AD

RCS OSD-1366

Research and Development Technical Report

ECOM 2-671-3

THE ENERGY BUDGET AT THE EARTH'S SURFACE: ESTIMATES OF THE DIFFUSION RESISTANCE OF SOME LARGE SUNFLOWER LEAVES IN THE FIELD

Contribution by:

L. A. Hunt, Ivan I. Impens and E. R. Lemon

INTERIM REPORT

E. R. Lemon - Investigations Leader

AUGUST 1967

Distribution of this document is unlimited

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND
Atmospheric Sciences Laboratory, Research Division
Fort Huachuca, Arizona
Cross Service Order 2-67
Microclimate Investigations, SWCRD-ARS-U. S. Department of Agriculture
Ithaca, New York 14850

14

Technical Report ECOM 2-671-3 August 1967

THE ENERGY BUDGET AT THE EARTH S SURFACE:
ESTIMATES OF THE DIFFUSION RESISTANCE
OF SOME LARGE SUNFLOWER LEAVES IN THE FIELD

INTERIM REPORT

Cross Service Order 2-67
Task 1V0-14501-B53A-08

Prepared by

L. A. Hunt, Ivan I. Impens and E. R. Lemon

Research Report No. 396

of

Northeast Branch
Soil and Water Conservation Research Division
Agricultural Research Service
U. S. Department of Agriculture

In Cooperation With

N. Y. State College of Agriculture
Cornell University
Ithaca, New York

For

U. S. Army Electronics Command
Atmospheric Sciences Laboratory, Research Division
Fort Huachuca, Arizona

ESTIMATES OF THE DIFFUSION RESISTANCE OF SOME LARGE SUNFLOWER LEAVES IN THE FIELD

L. A. Hunt, Ivan I. Impens and E. R. Lemon

Measurements of the resistance to water vapor movement from the intercellular spaces to the leaf surface (leaf resistance, r_ℓ) were made in a one-hectare field crop of sunflowers (Helianthus annuus L.) at Ellis Hollow (near Ithaca, N. Y.). Some of these measurements, supplemented with determinations of net radiation above and below the leaves, leaf temperature, and both air temperature and humidity, were used to estimate the resistance to mass and sensible heat transfer from the surface of the leaf to the bulk air outside the leaf boundary layer (boundary layer resistance, r_a).

The sunflower crop was sown early in June 1966, and thinned to 60,000 plants per hectare and irrigated in July. Measurements to determine both leaf and boundary layer resistances were made during clear intervals on days with scattered clouds (1 and 3 August); measurements of leaf resistance alone were made during the afternoon of a day that was cloudless from early morning (4 August). One large, representative leaf lamina approximately 27 cm wide along both major axes and located 1.5-1.8 m from ground level, was selected on each of ten plants. The experimental leaf was supported roughly parallel to the soil surface by cellophane tape strips joining the petiole and stem. All remaining leaves on each test plant were wrapped around the stem to avoid their interference in direct solar radiation on the test leaf.

Leaf resistances were measured with a small diffusion porometer of the type described by van Bavel, Nakayama and Ehrler (19). Five measurements were made on both upper and lower leaf surfaces, with each individual determination being made on a separate leaf. The leaves were examined in random order. Net radiation above and below the leaf was determined with a miniature Funk net radiometer which has a 12-mm-diameter sensing head (Middleton & Co., Adelaide, Australia). Leaf temperature was measured with a bolometer (Barnes Eng. Co. infrared thermometer, Model IT-3) with a 7° field of view. The indicated temperature was generally 0.5 °C higher when viewing the leaf from below than from above. The temperature recorded when viewing from below was considered more correct, and thus was used for calculation (7). Temperature and humidity of the bulk air in the community at the leaf level were measured with an aspirated wet and dry bulb thermistor psychrometer (Atkins Technical Inc.).

