The Journal of Agriculture of the University of Puerto Rico

In continuation of The Journal of the Department of Agriculture of Puerto Rico

Published by THE AGRICULTURAL EXPERIMENT STATION, Río Piedras, P. R.

Published Quarterly: January, April, July and October of each year.

VOL. XXVI OCTOBER, 1942 NO. 4

EFFECT OF SOLAR RADIATION INTENSITY ON THE VEGETATIVE GROWTH AND YIELD OF COFFEE

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The Arabian type of coffee is generally grown under shade in order to obtain favorable growth and good quality of the bean. In those cases some species of leguminous trees are used to provide the shade. A study was undertaken in the year 1936 in order to measure the effect of different degrees of solar intensity on the growth and yield of coffee.

REVIEW OF LITERATURE

According to investigations on the effect of solar radiation on plants it has been shown that, in general, light tends to hasten maturation of plant organs and to produce a decrease in size. These effects vary in accordance with increasing intensity and under various sets of conditions. Bates (1) found that coniferous seedlings increased in size with increasing light intensity, while Briggs and Shantz (2) showed in crop plants, that the correlation ratio between radiation and transpiration varied from 0.65 to 0.48 and that, of the total radiation received an equivalent of 50 to 100 per cent was dissipated in transpiration and Shantz (12) found that there was an increase in fresh weight as the light intensity was decreased from 100 to 50 per cent of full sunlight. Shading caused a decrease in the dry weight of soybeans according to Garner and Allard (3); reduced flowering of apple trees as shown by Gourley (4); and caused an increase of leaf area in peaches (Gourley and Nightingale (5)). Hartley (6) reported injuries of high sunlight to coniferous seedlings; Korstian (7) found it favorably affected development of Douglas fir and Engelmann spruce; Shirley (13) reported it favorably affected growth of loblolly pine and redwood seedlings; and Popp (11) reported it caused

twining of bush and lima beans but unfavorable effect on growth of soybeans. Shade plants showed a considerable increase in chlorophyll concentration with decreasing light intensity while sun plants showed approximately the same chlorophyll concentration at all light intensities, according to Lubimenko (8). McClelland (9 and 10) compared artificially shaded plants with plants of the same varieties grown under full sunlight. He observed differences between the shaded and unshaded plants as pronounced as varietal differences in plants grown under uniform conditions. High yields were obtained under full sunlight, but the life of the tree was shortened substantially. Under 1/2 and 1/3 sunlight exposures the yields were lower but growth was apparently normal.

Materials and Methods

In the year 1936 a homogenous one-acre piece of flat land of the Catalina soil type, 150 feet above sea level was selected in the grounds of the Puerto Rico Agricultural Experiment Station (U.S.D.A.) at Mayagüez, Puerto Rico for our study. A lath frame (Figures 1 and 2)

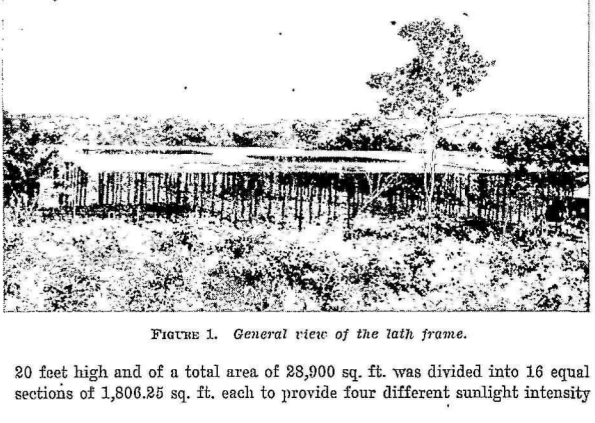

Figure 1. *General view of the lath frame.*

20 feet high and of a total area of 28,900 sq. ft. was divided into 16 equal sections of 1,806.25 sq. ft. each to provide four different sunlight intensity

