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Relationship Between Soil Apparent Electrical Conductivity and Cassava Plant (TMS 98/0505) Growth at Early Stages on Sandy Loam Soil

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Abstract

A thorough study of major soil properties such as soil Apparent Electrical Conductivity (EC_a) which influences plant productivity is of utmost importance if losses in output and input cost from a farm are to be minimized. Soil EC_a is a measure of the soil's ability to conduct electric current as well as its nutrient contents. It is affected by a combination of several soil properties such as soil water content, organic matter, clay and mineralogy, bulk density, soluble salts etc. This study discusses the relationship between soil EC_a and Cassava plant growth on sandy-loam soil. Electrical resistivity measurements were conducted on cassava field using Miller 400D resistance meter. EC_a were calculated and cassava plant growth parameters such as plant height (H_C) and number of sprouted stem (N_S) were measured. EC_a readings were correlated with H_C and N_S. Regression analysis was conducted on all significant relationships.

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The results indicated that cassava plants at their early growing stages on sandy-loam soil are significantly influenced by soil EC_a at 0 – 30 cm depth (EC_{as}) with **r =** 0.457 and R^2 = 0.320 (Cubic function). EC_{as}= 0.441 – 6.211 mS/m was observed to effectively support quality and better cassava plant growth than EC_{as} < 0.441 mS/m. The results obtained from this study provide the farmers with EC_a range suitable for cassava plant growth on a sandy-loam soil and can also help them predict the plant growth at early stages. It further helps them to understand the effect of EC_a to cassava plant production.

Keywords: Apparent Electrical Conductivity; Cassava plant growth; Sandy-loam soil; Regression analysis; Correlation analysis.

1. Introduction

Delineating the influence of soil EC_a on plant growth and yield is an essential matter for precision agricultural management and development. Soil EC_a is a measure of the soil's ability to conduct electric current due to the flow of salt in form of nutrients within the soil. Hence, soil EC_a measurement can be considered as a measure of soil nutrient content. Due to its rapidity and measurement ease, it had been in continuous use to acquire soil information which is crucial for optimizing crop yields and identification of soil properties affecting growth and yield in farm fields. An insight into the relationship between soil properties, plant stand and yield potential will pave the way for maximizing the product through an appropriate decision making strategy [1].

Soil EC_a is a reliable and most frequently used measurement to characterize field variability for application to precision agriculture due to its ease of measurement and reliability [2, 3]. Several researchers have reported that EC_a correlates to crop yield and can therefore be used to estimate yield from farm soils with few exceptions. In a study of EC_a and yield, a substantial correlation between EC_a and corn/soybean yield was found for five out of the six cases considered in the study [4]. In another experiment, a positive correlation between EC_a and corn yield was also observed [5]. Further studies have revealed that although crop yield inconsistently correlates with soil EC_a, there are specific instances where yield correlates with EC_a [6]. In instances where yield correlates with EC_a, spatial measurement of EC_a can be used in precision agriculture context [7]. In another study, soil EC was observed to have no direct effect on crop yield. The experiments documented no correlation between shallow EC_a and crop yield, even if the soil properties were indicative of productivity [8]. A significant correlation (r = 0.72) was again observed between soil EC_a and maize dry weight for shallow depth (0 - 30 cm) and r = 0.85 for deep depth (0 – 90 cm). Moderate correlation (r = 0.59) was also observed between soil EC_a and maize biomass dry weight for shallow depth and r = 0.65 for deep depth [9]. In a peat area experiment, both low and high EC_a values have been shown to be associated with a decrease in rice yield productivity, but the mid-range of the EC_a values correspond to high rice yield in both deep EC_a and shallow EC_a conditions [1]. In a study of the relationship between EC_a with pomological properties and yield in different apple varieties, a strong relationship (r = 0.94) between yield and EC_a in 'red chief' variety was found and the same value was also observed for yield per trunk cross sectional area (TCSA) and soil EC_a in 'Jonagold' variety [10].

The inconsistent relationship between yield and EC_a is due to complex interaction of soil properties that influence the EC_a measurement and complex interaction of other factors such as biological, anthropogenic and meteorological factors [3]. In addition, crop yield appears to be dependent on crop, growing season, precipitation and incidence of fallow, hence causing inconsistent relationship between yield and EC_a [11, 5].

