar made from specific feedstocks (e.g., manure) has high nutrient content and promotes plant growth [10][11][12].These agronomic benefits have been well demonstrated [13][14][15] especially on marginal and degraded soils [16][15]. However, the fundamental mechanisms by which biochar affects crop growth are insufficiently understood [17]

Recently, biochar has become increasingly the subject of scientific and public interest. It is claimed that biochar can improve soil properties and agronomic performance, inspired by investigations of Terra Preta in Amazon [18]. Several studies showed that the biochar application to soil can influence soil properties (e.g. water holding capacity, pH, and microbial activity) [19][20] Further studies observed enhanced nutrient uptake by plants after biochar application [14]. In contrast, some authors reported no significant effects of biochar on soil properties, plant nutrition, or biomass production after biochar application under field conditions [21]. Until now, most biochar studies were performed with pure biochar under laboratory or greenhouse conditions or in tropical environments [15]. Biochar studies under field conditions often show contrasting results to those conducted in the laboratory [22]. Therefore, we conducted a field experiment to quantify the effects of biochar on plant growth when combined with organic fertilizers (goat manure). We amended sandy soils using biochar created from woody material and examined the performance of peanuts on biochar-amended soils in situ experiments.

Material and methods

Location and soil

The field trial was conducted on the farm of Agriculture Facility, Sebha University, Libya. Latitude 26º58'21,58", Longitude 14º 26' 23,85". The experimental land was not cultivated before. The soil is classified as sandy soil (American soil taxonomy; sand 92 %, silt 6.4 %, clay 3.2 %). The mean annual precipitation is 22 mm and the mean annual temperature is 30ºC (data source: World Weather Online https://www.worldweatheronline.com/). During our study though, the soil site had not received any rainfall.

Experimental design and treatments

The experiment was established in Summer 2022 and was in a randomized complete block design RCBD with three replicates. The treatments were controlled, 10 t ha^{-1} GM, 2 % B + 10 t ha^{-1} GM, and 5 % B + 10 t ha^{-1} GM. Biochar was made in a hole on a micro-scale, ground into a powder of less than 0.5 mm particles, and stored in a sealed plastic bag until use. Biochar at the desired rates (2 or 5 % by weight) was hand applied to the soil surface and till to a depth of 15 cm. Goat manure was obtained from a private farm, and composted for six months under optimum conditions of air and moist content. Other cultural operations were done as per recommendation and crop requirements. The soil samples of the experimental sites were taken at a depth of 30 cm. Some physical and chemical analyses are presented in Table (1): -

Table 1. Chemical and physical properties of soil site.

Sand	Salt	Clay	pH	EC	O.M	N	P	K
%				dS m^{-1}	%	ppm		
93.65	3.64	2.80	7.2	0.48	0.44	9	3	80
Sandy			Neutral	Very low	Low	Low	low	low
Bouyoucos Hydrometer method (1952)			Jackson (1958)	Wilcox (1950)	Walkey and Black (1934)	Subbaih and Asija (1956)	Olsen *et al*. (1954)	Toth and Price (1949)

The data on morphological, physiological, and yield characteristics were collected. First, we measured plant height (cm), the number of leaves, and the number of branches after 40 and 80 DAS. Then, the number of flowers and the number of pods were taken. Finally, plants were harvested and weighed for the pods, and the biomass.

Statistical analysis

All data were analyzed by statistical analysis software (SAS) version 9.4. To test for significance, we use the analysis of variance (ANOVA). Treatment means were separated for significance using the Critical Difference (CD) test at P = 0.05.

Results and dissection

Effect of biochar on emergence percentage

The effects of biochar on emergence percentage were found not significant as shown in Table (2), It seems that biochar has no effects on the emergence percentage of peanuts specifically, which agreed with [23]. However, a study showed that the emergence percentage of *Robinia pseudoacacia* L. seeds in biochar-treated soils reached a peak of 2 to 3 days faster than the control [24]. These results were compatible with a study done by [25] that observed the emergence percentage of tomato seeds show 2 to 3 days faster with biochar-amended soil (data not published). Many studies have found no harmful effects of biochar on seed germinations or emergence percentage even with its nanoparticles [23].

Effect of biochar on peanut growth parameters

The growth indices of peanuts were collected two times (40 and 80 days after planting). Results are shown in Tables 2 and 3. Plant height was significantly affected by biochar addition at both measurements. The greatest increase in plant height relative to control was 58 % and 63 %with the addition of 5 % B + 10 t ha^{-1} GM after 40 and 80 days respectively. The number of branches was significantly affected by biochar addition as well, with the maximum branches noticed at 5 % B + 10 t ha^{-1} GM. On the other hand, no significant increase was seen in the number of leaves indicator. This may reflect an improvement in root morphology [26][27], or increase in nutrient retention and water-holding capacity [28].

