Investigation

2 Light Transmission and the Vegetative Canopy

Background

An agroecosystem is in essence an ecosystem designed to capture the energy in sunlight and use it to fix atmospheric carbon for the production of edible biomass. An important aspect of agroecosystem function, therefore, is the efficiency with which the capture of light energy takes place. How much of the solar energy reaching the system strikes leaf surfaces? How much of this energy is absorbed and how much is transmitted and reflected? The efficiency of light capture, in turn, is in large part a function of the structure of the vegetative canopy. Does the canopy allow a significant portion of the incident light to reach the ground, where it can only promote the growth of weeds? Does an upper layer of foliage from one species receive more light than it can capture, reducing the amount of light received by the foliage of other crop species below?

Answering these kinds of questions involves two basic avenues of investigation: analyzing the structure of the canopy as it relates to light capture, and analyzing the internal light environment — how light penetrates the canopy and is progressively absorbed down through the vertical structure of the system (Chapter 4, pp. xx–xx). With a better understanding of the relationship between agroecosystem structure and efficiency of light capture, we have an important basis for maximizing productivity in the design of agroecosystems (Chapter 4, pp. xx–xx).

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Textbook Correlation

Chapter 3: *The Plant*
Chapter 4: *Light*

Synopsis

Three existing cropping systems are analyzed to determine for each (1) the number of layers of leaves making up the canopy, as given by the leaf area index (LAI), and (2) the amount of light transmitted through the canopy to the ground. These measurements are used to characterize and interrelate the light environment and canopy structure of each system and provide useful information on how each system absorbs and captures sunlight.

Objectives

- Investigate how light is distributed in and absorbed by an agroecosystem.
- Get an impression of how agroecosystems vary in their canopy structures and internal light environments.
- Compare the effects of different cropping structures on the internal light environment.
- Learn a technique for determining the LAI of a cropping system.
- Learn techniques for measuring light quality, distribution, and capture.
- Consider the effects of the internal light environment on crop development.

Procedure Summary and Timeline

Week 1

- Collect data on the canopy structure and light transmission of three different cropping systems

After week 1

- Analyze data and write up results

Timing Factors

This investigation can be performed at almost any stage in the development of the cropping systems being examined. The measurements of light intensity within and outside of the cropping system should be performed near midday, when the sun is as close as possible to directly overhead for the latitude and season. In addition, there should be as little cloud cover as possible and no strong winds.

Coordination with Other Investigations

This investigation can be integrated with Investigation 19, *Overyielding in an Intercrop System*. The light environments of the three types of plots grown for that investigation can be examined and compared to both fulfill the objectives of this investigation and provide potentially valuable data for analyzing the results of the intercrop study.

Materials, Equipment, and Facilities

30-m tape measures
Compass
Fishing pole or dowel fitted with a screw eye at one end
Lead weight (e.g., for ocean fishing)
Several meters of string or cord
Table of random numbers, or random number generator
Light meter (photoradiometer), preferably dual-sensor, with capacity for reading photosynthetically active radiation (PAR) (if a light meter is not available, see Variations and Further Study, suggestion #3)
Electronic data logger, for use with the light meter (optional)

Advance Preparation

- Collect materials.
- Identify three appropriate cropping systems for study. The systems (or parts thereof) selected can be relatively small-scale, such as different beds within a diverse garden-scale system. The systems should differ in one or more of the following respects: crop type, crop age, planting density, canopy structure, and species diversity. They should also be similar in exposure and slope.

Very different kinds of systems, such as orchards, vineyards, and annual cropping systems, can be compared in this investigation. In general, the more variation, the more interesting the data.

A set of suitable agroecosystems might exist in a homegarden, an intensive organic farming operation, the fields of an agricultural experiment station, or even a community or school garden. The three types of plots planted for Investigation 19, *Overyielding in an Intercrop System*, are also suitable candidates.

Ongoing Maintenance

None required.

Investigation Teams

Form three teams, each with three to five members. Each team will be responsible for measuring the canopy and light environment of one agroecosystem. If there are more than about 18 students, a fourth group can be formed to study a fourth system. If the investigation is integrated with the intercrop overyielding investigation (#19), the four groups of that investigation may be used: one group studies one of the monocrop plots in its block, a second group studies the other monocrop plot (the one in its block), and two groups study the intercrop plots in their blocks.

Procedure

Data Collection

The following steps describe the procedure for collecting canopy structure and internal light environment data in one system.

1. Determine the LAI at 20 different random points within the system. LAI is a measure of the total surface area of leaves in the three-dimensional space above a certain two-dimensional area of ground. The overall, or average, LAI of a cropping system gives an indication of the density of the canopy of the system, which is a major determinant of how the system as a whole utilizes sunlight.