Amidst those contradicting results, EC_a is one sensor based measurement parameter that has shown promise for precision farming [1]. Therefore, EC_a is a valuable agricultural tool with that ability to estimate and predict plant yield variability on soils even before planting. It also provides spatial information for soil quality assessment and precision agriculture applications which in turn can help improve management decisions with respects to delineation of site specific management units, increase or decrease in agrochemical inputs and costs [7].

The main aim of this study is to determine the relationship between cassava plant growth and soil EC_a variability on sandy-loam soil. It also intends to examine the range of EC_a that is good enough to support quality cassava plant growth.

2. Materials and methods

2.1 Material studied

The material studied in this work is cassava plant (Manihot Esculenta Crantz) TMS 98/0505. Cassava is an industrial crop [12] and its production is limited by soil fertility status [13]. Cassava being an important calorie crop in tropical Africa [14] is one of the most widely grown crops in the world [15]. Therefore it requires thorough study in order to ensure its quality, maximum growth and yield.

2.2 *Study area description*

The study was conducted at an experimental field planted with cassava plants (Manihot Esculenta Crantz, TMS 98/0505) in an area of about 0.5 ha within the farm settlement area of Federal College of Education, Osiele, Abeokuta, Nigeria. The study field duly geo-referenced with the aid of a global positioning system (Garmin etrex 10) has its upper part located between latitudes 7º 11.920′ N and 7º 11.940′ N, and longitudes 3º 26.529′ E and 3º 26.539′ E. The lower part of the field lies between latitudes 7º 11.889′ N and 7º 11.909′ N, and longitudes 3º 26.591′ E and 3º 26.601′ E. Osiele has an altitude 148 km in Odeda Local Government Area, Abeokuta, Ogun State, Nigeria. The mean annual rainfall is about 80 mm, ranging between 0.5 mm and 81.1 mm while the average temperature ranges between 16º C and 38º C. The field is made up of two sections, 1 and 2. Section1 is an area that has been used in the preceding years for maize and cassava cultivation while section 2 is an area that has been left uncultivated for years. Both sections of the field are made up of sandy-loam soil.

2.3 *Soil EC_a measurement*

Electrical resistivity, ER_a (conductivity) measurements were conducted on the cassava field four months after planting (October, 2013), using Miller 400D resistance meter. The resistance meter uses four electrodes and measures the average electrical resistance of the soil to a depth equal to the electrode spacing using the principle of Wenner electrode array configuration as shown in Fig. 2.

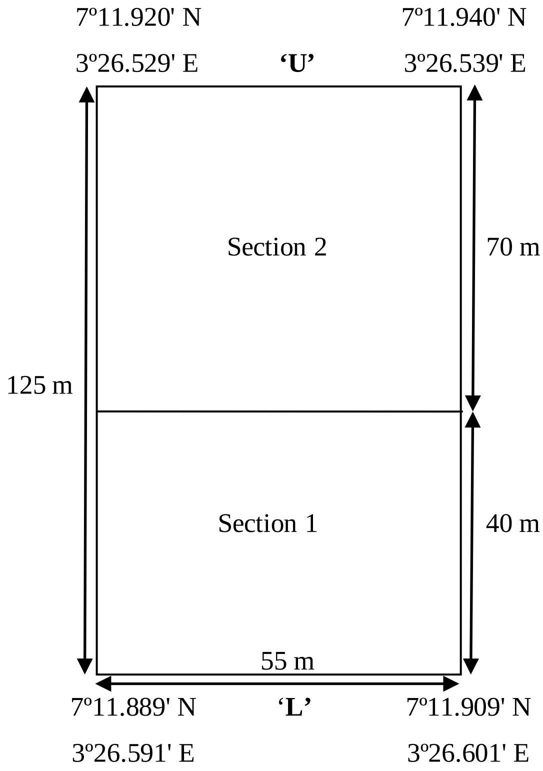

Fig. 1: Schematic diagram of the study field layout. 'U' and 'L' represent the upper and lower part of the study field respectively.