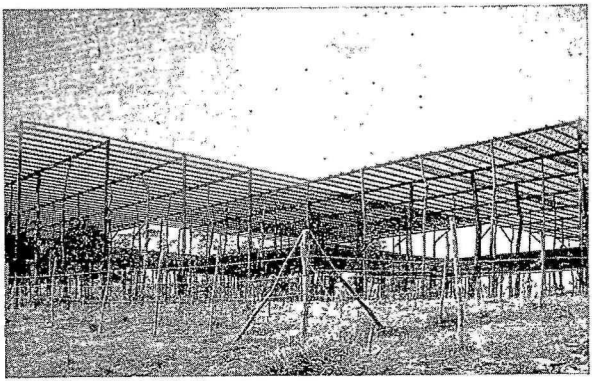

FIGURE 2. *Close view of the lath frame showing several different sunlight admitting sections or treatments.*

treatments replicated four times and arranged according to a 4 x 4 Latin square lay-out.

The laths in the four different treatments were so spaced as to provide approximately 2/3, 1/2 and 1/3 solar radiations. Four sections were left uncovered as checks to provide full sun exposure. Coffee was planted at distances of 8 x 8 ft., each plot containing 25 trees. Of these only nine coffee trees in the center of each plot were regarded as the experimental plots. Two rows of trees surrounded every experimental plot. Thus, the experimental plots were separated by a strip of land 16 feet wide. This was done to avoid as much as possible the effect of one treatment on another. The coffee trees were grown under ordinary cultural practices including an application of commercial fertilizer of the formula 15-5-15, at the rate of one-half pound per tree during the last 2 years of the experiment.

The solar radiation under every treatment was recorded by four sets of Leeds and Northrup Micromax Recorders and Eppley's Weather Bureau type Pyrheliometers (Figure 3). These records were integrated with a planimeter. Growth measurements of height, lateral branching and trunk diameter were recorded at definite intervals. Yield of coffee was recorded

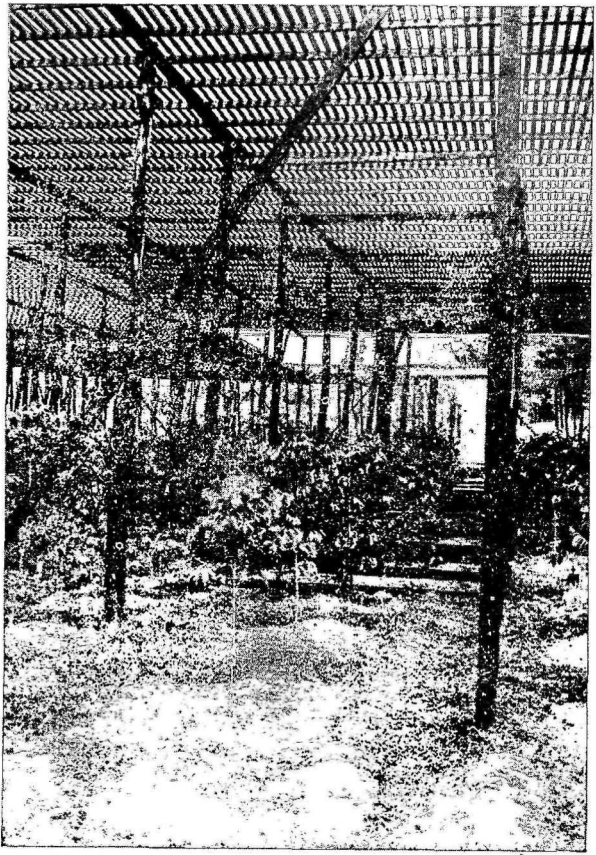

FIGURE 3. *Close view of the one-half sunlight treatment showing details of construction and disposition of the pyrheliometers under the various treatments.*

in pounds of beans. The relative humidity and temperature on every treatment was recorded by J. P. Friez Hygrothermographs. Soil samples were taken monthly from every plot to determine soil moisture. Outbreaks of leaf miner attacks and other insect pests were kept under control.

Experimental Results

In table 1, a complete record of the solar radiation for the experiment is given covering the period of June 1938 to May 1941.