   The method of determining LAI described below is called the point-intercept method. In essence, it reduces the three-dimensional area of space within which the leaf surface area is measured to a two-dimensional line above a one-dimensional point on the ground. (Note: Instruments are available that can measure LAI directly, along with PAR; if available, such an instrument can be substituted for this manual method.)

a. Construct an LAI measuring device. Find a pole or dowel approximately 2 m in length. Attach a screw eye near one end of the pole. (If a fishing pole is used, the terminal eyelet takes the place of the screw eye.) Pass a string about 3 m long through the eyelet at the end of the pole. To the distal end of the string attach a lead weight, such as a quarter-pound ocean-fishing sinker. Measuring from the end of the weight, place marks or tape on the string at 25 cm intervals.

b. Divide the cropping system (or some representative portion of it if it is very large) into rough quadrants. Mark the borders of the quadrants with stakes and/or string.

c. Randomly select a point within each quadrant. This can be done by tossing an object backwards over the shoulder and marking where it lands, or by generating two random numbers within an appropriate range to designate x and y coordinates within the quadrant.

d. Mark each of the four randomly selected locations, as well as the very center of the system (where the corners of all four quadrants meet). These five spots will be the locations from which sampling will take place.

e. Designate one person as the sampler. Position the sampler at one of the previously selected points, with the LAI measuring device in hand. *Note:* if the cropping system being studied is fairly small (e.g., a garden bed), this step, as well as steps f, g, and h, may have to be modified so that the sampler can stand outside the system.

f. Designate another person as the pointer. The pointer determines north with a compass (magnetic north is adequate) and directs the sampler to stand facing north.

g. The sampler extends the pole an arbitrary distance in a northerly direction, holding the string so that the weight is above the top of the crop canopy. The weight should be within the boundaries of the quadrant.

h. With eyes closed (so as not to bias the exact location of drop), the sampler lowers the weight into the foliage until it just touches the ground. He or she then holds the pole and line steady.

i. Designate a third person as the reader. The reader examines the string and notes each contact between the string and a leaf, beginning with the one highest above the ground (contact with a stem doesn't count). On the LAI Datasheet, the reader records, for each contact, the species or type of plant and the point of contact's distance above the ground to the nearest 25 cm.

j. Repeat steps g–i for the other three compass directions at that location.

k. Repeat steps f–j for the other four marked points in the cropping system, changing roles if the team is made up of more than three people.

l. When data have been collected for all 20 points in the system, add up the number of leaf contacts for each point where the weighted line was dropped and record these totals in the right-hand column of the datasheet. Each measurement of the total number of contacts is the LAI for that point in the cropping system.

m. Sum the column of point-wise LAI measurements and divide this total by 20 to derive a mean LAI, which is the estimated LAI for the cropping system.

2. Measure the average amount of PAR (wavelength = 400 to 700 nm) transmitted through the canopy of the cropping system to the ground. The procedure should be completed at midday.

   The ideal method for measuring transmitted light is to connect two sensors to a light meter via a switching box. One sensor is placed in a fixed position in a clearing just outside the cropping system, and the other is moved within the system to take shade readings at various locations. The light meter should be capable of measuring only PAR. With this setup, the full-sun light reading (which can vary over short periods of time) can be compared almost simultaneously with each shade reading. The recording of light transmission data can be simplified with the use of an electronic data logger connected to the light meter. The following steps assume dual sensors and a switching box are available; if they are not, see the note for "Alternative method."

a. Place a light sensor in a clearing near the cropping system, where it is exposed to full sunlight.
b. At an oblique angle to plant rows, extend a tape measure in a straight line along the soil surface 25 m through the cropping system. Light readings will be taken along this transect line at 50-cm intervals. Locate the transect near the center of the cropping system if possible, keeping in mind that a cable must be able to be stretched from every point on the transect to the fixed sensor in the clearing. If the cropping system is not large enough to accommodate a 25-m transect through it, use a shorter transect. However, if the transect is shorter than about 12 m, reduce the interval of measurement along it to 0.25 m (25 cm). The goal is to have at least 25 sampling locations.
c. At the distal end of the tape measure (0 m), place the second light sensor on the ground, making sure it is level. Connect it to the switching box. Connect the fixed sensor in the clearing to the switching box as well.
d. Note the unit of measurement on the light meter (e.g., foot-candles, watts, joules, micro-Einsteins) and record the unit at the top of the Light Transmittance Datasheet. Use this unit in all subsequent measurements and calculations.
e. Take a full sunlight reading and record it on the datasheet. Immediately thereafter, take a shade reading and record it as well. The person who positions the sensor inside the cropping system should take care to avoid affecting the light reading with his or her presence (by shading it or by reflecting light off clothing).
f. Move the shade-sampling sensor 50 cm further along the transect. Level the sensor and take both a full sunlight reading and a shade reading and record them.
g. Repeat the previous step until all the points along the transect have been sampled.