Table 2. Effect of biochar and organic manure on growth parameter of peanuts after 40 DAS

Treatment	Emergence percentage	Plant height	Number of branches	Number of leaves
Control	4.000	14.333[d]	3.000[b]	4.000
10 t ha^{-1} GM	3.666	18.666[c]	3.333[b]	3.666
2 % B + 10 t ha^{-1} GM	4.000	20.333[b]	3.666[b]	4.000
5 % B + 10 t ha^{-1} GM	4.333	22.666[a]	4.666[a]	4.333
F-test	NS	S	S	NS

CV %	26.676	3.167	10.169	24.653
CD (P = 0.05)	-	1.206	0.745	-

NS = nonsignificant, S = significant, CV= coefficient of variation and CD = Critical Difference

Table 3. Effect of biochar and organic manure on growth parameter of peanuts after 80 DAS

Treatment	Plant height	Number of branches	Number of leaves	Number of flowers
Control	16.333^{d}	4.333^{c}	14.666^{d}	1.666^{c}
10 t ha^{-1} GM	21.333^{c}	5.666^{b}	18.333^{c}	2.333^{c}
2 % B + 10 t ha^{-1} GM	24.333^{b}	6.333^{ab}	20.333^{b}	4.333^{b}
5 % B + 10 t ha^{-1} GM	26.666^{a}	7.000^{a}	23.666^{a}	6.666^{a}
F-test	S	S	S	S
CV %	3.445	6.387	2.296	16.026
CD (P = 0.05)	1.529	0.745	0.880	1.206

A number of branches were significantly affected by biochar in both measurements (after 40 and 80 DAS) as shown in Tables 2 and 3. Treatment of 5 % B + 10 t ha^{-1} GM gave the uppermost number of branches and considerably varied from control and manure treatments. Many studies have also reported that biochar affected plant growth in particular the number of branches [29][30][31].

A number of leaves were not affected by biochar addition in the first measurement (after 40 DAS), but the effect was significant at the second measurement (after 80 DAS). 5 % B + 10 t ha^{-1} GM gave the highest number of leaves and differ significantly from other treatments. This enhancement in plant growth was also reported by [32][33][30][34]

The number of flowers was high in a 5 % B + 10 t ha^{-1} GM treatment and statistically differ from other treatments. 2 % B + 10 t ha^{-1}GMtreatment had also changed the number of flowers and gave the second count of flowers and statistically differ from control and manure treatments Table (3). It is noticeable that biochar could enhance plant flowering as a result increase plant yield. Many other studies have reported that biochar had an increase in plant growth and flowering [29][34][35].

Effects of biochar on Peanut yield parameters

The number of pods was significantly affected by biochar Table 4. The addition of 2 % and 5 % biochar increased peanut yield by 50 % and 82 % respectively compared to the control. Without biochar, goat manure increased peanut yield by 20 %. [35] reported that 10 t ha^{-1} biochar application combined with organic fertilizer in infertile soil increased peanut yield by 50 %. Similarly, the biochar application rate of 10 t ha^{-1} significantly increased peanut pod yield by 23 % compared to the inorganic fertilizer treatment [36]

Table 4. Effect of biochar and organic manure on yield attribute, yield of peanut crop

Treatment	Number of pods	Weight of pods q/h	Straw yield q/h	Harvest index
Control	9.666^{d}	11.41^{d}	30.90^{d}	37.00^{c}
10 t ha^{-1} GM	19.000^{c}	14.29^{c}	34.50^{c}	41.43^{b}
2 % B + 10 t ha^{-1} GM	22.333^{b}	17.12^{b}	39.60^{b}	43.23^{ab}
5 % B + 10 t ha^{-1} GM	26.666^{a}	20.80^{a}	45.90^{a}	45.46^{a}
F-test	S	S	S	S
CV %	7.237	2.737	2.783	3.597
CD (P = 0.05)	2.808	0.865	2.098	2.994

The weight of pods as shown in Table 4, was significantly affected by biochar. As seen with the number of leaves, number of branches, and the number of flowers, 5 % B + 10 t ha^{-1} GM gave the greatest number of pods. The result is in agreement with [35][37][30].

The straw yield was also affected by biochar **(**Table 4). The addition of 5 % B + 10 t ha^{-1} GM cause a 50 % increase in straw yield compared to the control. Biochar enhanced most of the growth and yield parameters measured which was also noticed by other studies [36][38][31][39][22][27].

The harvest index was high in 5 % B + 10 t ha^{-1} GM treatment and vary significantly from other treatments Table 3. Adding less biochar (2 %) would not increase harvest much when 10 t ha^{-1} GM was added. In general, biochar improved plant yield and production here and elsewhere [32][37].

Conclusion

The objective of this study was to evaluate the effects of biochar in combination with goat manure on peanut yield in sandy soil. Results showed that biochar had the potential to improve peanut yield when organic fertilizer was practiced for growers. Our study conclude that a high dose of biochar (5%) gave the highest peanut yield which increased the yield by 82 %. In connection with this study, many studies reported that biochar increased plant productivity, with an average yield increase between 10 % to 42 % [40]. The following study should determine if applying more levels of biochar (for example 10 % and 20 %) would increase peanut yield.

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