Wide fluctuations in solar radiation. According to table 1, there is a wide fluctuation in the solar radiation recorded during different years. Under full exposure, 134,904.30 gr. cal./cm^2 were recorded for 1938, 158,081.70 for 1939, and 141,277.20 gr. cal./cm^2 for 1940. The fluctuation within any one year was even greater, for example, the radiation for the month of June 1938 was 13,031.40 gr. cal./cm^2 while for the month of November it was 8,933.70 gr. cal./cm^2. For all years the greatest intensity was recorded during the months of June, July, August, September, and the lowest during December, January and February.

Although the laths were arranged to provide 2/3, 1/2 and 1/3 radiation, the amounts recorded do not correspond exactly to these figures but to 55, 37, and 22 per cent respectively, of full sunlight. The reason for this is that during the first three hours of sunlight after sunrise and the last three hours previous to sunset all treatments are equally affected due to the angle of the sun's rays. It was from 10:00 A. M. to 3:00 P. M. that the various treatments received 2/3, 1/2 and 1/3 sunlight intensity since during this period the sun's rays are almost vertical. However, it is during this period that sunlight reaches its optimum intensity.

Shade tends to reduce annual fluctuations in radiations. While under full sunlight there is quite a wide fluctuation in solar radiation from year to year; 134,904.30 gr. cal./cm^2 for 1938; 158,081.70 for 1939 and 141,277.20 for 1940; during the same years for 2/3, 1/2 and 1/3 radiation fluctuates between 76,542.60 and 83,687.10; 51,569.10 and 54,485.70 and 29,608.80 and 32,699.60 gr. cal./cm^2, respectively.

Decrease in solar radiation increases growth and yield of coffee. Considering the average for three years, the trees under one-third and one-half radiation produced crops significantly superior to the trees under two-thirds and full radiation. The average yields in pounds of market coffee for 3 crops under one-third and one-half radiations was 28.77 and 24.13

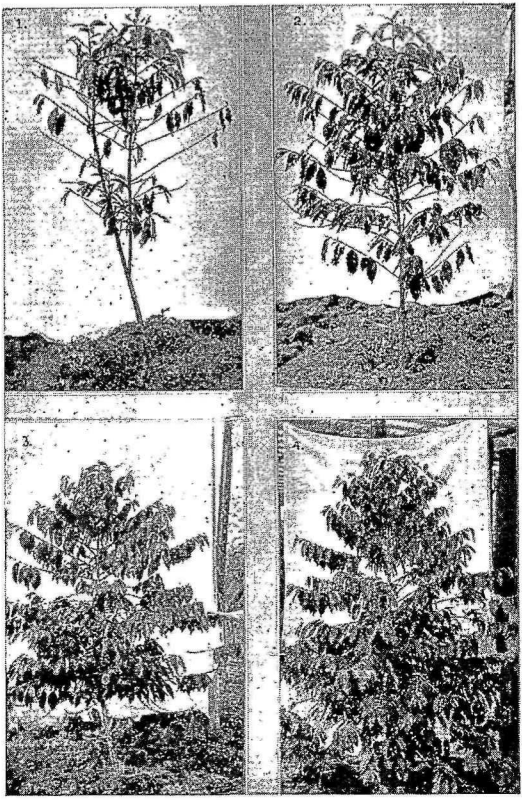

FIGURE 4. *Growth conditions of coffee trees under various solar radiation intensities: 1, under full sunlight; 2, under ⅔ sunlight; 3, under ½ sunlight; 4, under ⅓ sunlight.*

TABLE I. *Total solar radiation recorded at Mayagüez, Puerto Rico, at the experiment from June 1938 to May 1941 under various exposures (Gram calories per square centimeter).*