Alternative method: If two sensors are not available, take a full-sunlight reading, sample all the shade locations along the transect, and then take a second full-sun reading. Average the two full sun readings and use this figure in the datasheet.

h. On the datasheet, sum the column of full sunlight readings and the column of shade readings along the transect. Divide each total by 50 to determine the mean value for full sun light intensity and the mean value for light intensity under the vegetation of the cropping system.
i. Calculate the mean percentage of light transmission for the cropping system by dividing the mean under-vegetation light intensity by the mean full sun light intensity and multiplying by 100.

Data Analysis

1. Obtain other groups' data and use it to construct tables or graphs comparing the LAIs and mean percent transmittances of each system.
2. Map the LAI profile of the vegetation in each cropping system. An LAI profile, constructed from the data showing which species touched the string at what height, shows the vertical distribution of leaf area in a cropping system. The following steps describe how to construct an LAI profile for one system.
   a. For each 25-cm increment of height in the cropping system, tally up the number of contacts for each species. (The data from Figure 2.1, for example, show 9 squash contacts and 0 corn contacts at 25 cm.)

Leaf Area Index Datasheet

Sampling date: 23 Apr 2007 System: Corn–squash intercrop

Quadrant-Direction (C=center)	Contact #1 (Species, Height)	Contact #2 (Species, Height)	Contact #3 (Species, Height)	Contact #4 (Species, Height)	Contact #5 (Species, Height)	Total Number of Contacts (= Point LAI)
1-N	Squash, 25					1
1-W	Corn, 200	corn, 150	corn, 125	squash, 25		4
1-S	Corn, 225	corn, 100				2
1-E	Squash, 50					1
2-N	Corn, 175	corn, 150	corn 75	squash, 50	squash, 25	5
2-W						0
2-S	Corn, 200	corn, 100	squash, 50	squash, 50		4
2-E						0
3-N	Squash, 25					1
3-W	Corn, 100	squash, 50	squash, 50			3
3-S	Corn, 200	corn, 175	squash, 25			3
3-E	Corn, 175	corn, 175	squash, 25			3
4-N	Corn, 150	corn, 150				2
4-W						0
4-S	Corn, 225	squash, 25				2
4-E	Squash, 25					1
C-N	Corn, 200	corn, 175	corn, 175	squash, 50	squash, 50	5
C-W	corn, 200	corn, 175				2
C-S	corn, 175	corn, 175	squash, 25			3
C-E	corn, 200					1
					Total	43
					Mean LAI (total/20)	2.15

FIGURE 2.1
Example of a completed LAI Datasheet

Light Transmittance Datasheet

Sampling date: 23 July 2007

System: Corn–squash intercrop

Unit of measurement: foot-candles

Location on Transect (m)	Light Intensity	Full Sun Intensity
0	207	9004
0.5	256	9009
1	1900	9018
1.5	1509	9035
2	1235	9042
2.5	267	9051
3	289	9066
3.5	789	9073
4	760	9088
4.5	902	9091
5	933	9099
5.5	821	9103
6	1309	9108
6.5	1400	9119
7	487	9132
7.5	207	9147
8	338	9152
8.5	992	9160
9	1002	9163
9.5	1670	9169
10	1888	9189
10.5	1867	9187
11	690	9193
11.5	488	9199
12	296	9200
12.5	1266	9101

Location on Transect (m)	Light Intensity	Full Sun Intensity
13	1376	8773
13.5	244	8698
14	207	8723
14.5	210	9139
15	1890	9201
15.5	2011	9202
16	1119	9202
16.5	646	9200
17	900	9198
17.5	700	9192
18	865	9191
18.5	198	9178
19	1098	9171
19.5	178	9165
20	675	9155
20.5	664	9150
21	677	9149
21.5	346	9148
22	198	9139
22.5	1234	9132
23	488	9121
23.5	295	9110
24	1006	9104
24.5	875	9103
Total	41868	455442
Mean	837.36	9108.84

Mean percent transmission of light (Mean light intensity under vegetation/mean full sun intensity × 100)	9.2%

FIGURE 2.2
Example of a completed Light Transmittance Datasheet

b. Divide each of the totals derived in the previous step by the total number of contacts in the system. Then multiply each result by the mean LAI for the system. Each final result is a species-specific partial LAI for that height in the cropping system. All of the partial LAIs added together will equal the mean LAI for the system.

c. Use the partial LAIs derived in the previous step to construct a bar graph showing the partial LAIs for each species at each height. If there is more than one species at a particular height, the bar for that height will be a stacked bar showing two or more partial LAIs. An example of an LAI profile graph, constructed from the data in Figure 2.1 (and lacking stacked bars) is shown in Figure 2.3.