The leaf resistance was determined from diffusion meter measurements for the upper and lower leaf surfaces by.

$$\frac{1}{r_{\ell}} = \frac{1}{r_{\ell b}} + \frac{1}{r_{\ell d}}$$

where $r_{\ell b}$ and $r_{\ell d}$ are the measured resistances for abaxial and adaxial leaf surfaces respectively. The boundary layer resistance, r_a, was calculated by solving the following energy balance equation:

$$R_N = \frac{L\ (\Delta\rho)}{r_a + r_{\ell}} + \frac{C_p\ \rho_a\ (\Delta T)}{r_a}$$

where R_N is the net radiation intercepted by the leaf, in cal cm^{-2} sec^{-1}; L is the heat of vaporization of water (590 cal g^{-1}); C_p is the specific heat of air (0.24 cal g^{-1} $°C^{-1}$); ρ_a is the air density (1.205 x 10^{-3} g cm^{-3}); $\Delta\rho$ is the difference between the saturation water vapor density at leaf temperature and water vapor density of bulk air, in g cm^{-3}; and ΔT is the difference between leaf and bulk air temperature, in °C. The bulk air is considered as that having representative properties of the air in the plant community at the level of the leaf measurements but outside the leaf boundary layer.

The leaf and boundary layer resistances for clear periods during two days with scattered clouds are given in Table 1. The leaf resistances, which varied from 3.3 to 4.7 sec cm^{-1}, were higher than the minimum values (0.3 sec cm^{-1}) reported by Holmgren, Jarvis and Jarvis (9) for sunflowers. This may be attributable either to the environment and/or to the leaves themselves, because (a) intermittent clouds may have caused partial stomatal closure, and (b) minimum stomatal resistance is not constant throughout the life of a leaf (9, 16).

Values of boundary layer resistances calculated by the energy balance equation (0.05 - 0.13 sec cm^{-1}) are lower than values calculated from formulas based either on: (a) forced convection laminar flow theory applicable to isolated, rigid, smooth bodies that are flat and thin, oriented parallel to a relatively uniform airstream; or (b) empirical data dealing with water vapor loss from isolated small leaf models studied under laboratory conditions. Combining both theoretical and empirical formulas, Monteith (12) suggested that the following formula was most appropriate for describing boundary resistance to water vapor transfer of leaves under field conditions:

$$r_a = 0.65 \left(\frac{x}{u}\right)^{0.5} \quad \text{sec cm}^{-1} \text{ per unit area of leaf}$$

where x is the width of the leaf (cm) and u is the velocity of the bulk air stream (cm sec^{-1}). This formula, when adjusted for the difference in both thickness of boundary layer and diffusion coefficient, yields the following expression for boundary resistance to heat transfer:

$$r_a = 0.75 \left(\frac{x}{u}\right)^{0.5}$$

Such formulas when applied to leaves of the size examined in the present work yield the following estimates of r_a:

u (cm sec^{-1})	r_a (sec cm^{-1}) Water vapor	 Heat
10	1.07	1.23
100	0.33	0.41
1,000	0.10	0.12

Thus, exceptionally high windspeeds would be required to yield r_a values of the magnitude found in Table 1.

Another method of determining r_a of sunflower leaves in the field was tried. We used a transient heat pulse method described by Linacre (11):

$$r_a = 4.05 \times 10^{-6} \, t_{0.5} \, S_A(F) \, B,$$

where $t_{0.5}$ is the time required after shading for the temperature to fall from its initial value to that halfway between the initial and final states, $S_A(F)$ is the leaf surface area per unit of fresh weight (specific leaf area on a fresh weight basis), and

$$B = \frac{r_\ell + r_a(\Delta + \gamma)/\gamma}{r_\ell + r_a}$$

in which γ is the psychometric constant and Δ is defined by:

$$\Delta = \frac{e_s - e_{as}}{T} \approx \left[\frac{d(e_{as})}{dT}\right]_{T_a}$$

where e_s is the saturated water vapor pressure at leaf temperature, e_{as} is the saturated water vapor pressure at the bulk air temperature, and ΔT is the difference between leaf and bulk air temperature. T_a is the absolute temperature of the air. Four separate temperature determinations were made using a bolometer during clear weather on the morning of 4 August, when the windspeed immediately above the crop was approximately 100 cm sec^{-1}. Intermittent shading was accomplished with a 1 x 1 m plywood board held normal to the incoming sunlight with its central point approximately 50 cm from the leaf. This arrangement permitted sharp delineation between the unshaded and shaded regimes. The $t_{0.5}$ values were determined with the bolometer coupled to a sensitive mV strip chart recorder (Leeds & Northrup Co.) when ΔT was approximately 2.5°C; actual values (8 sec, 8 sec, 10 sec, 7 sec) were read from curves drawn by hand through the recorder trace. The mean r_a estimate was 0.06 ± 0.01 sec cm^{-1}, a value substantially less than those calculated on the basis of Monteith's equation. Evidently, therefore, the present findings reflect other than the commonly accepted ideas of the magnitude of leaf boundary layer resistances. Results of this method thus agree with those determined by the energy balance method.