MONTHS	1938 - 1939				1939 - 1940				1940 - 1941			
	FULL	2/3	1/2	1/3	FULL	2/3	1/2	1/3	FULL	2/3	1/2	1/3
June	13,031.40	6,960.30	5,867.70	2,713.20	12,450.30	7,569.00	4,760.40	3,062.70	10,269.60	7,224.60	4,267.20	3,187.10
July	11,887.20	7,465.20	4,823.40	2,816.70	13,883.70	7,728.90	4,638.00	3,100.80	12,486.00	7,719.60	4,578.90	3,397.20
August	11,442.90	7,057.20	5,538.90	2,760.00	14,630.70	8,144.40	4,873.80	3,267.30	13,243.80	7,385.10	4,504.50	2,927.40
September	11,498.40	7,001.70	4,753.20	2,631.90	14,382.90	8,006.40	4,794.30	3,212.10	12,321.00	7,026.00	5,318.70	2,704.50
October	12,085.50	6,941.70	4,894.20	2,817.60	14,714.10	8,181.00	4,904.70	3,285.90	10,735.20	5,270.10	4,005.30	2,262.30
November	8,933.70	4,641.90	3,708.60	2,084.70	11,153.40	5,709.90	3,723.10	2,534.10	10,053.90	4,469.10	3,735.60	2,136.30
December	9,027.30	4,638.90	3,599.10	2,165.10	10,886.70	4,837.20	3,318.00	2,508.30	9,203.70	4,719.90	3,347.10	2,328.90
January	9,098.10	4,762.50	3,803.40	1,837.20	10,888.50	5,099.10	3,736.80	2,167.50	9,094.80	4,639.20	3,598.80	1,884.90
February	10,604.70	5,827.80	4,102.20	2,213.40	12,293.40	6,219.60	4,489.80	2,513.10	12,054.00	5,956.50	4,823.40	2,550.90
March	12,358.80	7,120.50	4,173.90	2,665.50	13,786.20	6,855.00	4,845.90	2,859.00	13,240.80	7,289.40	3,446.40	3,159.60
April	13,048.80	6,978.00	4,847.10	2,483.10	14,910.30	7,950.90	4,975.20	3,045.90	14,142.00	8,023.80	5,056.50	3,278.10
May	11,887.50	7,146.90	4,374.00	2,420.40	14,101.50	7,385.40	4,806.80	3,019.50	14,432.40	7,912.20	4,886.70	2,882.40
All months	134,904.30	76,542.60	54,485.70	29,608.80	158,081.70	83,687.10	53,374.80	34,576.20	141,277.20	77,635.50	51,569.10	32,699.60

Average for three years:

Full	144,754.40
Two-thirds	79,288.20
One-half	53,143.20
One-third	32,291.54

Greatest and lowest intensity recorded in gram calories per minute per square centimeter.

YEARS	FULL	2/3	1/2	1/3
1938-39	1.88 - 1.51	1.71 - 1.16	1.54 - 1.09	1.42 - 0.92
1939-40	1.88 - 1.35	1.59 - 1.08	1.51 - 1.08	1.40 - 0.81
1940-41	1.91 - 1.68	1.71 - 1.15	1.61 - 1.14	1.45 - 0.85

in comparison to 17.00 and 9.29 pounds for the same period under two-thirds and full sunlight, respectively. (Table 2).

The maximum and minimum intensities vary for the 4 exposures. The maximum intensity recorded under full sunlight was 1.91 gr. cal./ min./ cm.^{2} while the minimum was 1.35 gr. cal. min./ cm.^{2}. The maximum under 1/3 sunlight was 1.45 and the minimum 0.81 gr. cal./ min./ cm.^{2}. The maximum under 2/3 was 1.71 and the minimum 1.08 while the maximum under 1/2 sunlight was 1.61 and the minimum 1.08 gr. cal./ min./ cm.^{2}.

The differences in yield between trees under one-third and one-half radiations and full exposure were highly significant. These results do not agree with those of McClelland (9 and 10) who obtained higher yields from trees fully exposed to sunlight.

Growth was significantly greater also for the trees under one-third and one-half radiation intensities when compared with growth under two-thirds and full sunlight. For a three year period the increase in growth under one-third and one-half radiation was 718 and 628 centimeters in height, 498 and 418 centimeters in branch spread and 14.10 and 12.98 centimeters in trunk diameter, respectively. For two-thirds and full sunlight the increase in height was 577 and 498 centimeters, 343 and 209 centimeters in branch spread and 10.82 and 11.16 centimeters in trunk diameter, respectively. (Table 2).