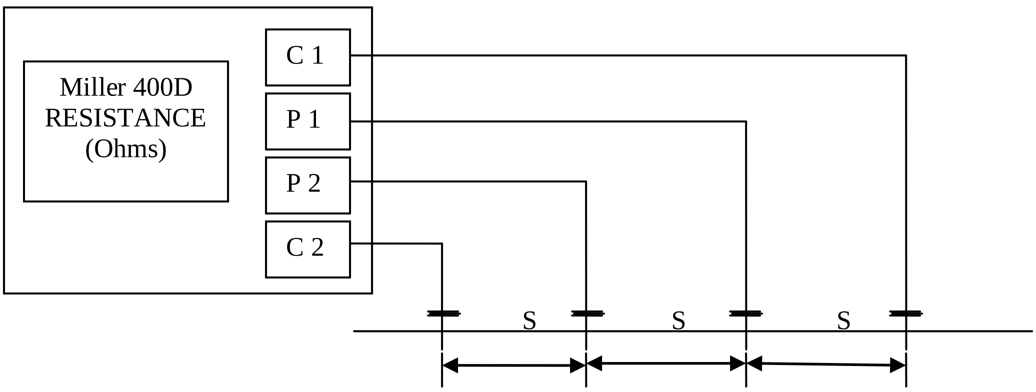

Fig. 2: Schematic diagram of Miller 400D resistance meter in Wenner electrodes array: C_1 and C_2 represent the current electrodes, P_1 and P_2 represent the potential electrodes, and S represents the spacing between the electrodes.

The electrodes (C1, C2, P1, and P2) are driven down into the soil and are equally spaced along a line. The outer electrodes C1 and C2 serve as the current electrodes, while the inner electrodes P1 and P2 serve as the potential electrodes. The actual point measured in the soil using the meter is the midpoint between the P1 and P2 electrodes. The apparent electrical resistivity ER value was calculated using equation (1).

$$ER_a = 2\pi SR \tag{1}$$

Where:

ER_a = soil apparent electrical resistivity (in Ωm) $\pi = 3.142$

S = electrode spacing (in metre) R = average soil electrical resistance

The soil apparent electrical conductivity, EC_a in ($\Omega^{-1}m^{-1}$ or S/m) was obtained by inversing the apparent electrical resistivity as shown in equation (2).

$$EC_a = ER_a^{-1} = (2\pi SR)^{-1} \tag{2}$$

All ER_a (EC_a) measurements were taken horizontally along the rows at 5 m separation distance and at electrode spacing of 30 cm and 90 cm. This implies that EC_a data were collected from a total number of 26 cassava rows (12 rows in section 1 and 14 rows in section 2) on the study field. Eight (8) EC_a data were collected per row. ER_a (EC_a) measurements were taken at depths 0 - 30 cm and 0 - 90 cm directly below the plants and soil surface. EC_a taken at depth 0 - 30 cm is called shallow apparent electrical conductivity (EC_{as}) while that taken at depth 0 - 90 cm is called deep apparent electrical conductivity (EC_{ad}).

2.4 *Collection of Cassava growth data*

Growth parameter such as cassava plant height, H_C and number of sprouted cassava stem, N_S were measured on cassava plants whose soil EC_a has also been measured. The cassava heights were measured using a measuring tape while the number of sprouted stems were counted and recorded.

2.5 *Data analysis*

Descriptive statistics such as minimum, maximum, mean and standard deviation were used for analyzing all the collected data. Correlation and regression analysis were also used. All statistical analysis was implemented with the aid of SPSS statistical software version 19.0.

The standard deviation, δ was used for expressing deviation on a relative basis for the different parameters compared. Pearson's product moment correlation coefficient, r analysis was used to investigate and analyze the nature and strength of the relationship between the soil EC_a and cassava growth parameters. Multiple regression analysis (linear and curve estimation techniques) was performed on all soil EC_a and cassava growth parameters. The regression analysis has a regression coefficient (R^2) which measures how well the regression line approximates the real data points. An R^2 of 1.0 indicates that the regression line perfectly fits the data. The soil

EC_a and cassava growth parameters based on the values of their correlation coefficient, r were fitted to linear, logarithm, inverse, quadratic, cubic, power and exponential functions. The function with the best regression coefficient, R^2 was then used to produce a relationship between the soil EC_a and cassava growth parameters.