Such results could stem from hairs present on both the upper and lower surfaces of the sunflower leaves. This follows, as pointed out by Wolpert (20), because heat transfer through a laminar boundary layer is by conduction. Thus, when certain roughness elements lie within a laminar boundary layer, the distance through which heat must travel by conduction through the fluid medium is reduced, and the rate of heat transfer is increased, relative to a surface without roughness projections. In certain cases, the reduction in the boundary layer resistance of rough, relative to smooth, surfaces may equal the percentage increase of surface area due to the roughness elements (20).

However, the present findings could also stem from the turbulence of the bulk air in the plant community. The laminar, forced convection equation was derived from studies under conditions of relatively steady air movement. When the airstream is turbulent, the edge of a laminar boundary layer is irregular and its resistance is reduced by penetrating eddies. Hinze (8) indicates that for turbulent intensities of 10%, the resistance value is 10 - 50% less than that given by Monteith's equation. The actual reduction depends on the geometry of the object considered and the scale of turbulence of the airstream. Under field conditions the turbulent intensity is often greater than 10% (18), thus reductions of more than 50% in the laminar flow resistance values should be expected.

Furthermore, the results could reflect a complete change in the nature of the boundary layer. With flat, smooth objects that are thin and rigid, a transition from a laminar to a turbulent boundary layer occurs when the Reynolds number is 3-5 x 10^5. Transition will occur at the lower value when (a) the free stream is turbulent, or (b) the free stream is not uniform (2). With rough, irregular, flexible objects, the boundary layer probably is turbulent from the leading edge (2). In the present study a Reynolds number of 3 x 10^5 would require windspeeds of 1500 cm sec^{-1}. Transition at windspeeds as low as 100-500 cm sec^{-1} could arise from hairs and veinal undulations making the surface aerodynamically rough, as well as from elastic properties permitting flexing and bending of the leaf surface under the influence of larger eddies in the bulk air stream. However, only a small amount of leaf movement was observed; thus it is likely that the geometric properties of the surface would have played the more important role among the various leaf characteristics in bringing about any complete change in the nature of the boundary layer. The scale of turbulence experienced by the test leaves being in an array of other plant parts under field conditions could be of the greatest importance of all.

Our results reported here for sunflower leaves agree with those calculated for leaves in a stand of corn at the same location (17, 3). These latter calculations involved: (a) the application of an energy budget approach to evaluate both the eddy diffusivity (K) and the boundary layer resistance (r_a) at different levels within the crop canopy, (b) mathematical approximation of the attenuation of both of these components, and (c) comparison of the attenuation characteristics of K and r_a. Interpretation was based on the implicit assumption that windspeed was attenuated within the canopy in the same way as K.

Our results, by indicating that the r_a values of large sunflower leaves under field conditions are less than those estimated on the basis of laminar flow theory, also add weight to the contentions of Philip (14) and Budagovsky (4). Philip (14), commenting on Raschke's (15) generalization that leaf boundary layers are laminar and that narrow leaves have the smallest r_a values, has argued that large leaves may have a greater scale of turbulence and may in consequence have smaller r_a values than small leaves. Budagovsky (4) has also commented on the possibility of leaf boundary layers being turbulent under outdoor conditions.

The realization that some form of turbulent boundary layer may exist around leaves under field conditions is of secondary importance to water vapor movement from the intercellular spaces to the bulk air in the plant community. This follows, as pointed out by Impens et al. (10), because r_a under outdoor conditions is usually an order of magnitude smaller than r_ℓ. If one assumes a laminar boundary layer and a windspeed of 100 cm sec^{-1}, and then calculates the air resistance for the leaves tested, the sum of r_a and r_ℓ gives a mean of 4.3 sec cm^{-1}, whereas the measured mean of r_a and r_ℓ is 4.1 sec cm^{-1} (mean values from Table 1). The boundary layer resistance is of primary importance, however, in controlling sensible heat losses from leaves. This fact should not be minimized.