According to the differences necessary for significance, the yields were practically the same under one-third and one-half solar radiation. Growth in height and trunk diameter was significantly greater under one-third radiation than under other treatments. The growth condition and general appearance of the coffee trees under the various exposures offered contrasting differences as noticed in figure 3. The trees under one-third and one-half solar radiation were very healthy and the leaves were of a normal green color, thin, shiny and tender. The development of internodal length was normal and comparable to that of trees growing under natural conditions. The difference in yields between treatments under one-third and one-half sunlight radiation was 4.64 pounds while the quantity needed for a difference statistically significant was 8.08. Therefore, there was no statistical difference between yields under these two radiations. (Table 2). In relation to growth, the difference for significance is greater than that actually obtained in the case of branch spread and trunk diameter attained under both treatments. The difference between branch spread of one-third and one-half sunlight was 80 centimeters and

TABLE 2. *Yields in pounds and growth increases of coffee trees for a three year period.*

TREATMENT	YIELDS			GROWTH INCREASE 3-YEAR PERIOD			AVERAGE YIELDS 3 CROPS
	1938	1939	1940	HEIGHT	BRANCH SPREAD	TRUNK DIAMETER	
				CM.	CM.	CM.	(LBS.)
None-full sunlight	10.97	11.11	5.82	498	209	11.16	9.29
Two-thirds sunlight	15.26	23.66	12.12	577	343	10.32	17.00
One-half sunlight	19.99	34.41	18.04	628	418	12.98	24.13
One-third sunlight	23.64	45.96	16.76	718	498	14.10	28.77
Difference necessary for significance	10.18	21.09	9.05	46.57	92.47	1.17	8.08
Difference necessary for high significance	15.42	31.95	13.80	70.54	140.08	1.77	12.27

TABLE 3. *Yields and growth increases of coffee trees under the various ecological factors measured.*

TREATMENTS	YIELDS	SOLAR RADIATION	HEIGHT	BRANCH SPREAD	TRUNK DIAMETER	TEMPERATURE	RELATIVE HUMIDITY	SOIL MOISTURE
	POUNDS	KGR. CAL./ ρM^2/YEAR	CENTIMETERS	CENTIMETERS	CENTIMETERS	°F	%	%
A— Full sunlight	10.97	134.90	131	111	2.3	73.26	64.74	24.17
	11.11	158.08	209	130	4.3	76.14	63.25	23.81
	5.82	141.27	237	133	4.8	76.20	60.00	23.36
B— 2/3 sunlight	15.26	76.54	145	137	2.7	72.49	62.22	25.35
	23.66	83.08	236	172	4.4	74.84	63.16	23.92
	12.12	77.63	264	172	4.9	75.10	60.20	24.73
C— 1/2 sunlight	19.99	54.48	147	149	2.9	70.51	65.31	25.44
	34.41	53.37	245	194	5.0	72.76	66.16	25.42
	18.04	51.56	280	201	5.6	73.20	65.50	23.78
D— 1/3 sunlight	23.64	29.60	143	153	3.1	68.80	77.58	26.82
	45.96	34.57	295	213	5.2	71.94	79.54	25.99
	16.76	32.69	296	229	5.5	71.70	75.20	25.73

a difference of 92.47 cms. was necessary for results to be significant. The significant difference required between trunk diameter under both radiations was of 1.7 and that actually obtained was of 1.12.

The trees under two-thirds and full solar radiation, specially the latter, were sickly and stunted. The leaves were underdeveloped, greenish and yellow, coriaceous, and dull. Internodal length was considerably reduced. The internodes were also greenish yellow and thin. The berries produced were smaller than those under shade and with a smaller quantity of mucilaginous substance.

Other Ecological Factors

Several environmental factors such as air temperature, relative humidity and soil moisture were recorded under the various solar radiation treatments.

The temperature fluctuations recorded lie between 68.80 and 76.20°F. Relative humidity fluctuated between 60.00 and 79.54 per cent. Soil moisture was the least variable, fluctuating between 23.78 and 26.82 per cent. Solar radiation ranged from 29.60 to 158.08 Kgr. cal. per square centimeter per year.

Solar radiation was found negatively correlated with yields and growth. Table 4 gives the correlation between yields and growth and the ecological factors recorded.

Solar radiation was negatively correlated with yields ($r = -0.64$) showing that increase in solar radiation intensity resulted in a decrease in yield. It was also negatively correlated with growth expressed as height, trunk diameter and branch spread.