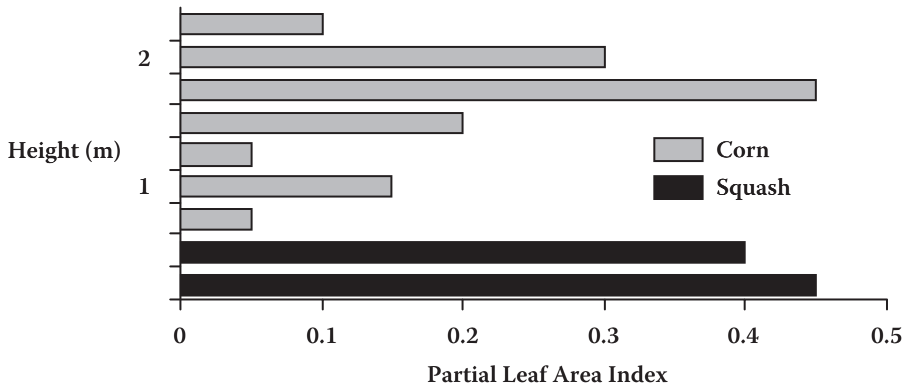

FIGURE 2.3
Example of an LAI Profile

Write-Up

Below are some suggestions for reporting on the results of the investigation.

- Describe each agroecosystem's canopy structure and internal light environment, based on its LAI, mean percent transmittance, and LAI profile.
- Discuss how each system's canopy structure and internal light environment are related.
- Discuss how observed differences in the internal light environments among the three systems may relate to differences in the makeup or structure of each system.
- Suggest ways of managing the internal light environment by altering the structure of the cropping system.

Reports can also discuss efficiency of light capture, shading for weed management, how the light factor might interact with other factors of the crop environment (temperature, moisture, etc.), and how time might be a factor as the crop develops, matures, and is harvested.

Variations and Further Study

1. Use the LAI data from one or more cropping systems to calculate (and compare) additional measures of canopy structure. *Canopy patchiness* is the ratio of LAI variability to mean LAI (a measure of LAI variability is the standard deviation of all the individual LAI measurements in a system). *Cover* is the number of LAI sample points for which LAI is greater than 0, divided by the total number of sample points.

2. On the basis of the results of this investigation, form an hypothesis about the relationship between canopy structure and/or makeup and the light environment and test the hypothesis with further sampling and measurement.
3. Percent transmission can be estimated if a light meter is not available. Lay the tape measure inside the cropping system as described in the investigation. Then, at determined intervals, determine if the transmitted light at that point is (1) full sun, (2) filtered or light shade, or (3) deep shade. This determination will be subjective, but it does give an idea of how the systems vary and compare. The technique works best in systems with broad, thick leaves, and when the wind is not blowing. Data are expressed as percent of sample points at each of the three levels of light intensity.
4. Set up a single crop system and take readings at weekly or 2-week intervals to see how the internal light environment and LAI change during the course of the crop cycle.
5. Measure light attenuation from the top of the crop canopy to the ground to get a more complete picture of how light varies inside the system, and how this variation is determined by canopy structure. Place a fixed sensor in full sunlight as described in the investigation, but position the moveable sensor at each of several heights above each sample point on the transect. The specific heights at which readings are taken are determined by the structure of the cropping system. (See Chapter 4, pp xx, Figure 4.6, for an example of reading heights and attenuation data.) Once the data are used to construct a diagram such as that in the aforementioned Figure 4.6, each crop's role in altering the light environment can be determined.

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Leaf Area Index Datasheet

Sampling date: System:

Quadrant-Direction (C=center)	Contact #1 (Species, Height)	Contact #2 (Species, Height)	Contact #3 (Species, Height)	Contact #4 (Species, Height)	Contact #5 (Species, Height)	Total Number of Contacts (= Point LAI)
1-N						
1-W						
1-S						
1-E						
2-N						
2-W						
2-S						
2-E						
3-N						
3-W						
3-S						
3-E						
4-N						
4-W						
4-S						
4-E						
C-N						
C-W						
C-S						
C-E						
					Total	
					Mean LAI (total/20)	

Light Transmittance Datasheet

Sampling date: System:

Unit of measurement:

Location on Transect (m)	Light Intensity	Full Sun Intensity
0		
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		
5.5		
6		
6.5		
7		
7.5		
8		
8.5		
9		
9.5		
10		
10.5		
11		
11.5		
12		
12.5		

Location on Transect (m)	Light Intensity	Full Sun Intensity
13		
13.5		
14		
14.5		
15		
15.5		
16		
16.5		
17		
17.5		
18		
18.5		
19		
19.5		
20		
20.5		
21		
21.5		
22		
22.5		
23		
23.5		
24		
24.5		
Total		
Mean		

Mean percent transmission of light (Mean light intensity under vegetation/mean full sun intensity × 100)	

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