3. Result and discussion

3.1 *Spatial variability of soil EC_a*

A total of 112 EC_a data each were obtained for EC_{as} and EC_{ad} in section 2. In section 1, a total of 92 EC_a data each (instead of 96 EC_a data) were obtained for EC_{as} and EC_{ad}. This is as a result of some missing cassava stands. The results are as shown in Table 1.

Table 1: Soil EC_a values in all sections of the study area

Section	N	EC_{as} (mS/m)				EC_{ad} (mS/m)			
		Min	Max	Mean	SD	Min	Max	Mean	SD
1	92	0.189	1.695	0.441	0.212	0.011	0.768	0.234	0.201
2	112	0.601	6.211	1.217	0.686	0.019	1.510	0.112	0.189

From the results in table 1, section 1 had the lowest EC_{as} (EC_a at shallow depth 0 – 30 cm) in the study area with minimum, maximum and mean EC_{as} values of 0.189, 1.695 and 0.441 mS/m respectively, while section 2 had the highest EC_{as} with minimum, maximum and mean EC_{as} values of 0.601, 6.211 and 1.217 mS/m respectively. There was a large difference (0.776 mS/m) between the mean EC_{as} of section 1 (0.441 mS/m) and mean EC_{as} of section 2 (1.217 mS/m). This implies that soil EC_{as} is highest in areas that have been left fallowed for years and lowest in areas that have been under continuous cultivation for years. The higher EC_{as} in section 2 might be because the area had been left uncultivated for years so nutrient contents at the topsoil may have built up and thus leads to higher soil conductivity at shallow depth. The observed lower EC_{as} in section 1 might have been because the area had been under cultivation for years thus nutrient contents at the topsoil may have reduced due to continuous use by plants.

Unlike the soil EC_a, EC_{ad} was generally very low across the whole sections of the field. However, the EC_{ad} is slightly higher in section 1 (with mean EC_{ad} value of 0.234 mS/m) than in section 2 (with mean EC_{ad} value of 0.112 mS/m). Section 1 had minimum and maximum EC_{ad} values of 0.011 and 0.768 mS/m respectively, while section 2 had minimum and maximum EC_{ad} values of 0.019 and 1.510 mS/m respectively. As shown by the results, the minimum and maximum EC_{ad} values in section 1 are lower than minimum and maximum EC_{ad} values in section 2 yet the mean EC_{ad} in section 1 is higher than the mean EC_{ad} in section 2. This is because section 1 was dominated by EC_{ad} which are slightly higher in value than the EC_{ad} which dominates section 2. However, there was a small difference (0.122 mS/m) between the mean EC_{ad} (0.234 mS/m) in section 1 and mean EC_{ad} (0.112 mS/m) in section 2. In other words, areas that have been under cultivation for years tend to have a slightly higher EC_{ad} than areas that have been left fallowed for years.

The observed very low EC_{ad} in section 2 might be because the area had been uncultivated for years so it's been covered with bushes. This bushes may have greatly reduced effective percolation of nutrients, salts or clay from the soil surface to the deeper soil depth and consequently a reduced conductivity at the deeper soil depth. The slightly higher EC_{ad} in section 1 might be because the area was under continuous use and exposure over years. Therefore a larger percentage of nutrients and salts compared to section 2 might have percolated into the deeper soil depth. Consequently, this may have lead to the observed slightly higher conductivity (EC_{ad}) in the section.

Table 2: Cassava plant growth in all sections of the study area.

Section	N	Cassava plant height, H_C (m)				Number of sprouted stem, N_S			
		Min	Max	Mean	SD	Min	Max	Mean	SD
1	92	0.15	1.31	0.72	0.220	1	5	2.25	1.00
2	112	0.32	2.29	1.01	0.308	1	5	2.40	1.01

3.2 Variability in Cassava plant growth

In Table 2, the Cassava plant height (H_C) across the field ranged from 0.15 m to 2.29 m. Section 2 of the study area had the highest cassava plant height with minimum, maximum and mean heights of 0.32, 2.29 and 1.01 m respectively, while section 1 had the lowest cassava plant height with minimum, maximum and mean heights of 0.15, 1.31 and 0.72 m respectively. Since the cassava (TMS 98/0505) plants at full maturity (in 12 months) can grow to a height of about 2 m, then the mean height in section 1 even though is lower than the mean height in section 2, is still good for cassava plants at 4 months.