Increases in height, branch spread and trunk diameter resulted in increases in yields and these were positively correlated as expressed by the corresponding results: $r = +0.78$; $r = +0.85$ and $r = +0.71$ for height, branch spread and trunk diameter respectively.

Temperature, relative humidity and soil moisture were influenced by solar radiation. These factors, were thought to be related to growth of coffee.

Temperature was positively correlated with increases in height and trunk diameter and negatively correlated with yields and branch spread. That is, lower temperatures were associated with higher yields and greater branch spread.

TABLE 4. *Correlation of yields and growth of coffee with solar radiation, temperature, relative humidity and soil moisture.*

FACTORS STUDIED	CORRELATION FACTOR (R)	CALCULATED SIGNIFICANCE	VALUES AT PH = .05	TABLES AT P = .01
Solar radiation and yields	—0.64 xxx	3.43	0.70	3.16
Solar radiation and growth in height	—0.20 xx	0.64	0.70	3.16
Solar radiation and growth in branch spread	—0.35 xx	1.18	0.70	3.16
Solar radiation and growth in trunk diameter	—0.38 xx	1.29	0.70	3.16
Growth (height) and yields	+0.78 xxx	4.66	0.69	2.97
Growth (branch spread and yields)	+0.85 xxx	6.11	0.69	2.97
Growth (trunk diameter) and yields	+0.71 xxx	3.77	0.69	2.97
Temperature and yields	—0.46 xx	1.63	0.70	3.16
Temperature and growth in height	+0.32 xx	1.06	0.70	3.16
Temperature and growth in branch spread	—0.25 xx	0.82	0.70	3.16
Temperature and growth in trunk diameter	+0.30 xx	0.99	0.70	3.16
Relative humidity and yields	+0.63 xx	2.56	0.70	3.16
Relative humidity and growth in height	+0.10 x	0.31	0.70	3.16
Relative humidity and growth in branch spread	+0.55 xx	2.08	0.70	3.16
Relative humidity and growth in trunk diameter	+0.13 x	0.41	0.70	3.16
Soil moisture and yields	+0.47 xx	1.68	0.70	3.16
Soil moisture and growth in height	—0.08 x	0.25	0.70	3.16
Soil moisture and growth in branch spread	—0.08 x	0.25	0.70	3.16
Soil moisture and growth in trunk diameter	—0.08 x	0.25	0.70	3.16

xxx highly significant (P = .01)
xx significant (P = .05)
x not significant

Relative humidity was positively correlated with yields and branch spread, and apparently did not show any relationship to growth in height and trunk diameter.

Soil moisture showed some relationship to yields, and apparently was not correlated with growth.

Total sugars, phosphorous, potash, and nitrogen were generally found in greater quantities in the leaves of plants under full sunlight. Air dry and absolute dry basis analyses of the leaves for total sugars, phosphorous, potash and nitrogen (Table 5) showed that these substances were generally found in greater quantities, specially potash and nitrogen, in the leaves of coffee trees exposed to full sunlight.

Discussion and Summary

It is obvious that solar radiation is an influencing factor in the growth and yield of coffee; insufficient and excessive light both impair growth and yield.

Contrary to what was expected, soil moisture was found to be the least fluctuating of all factors. All plots showed practically the same content. It is probable that although the plots under full exposure were expected to be submitted to the greatest soil evaporation, the transpiration from these trees was much less due to the smaller leaf area. In the shaded plots the transpiration of the trees was much greater because of their larger area of leaf. In either case the evidence points to a greater importance of transpiration than evaporation.

Sunlight had a formative effect on the coffee trees. Trees fully exposed offered contrasting differences when compared to shaded coffee plants. Growth was checked in every respect in trees fully exposed. The leaves were considerably smaller in size, the internodes were shortened, the height of vertical shoots and the lateral spread of fruiting branches was reduced and the berries were smaller than those of trees under shade.