The leaf resistances recorded on the clear day varied from 3.2 to 4.8 sec cm^{-1} (Table 2). These values, when expressed on an hourly basis, were higher in the periods 1100 to 1300 and 1400 to 1500 than during 1300 to 1345. This latter pattern, which agrees in general with that reported for both bulrush millet (1) and corn (3) indicates stomatal closure during the middle of the day and stomatal opening in the afternoon. By contrast to the millet and corn, however, stomatal opening in the sunflower apparently occurred in the period 1300 to 1345 rather than later in the afternoon around 1500. These differences presumably stem from differences either in the soil-plant water relations, or in the intrinsic pattern of stomatal behavior of the species.

By contrast to the hourly mean r_ℓ values, the 15-min means exhibited a shorter cycle, with minima occurring at 1100, 1300 and 1430, and maxima at 1215, 1415 and 1500. Such a pattern conforms with that reported by Ehrler et al. (6) for cotton and by Parkhurst and Gates (13) for cottonwood, under standard conditions. In both of the latter cases, the cycling was explained in terms of an "overshoot" mechanism, in which partial stomatal closure, occurring in response to an increased leaf water deficit, resulted in rehydration of leaf tissue and in opening of the stomates. Increased water loss following stomatal opening ultimately resulted in an increased leaf water deficit and stomatal closure. The present data suggest that a similar mechanism could be involved in the field. Such a mechanism could be associated with the cyclical pattern reported for the rate of evaporation of tamarisk during the afternoon hours of days of high solar radiation (5).

The present results thus indicate that erroneous conclusions may result from both: (a) computation of leaf boundary layer resistance on the basis of laminar flow theory, and (b) analysis of diurnal changes in evapotranspiration on the assumption that leaf resistance exhibits only one maximum value at midday or thereabouts.

REFERENCES

1. Begg, J. E., J. F. Bierhuizen, E. R. Lemon, D. K. Misra, R. O. Slatyer and W. R. Stern. 1964. Diurnal energy and water exchanges in bulrush millet in an area of high solar radiation. Agr. Meteorol. 1: 294-312.

2. Bird, R. B., W. E. Stewart and E. M. Lightfoot. 1960. Transport phenomena. Wiley, New York.

3. Brown, Kirk W. and Winton Covey. 1966. The energy-budget evaluation of the micrometeorological transfer processes within a cornfield. Agr. Meteorol. 3:73-96.

4. Budagovsky, A. I. 1964. Isparenie pochvennoi vlagi. Nauk, Moscow.

5. Decker, J. P., W. G. Gaylor and F. D. Cole. 1962. Measuring transpiration of undisturbed tamarisk shrubs. Plant Physiol. 37: 393-397.

6. Ehrler, W. L., F. S. Nakayama and C. H. M. van Bavel. 1965. Cyclical changes in water balance and transpiration of cotton leaves in a steady environment. *Physiol. Plant.* 18:766-775.

7. Fuchs, M. and C. B. Tanner. 1966. Infrared thermometry of vegetation. Agron. J. 58:597-601.

8. Hinze, J. O. 1959. Turbulence. McGraw-Hill, New York.

9. Holmgren, P., P. G. Jarvis and M. S. Jarvis. 1965. Resistances to carbon dioxide and water vapor transfer in leaves of different plant species. Physiol. Plant. 18:557-573.

10. Impens, I. I., D. W. Stewart, L. H. Allen, Jr. and E. R. Lemon. 1967. Diffusive resistances at, and transpiration rates from leaves in situ within the vegetative canopy of a corn crop. Plant Physiol. 42:99-104.

11. Linacre, E. T. 1966. Resistances impeding the diffusion of water vapor from leaves and crops. Ph.D. Thesis, University of London.

12. Monteith, J. L. 1965. Evaporation and environment. Proc. Symp. Soc. Exp. Biol. 19:205-234.

13. Parkhurst, D. F. and D. M. Gates. 1966. Transpiration resistance and energy budget of *Populus sargentii* leaves. Nature 210:172-174.