The observed higher plant height in section 2 might be due to higher EC_{as} in the area. This higher EC_a may have resulted from availability of more and better soil nutrients due to the fact that the area had been uncultivated for years. The observed lower plant height in section 1 might be due to lower EC_{as} in the area. This lower EC_{as} may also be due to poor soil nutrients' availability in the area because it had been under continuous cultivation for years. The trend of observed results in Tables 1 and 2 suggests that EC_{as} correlates to cassava height better than EC_{ad}. This may also be because the plants had not develop roots long enough to tap considerable amount of nutrients from the deep soil depth.

The number of sprouted cassava stem (N_S) ranged from 1 to 5 with mean value ranging from 2.25 to 2.40. Even though there was a small difference (0.15) between the means, section 2 seems to have a better number of sprouted cassava stem (mean N_S = 2.40) compared to section 1 with mean N_S = 2.25. The same reasons responsible for lower cassava plant heights in section 1 and higher cassava plant heights in section 2 might also be responsible for the observed difference in the mean N_S in section 1 and 2.

3.3 *Relationship between EC_a and Cassava plant growth*

The correlation coefficients for cassava plant height, H_C and number of sprouted stem, N_S to soil EC_{as} and EC_{ad} are given in the table 3.

Table 3: Correlation coefficients (r) for soil EC_a (in mS/m) and Cassava plants growth.

Parameter	Correlation coefficient, r	Remarks
$EC_{as} - H_C$	0.457[d]	Significant
$EC_{as} - N_S$	- 0.014	Non-significant
$EC_{ad} - H_C$	- 0.048	Non-significant
$EC_{ad} - N_S$	0.000	Non-Significant
$H_C - N_S$	0.184[d]	Significant
$EC_{as} - H_CN_S$	0.232[d]	Significant
$EC_{as} - {}^{H_C}/_{N_S}$	0.255[d]	Significant
$EC_{ad} - H_CN_S$	- 0.029	Non-Significant
$EC_{ad} - {}^{H_C}/_{N_S}$	0.032	Non-Significant
$EC_{as} - EC_{ad}$	- 0.124[c]	Significant

[c]: Correlation is significant at 0.05 level (1-tailed and 2-tailed)

[d]: Correlation is significant at 0.01 level (for both 1-tailed and 2-tailed)

From Table 3, plant height (H_C) was significantly correlated to EC_{as} with r = 0.457[d] but was non-significantly correlated to EC_{ad} with r = - 0.048. This implies that H_C was majorly influenced by EC_{as} rather than EC_{ad}. The number of sprouted cassava stem (N_S) was also found to be non-significantly correlated (r = - 0.014 and r = 0.000) to EC_{as} and EC_{ad}. This implies that N_S is not influenced by the soil EC_{as} and EC_{ad}. However, H_C was found to be significantly correlated to N_S with r = 0.184[d]. This then implies that apart from the soil EC_{as}, some other soil properties which influence H_C may also have significant effect on N_S.

Further analysis also showed that EC_{as} was significantly correlated to the product of H_C and Ns (H_CN_S) and to the ratio ${}^{H_C}/_{N_S}$ with r = 0.232[d] and r = 0.255[d] respectively. This may have been due to significant correlation between EC_{as} and H_C, as well as H_C and N_S. From the correlation values, the correlation of EC_{as} to ${}^{H_C}/_{N_S}$ was higher and better compared to its correlation to H_CN_S. This means that EC_{as} and ${}^{H_C}/_{N_S}$ had a better relationship than EC_{as} and H_CN_S.

Again, EC_{ad} was found to be non-significantly correlated to the product of H_C and N_S (H_CN_S) and to the ratio ${}^{H_C}/_{N_S}$ with r = - 0.029 and r = 0.032 respectively. This may be due to the non-significance correlation of EC_{ad}

to H_C and EC_{ad} to N_S. EC_{as} was observed to be significantly correlated to EC_{ad} with r = - 0.124[c]. This implies that EC_{ad} can be estimated from EC_{as}.

Based on the suggestion of this correlation test, curve estimation techniques were performed using EC_{as} and N_S as independent variables, and H_C and H_C/N_S as dependent variables.