According to the results obtained, an average of 53,143.20 gram calories per square centimeter per year is the optimum cumulative solar radiation for coffee growing in Puerto Rico. These figures compare favorably with solar radiation obtained under natural shade of Guaba trees (*Inga Inga* Br.) spaced at 16 x 16 ft. and under ordinary cultural methods. Generally, the solar radiation admitted in commercial plantations is much less on account of the excessive number of shade trees.

The effect of solar radiation on coffee trees was due obviously to

TABLE 5. *Analyses of coffee leaves.*

SAMPLES FROM TREATMENT	AIR DRY BASIS				ABSOLUTE DRY BASIS			
	TOTAL SUGARS	TOTAL P_2O_5	TOTAL K_2O	NITRATE NITROGEN	TOTAL SUGARS	TOTAL P_2O_5	TOTAL K_2O	NITRATE NITROGEN
Full radiation	3.63	0.44	1.95	1.22	3.89	0.47	2.09	1.31
2/3 radiation	3.27	0.29	1.75	0.39	3.52	0.31	1.88	0.42
1/2 radiation	3.89	0.41	1.74	0.80	4.31	0.45	1.93	0.89
1/3 radiation	3.26	0.30	1.42	0.59	3.68	0.34	1.60	0.67

both the cumulative and the intensity of radiation. The full sunlight plots received in three years 434,263.20 gr. cal./cm.$_2$ and the maximum and minimum intensities were from 1.91 to 1.35 gr. cal./min./cm.^{2}. The plots under 1/3 exposure received in 3 years 96,291.54 gr. cal/cm.^{2}, and the maximum and minimum intensities fluctuated between 1. 45 and 0.81 gr. cal./ min./ cm.^{2}. (Table 1).

According to the records of solar radiation (Table 1), shade contributed to equalize the solar radiation received in the plots under 2/3, 1/2 and 1/3 exposure, since there was little annual fluctuation in the total amount of solar radiation received. Increase in solar radiation resulted in a decrease of both yield and growth of coffee. This agrees with results obtained with other plants, Gourley, Nightingale (5), Korstian (7), Shirley (13). No significant difference was obtained between the growth and yields of plants growing under one-half and one-third exposures. Under full exposure, the growth, yield and general appearance of the trees was absolutely inferior to those under one-half and one-third radiation. The leaves of trees under full exposure were smaller, dull-colored and chlorotic.

The various ecological factors measured were correlated with yield and growth (Table 4) and as a result, solar radiation was found to be negatively correlated with yield and growth, thus as solar radiation increased, growth and yield decreased. Growth and yield were positively correlated, that is, greater growth resulted in greater yield. Temperature and yield were negatively correlated and this has been found to be true from observation. In Puerto Rico the greater yields of coffee have been obtained in the regions with lower temperatures. Temperature was found to be positively correlated with height, which according to observations is the general trend in Puerto Rico, vegetation being more luxuriant at lower elevations where the temperature is higher. Relative humidity was positively correlated with yields but apparently was not correlated with height.

Under full radiation the accumulation of potash and nitrogen was greater and that of phosphorous lower than in the shade (Table 5). This suggests that these relations be studied carefully to determine if plants when fully exposed utilize more nitrogen and potash than when shaded.

Conclusions

In this study, four ecological factors were observed: solar radiation, air temperature, relative humidity and soil moisture. Of the four, solar radiation fluctuates more than any other and undoubtedly the other three factors are influenced by solar radiation to a great extent.

1—Solar radiation varies widely with season and year.

2—The greatest intensity takes place during the months of June to September and the lowest from November to February.

3—The greatest intensity recorded under full sunlight was 1.91 gr. cal./ min./ cm.^{2} and the lowest was 1.35 gr. cal./ min./ cm.^{2}.

4—The yearly average solar radiation under full sunlight was 144,754. 40 gr. cal./ cm.^{2}.

5—The cumulative radiation for the 3 years that lasted the experiment was 434,263.20 gr. cal./ cm.^{2}, under full sunlight.

6—Shade regulates solar radiation making it more uniform from one year to the other.

7—As solar radiation increases, growth and yield of coffee decrease.

8—Yield and growth of coffee were definitely higher under 1/2 and 1/3 than under 2/3 and full sunlight.

9—Statistically significant differences in yield were not found between plots with 1/2 and 1/3 sunlight. Growth was significantly higher under 1/3 exposure.