14. Philip, J. R. 1966. Plant water relations: some physical aspects. Ann. Rev. Plant Physiol. 17:245-268.

15. Raschke, K. 1960. Heat transfer between the plant and the environment. Ann. Rev. Plant Physiol. 11:111-126.

16. Slatyer, R. S. and J. F. Bierhuizen. 1964. Transpiration from cotton leaves under a range of environmental conditions in relation to internal and external diffusive resistances. Australian J. Biol. Sci. 17:115-130.

17. Uchijima, Z. 1966. Micrometeorological evaluation of integral exchange coefficient at foliage surfaces and source strengths within a corn canopy. Bull. Natl. Inst. Agric. Sci. 13A:81-92.

18. Uchijima, Z. and J. L. Wright. 1964. An experimental study of air flow in a corn plant-air layer. Bull. Natl. Inst. Agric. Sci. 11A:19-65.

19. Van Bavel, C. H. M., F. S. Nakayama, and W. L. Ehrler. 1965. Measuring transpiration resistance of leaves. Plant Physiol. 40: 535-540.

20. Wolpert, A. 1962. Heat transfer analysis of factors affecting plant leaf temperature. Significance of leaf hair. Plant Physiol. 37: 113-120.

Table 1. Leaf and boundary layer resistances during clear periods on two days with scattered clouds

Time (EST) Hour	Leaf resistances (r_ℓ) (diffusion meter method) (sec cm^{-1})	Boundary layer resistance (r_a) (energy balance method) (sec cm^{-1})
0900 *	4.7	0.06
1000	3.6	0.12
1030	3.3	0.06
1130	3.7	0.07
1200	3.4	0.05
1230	4.2	0.06
1300	3.9	0.07
1330	4.3	0.13
1400	4.4	0.12
1500	4.7	0.06
Standard error of mean (n = 5)	0.4	0.02

* 3 August. Remainder on 1 August 1966.

Table 2. Leaf resistances on a clear day. 4 August 1966.

Time (EST) Hour	Leaf resistance (r_{ℓ}) (diffusion meter method) (sec cm^{-1})	
1100	3.7	
1115	4.1	4.2
1130	4.5	
1145	4.6	
1200	4.7	
1215	4.8	4.4
1230	4.4	
1245	3.6	
1300	3.2	
1315	3.9	3.8
1330	3.9	
1345	4.3	
1400	4.3	
1415	4.9	
1430	3.6	4.4
1445	4.7	
1500	4.8	
Standard error of Mean (n - 5)	0.3	

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Microclimate Investigations, SWCRD-ARS-USDA Tower Road, Ithaca, New York 14850	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
ESTIMATES OF THE DIFFUSION RESISTANCE OF SOME LARGE SUNFLOWER LEAVES IN THE FIELD

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Interim report

5. AUTHOR(S) *(Last name, first name, initial)*
L. A. Hunt, Ivan I. Impens and E. R. Lemon

6. REPORT DATE August 1967	7a. TOTAL NO. OF PAGES 9	7b. NO. OF REFS 20

8a. CONTRACT OR GRANT NO. CSO 2-67	9a. ORIGINATOR'S REPORT NUMBER(S) Research Report No. 396
b. PROJECT NO.	
c. Task 1V0-14501-B53A-08	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ECOM 2-671-3
d.	

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Electronics Command Atmospheric Sciences Laboratory, Research Division, Fort Huachuca, Arizona 85613

13. ABSTRACT

Studies of resistance to gaseous exchange between large sunflower leaves and the bulk air in a crop canopy were made. Two components of the diffusive pathway for mass and sensible heat were evaluated; (a) the resistance from the interior of the leaf to the leaf surface, and (b) the resistance from the surface of the leaf through the leaf boundary air layer to the bulk air.

It was found that: (a) leaf resistance not only displays diurnal trends but shorter fluctuations, and (b) boundary air layer resistance was significantly smaller than predicted from classical boundary layer formulae.

DD FORM 1 JAN 64 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Diffusion resistance						
sunflower leaves						
leaf resistance						
boundary air layer resistance						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8*a*. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.