Table 4: Curve estimation for cassava plant height, H_C (m) and EC_{as} (mS/m)

Independent variable: EC_{as}					
Dependent Variable: H_C					
Function Type	R^2	Constant b_0	b_1	b_2	b_3
Linear	0.209	0.689	0.216		
Logarithm	0.312	0.972	0.275		
Inverse	0.298	1.158	- 0.166		
Quadratic	0.301	0.542	0.471	- 0.063	
Cubic	0.320[e]	0.434	0.773	- 0.246	0.023
Power	0.270	0.916	0.328		
Exponential	0.165	0.661	0.245		

[e] : Best fit regression coefficient

From Table 4, the cubic function had a better regression coefficient (R^2 = 0.320) to estimate H_C from EC_{as} compared to other functions, with b_o, b_1, b_2 and b_3 of 0.434, 0.773, -0.246 and 0.023 respectively. Therefore H_C can be estimated from EC_{as} using equation (3);

$$H_C = 0.434 + 0.773\,EC_{as} - 0.246\,EC_{as}^{\,2} + 0.023\,EC_{as}^{\,3} \tag{3}$$

From Table 5, the cubic function had a better regression coefficient (R^2 = 0.095) to estimate H_C/N_S from EC_{as} compared to other functions with b_0, b_1, b_2 and b_3 of 0.250, 0.306, - 0.092 and 0.008 respectively. Therefore, H_C can be estimated from equation (4);

$$H_C/N_S = 0.250 + 0.306\,EC_{as} - 0.092\,EC_{as}^{\,2} + 0.008\,EC_{as}^{\,3}$$

$$H_C = (0.250 + 0.306\,EC_{as} - 0.092\,EC_{as}^{\,2} + 0.008\,EC_{as}^{\,3})\,N_S \tag{4}$$

Table 5: Curve estimation for soil EC_{as} (mS/m) and H_C/N_S

Independent Variable: EC_{as}					
Dependent Variable: H_C/N_S					
Function Type	R^2	Constant b_0	b_1	b_2	b_3
Linear	0.065	0.350	0.093		
Logarithm	0.089	0.470	0.114		
Inverse	0.079	0.543	- 0.066		
Quadratic	0.091	0.289	0.198	- 0.026	
Cubic	0.095[e]	0.250	0.306	- 0.092	0.008
Power	0.082	0.407	0.258		
Exponential	0.058	0.311	0.209		

[e]: Best fit regression coefficient

Table 6: Curve estimation for EC_{as} (mS/m) and EC_{ad} (mS/m)

Independent Variable: EC_{as}					
Dependent Variable: EC_{ad}					
Function Type	R^2	Constant b_0	b_1	b_2	b_3
Linear	0.015	0.201	- 0.039		
Logarithm	0.037	0.146	- 0.062		
Inverse	0.042	0.097	0.041		
Quadratic	0.033	0.243	- 0.112	0.018	
Cubic	0.047[e]	0.307	- 0.291	0.127	- 0.014
Power	0.008	0.086	- 0.159		
Exponential	0.008	0.090	0.010		

[e]: Best fit regression coefficient

From Table 6, the cubic function had a better regression coefficient (R^2 = 0.047) to estimate EC_{ad} from EC_{as} compared to other functions, with b_0, b_1, b_2 and b_3 of 0.307, - 0.291, 0.127 and - 0.014 respectively. Therefore, the equation for EC_{ad} estimated from EC_{as} can be stated as shown in equation (5);

$$EC_{ad} = 0.307 - 0.291\, EC_{as} + 0.127\, EC_{as}^{2} - 0.014\, EC_{as}^{3} \quad (5)$$

4. Conclusion

This study showed the ability of soil apparent electrical conductivity (EC_a) for rapid soil information acquisition which can be used to effectively assess plant growth on sandy loam soil. It also showed that cassava plants at their early growing stages on sandy-loam soil are significantly influenced by soil EC_{as} rather than EC_{ad}. This may be because the plants had not yet developed roots that are long enough to tap nutrients from the deep soil depth. This study further showed that soil EC_{as} ranging from 0.441 to 6.211 mS/m on sandy-loam soil effectively support cassava plants for better and quality growth than soil $EC_{as} < 0.441$ mS/m. In addition, farming soil that had been left fallowed for years was observed to have higher EC_{as} than those that had been under continuous cultivation for years.

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