10—Radiation produces distinctive formative effects on coffee. Plants under full sunlight were very weak, chlorotic and poorly developed.

11—Four ecological factors were measured: solar radiation, temperature, relative humidity and soil moisture. All are affected by radiation to a great extent, but other factors as vegetation have also some effect.

12—Solar radiation is negatively correlated with yields and growth.

13—Growth and yields are positively correlated. As expected low temperature and yield are associated and soil moisture acts independently in relation to growth.

14—Plants under full sunlight accumulated greater amounts of nitrogen and potash and to a less extent of phosphorous than under any other exposure.

15—An average of 53,143.20 gram calories per square centimeter per year is the optimum cumulative solar radiation for yield and growth of coffee. This amount is obtainable under natural shade of Guaba trees (*Inga Inga*) planted at not less than 16 x 16 feet.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to Mr. Atherton Lee, Director of the Puerto Rico Agricultural Experiment Station (U.S.D.A.)

at Mayagüez, and to Mr. Francisco López Domínguez former Director of the Agricultural Experiment Station of the University of Puerto Rico, for their suggestions and valuable help in the planning of the study; to Mr. Ventura Barnés, Jr. for valuable help; to Mr. Rafael Arroyo for the chemical analyses of the leaves; to Mr. J. O. Carrero for the analyses of soil moisture; and to Mr. Roberto Cole for the photographs.

SUMARIO

1—La radiación solar varía grandemente con los años y las estaciones.

2—La mayor intensidad se registra generalmente entre los meses de junio y septiembre mientras que la menor intensidad ocurre entre los meses de noviembre y febrero.

3—La mayor intensidad registrada fué de 1.91 calorías-gramos por centímetro cuadrado por minuto, y la menor fué de 1.35.

4—A pleno sol la radiación media anual fué de 144,754.40 calorías-gramos por centímetro cuadrado.

5—La radiación solar total por los tres años que duró el estudio fué de 434,263.20 calorías-gramos por centímetro cuadrado.

6—Aparentemente la sombra regula la radiación solar haciéndola más uniforme en el transcurso de los años.

7—A medida que la radiación solar aumenta, el crecimiento y la producción de los cafetos disminuyen.

8—El crecimiento y la producción de los cafetos fué superior bajo exposiciones solares de una mitad y de un tercio.

9—No hubo diferencias significativas en producción entre los tratamientos bajo exposiciones de un tercio y una mitad de luz solar. Hubo, no obstante, diferencia significativa en crecimiento entre los tratamientos bajo un tercio y una mitad de luz solar siendo mayor el crecimiento bajo un tercio.

10—La radiación solar produce marcados cambios en la morfología de los cafetos. Cuando éstos están bajo plena luz solar, son tan mediocres en crecimiento y sus hojas y tallos adquieren tales características que dan la apariencia de ser una variedad distinta a la que se obtiene bajo sombra.

11—Cuatro factores ecológicos fueron estudiados; temperatura, humedad relativa del aire, humedad del suelo y radiación solar. Este último es el que más afecta el desarrollo del cafeto y afecta marcadamente los otros tres factores.

12—La radiación solar y la producción y el crecimiento están negativamente correlacionados. Esto es, mientras la radiación solar aumenta, la producción y el crecimiento disminuyen.

13—El crecimiento y la producción están positivamente correlacionados, como era de esperarse a mayor crecimiento, mayor producción. La temperatura baja y la producción están aparentemente asociadas. La humedad del suelo está afectada no solamente por la radiación solar sino también por la vegetación de las plantas que la cubren.

14—Las plantas bajo pleno sol acumularon en las hojas mayores cantidades de nitrógeno y potasa que bajo las otras exposiciones. Hubo además, acumulación de fósforo, pero en menor cantidad.

15—De acuerdo con los resultados de este estudio una radiación solar media anual de 53,143.20 calorías-gramos por centímetro cuadrado es la óptima para el mejor crecimiento y producción del cafeto. Esto es posible lograrlo bajo sombra natural de árboles de guaba, (*Inga Inga*) sembrados a no menos de 16 x 16 pies.

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