AN APPLICATION OF COMMUNICATION SYSTEM THEORY TO THE STUDY OF SOIL-PLANT RELATIONSHIPS

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Abstract: The study has been initiated with the objective to evaluate whether the means of communication system theory could be used to describe soil-plant relationships. In this system, the soil represents the source, while the receiver is the plant. The theory of communication systems is closely related to information theory, but it puts emphasis on uncertainty.
Plant and soil samples were collected in a stand of the *Potentillo-Festucetum pseudovinae* community in the East-Hungarian sand region in the spring of 1992 and again in the autumn of 1993. On each sampling date, 60 individuals of *Potentilla arenaria* Borkh. were chosen with special attention to the condition that individuals of other species are not in the proximity of *Potentilla* individuals. After harvesting the above-ground plant biomass, the soil sample was collected from the upper 15 cm of the rhizosphere. In communication system terms, the concentrations of available phosphorus, potassium and calcium were regarded as the sources and plant dry weight as the receiver.
From spring to autumn, all information values relating the source and receiver information (the joint and mutual) showed increasing tendencies, and so did the values of equivocation, coherence coefficient and the entropy. For every information value, the smallest change was obtained in the Ca/plant dry weight relationship. The increase in the joint information from spring to autumn was connected to the abundance of the P and K resources.
The mutual information increased by the autumn, but the coherence coefficient remained relatively low (0.4). This indicates that only highly uncertain predictions can be attained in both directions for the behavior of the receiver (plant) and the source (nutrients in the soil). Since joint information, divided by sample size, defines the niche breadth (when it is estimated with the Shannon formula) and the diversity of the source divided by the logarithm of the number of the source symbols defines evenness that indicates channel efficiency, the results provide a basis for evaluation of change in the species niche.

Introduction

The paper emphasizes that the study of soil-plant relationships can be approached as a "communication system". According to Reza (1966), "the common feature of the communication processes is that some information is flowing in some network; .....in each communication system at least three parts can be distinguished: a) the transmitter or source, b) the receiver or sink and c) the channel which forwards the communication from the source to the receiver". The information carrier is potentially the most variable part of the system. This is because the carrier could be anything (e.g., chemical substances, set of symbols).

The theory of communication systems is closely related to information theory, applied to estimating the similarity of vegetation units and to investigating their complexity (Orlóci 1978, 1991, Anand and Orlóci 1997). The theory of communication systems is different from information theory in its approaches and terminology so the results highlight different aspects of the ecological system. Communication system theory puts emphasis on uncertainty, expressed as diversity in ecology (Pielou 1975). Since diversity and niche breadth can be estimated in the same way (e.g., by Shannon formula), it is possible to link the communication system theory and the ecological theories on this basis. The joint application of the theories should result in better insight into the properties of ecological systems. In this paper, an application is described using a case of soil-plant relationships. Other aspects of application of theories are discussed by Orlóci (1991) and Anand and Orlóci (1997).

Materials and methods

The plant and soil samples were collected in a pasture situated near Debrecen ("Daru Hills" at Bagamér). Spring sampling was done on May 4 1992 and autumn sampling on September 29 1993. During the first period, individuals of *Potentilla* were in full flowering stage, while on the second sampling occasion the plants were well after shedding their seed. In this phase of development, the individuals had rosette leaves. The pasture vegetation belongs to the *Potentillo-Festucetum pseudovinae* community (Nagy et al. 1990, Précsényi and Mészáros 1998). Plant cover is 40 to 50%, the soil is slightly acidic (low $CaCO_3$ content).

On each sampling date, 60 *Potentilla* individuals were chosen. The sampling criterion required that individuals of no other species occurred in the proximity of the selected individuals. After harvesting the above-ground part of the plants, at each plant soil sample was taken from the upper 15 cm (the monolith size: 10x10x15 cm). In this way, soil sampling unit and plant could be unambiguously paired. After counting the number of shoots in the above-ground plant sample, plant dry weight was determined after drying at 85 ^{0}C. The dry weight was divided by the number of shoots (DM) to obtain a comparable weight in further manipulations with the data (Tables 1-3).

Available soil P, K, and Ca were determined according to Allen et al. (1974). Soil characteristics represent the source (X), and the dry plant mass is the receiver (Y). The symbols of the source and the receiver are the classes in the table below. The "channel" is the incidental frequency of certain source symbols (f_{ij}) at the receiver.

		Y 1........ j ....s	
	1		
	.		
	.		
X	i	.... f_{ij}	$f_{i.}$
	.		
	.		
	r		
		$f_{.j}$	$n = \Sigma f_{.j} = \Sigma f_{i.}$

The formulae used for 9AI information quantity are summarized below following Orlóci (1978).

$I(X) = n \ln n - \Sigma f_{i.} \ln f_{i.}$ – the information of the source,

$I(Y) = n \ln n - \Sigma f_{.j} \ln f_{.j}$ – the information of the receiver,

$I(X,Y) = n \ln n - \Sigma f_{ij} \ln f_{ij}$ – joint information,

$I(X;Y) = I(X) + I(Y) - I(X,Y)$ – mutual information,

$E(X;Y) = I(X,Y) - I(X;Y)$ – equivocation,

$d(X;Y) = E(X;Y) / I(X,Y)$ – Rajski metric,

$r(X;Y) = (1 - (d(X;Y))^2)^{1/2}$ – coherence coefficient, its value ranges between 0 and 1 (details in Orlóci 1978, 1991).

The mean of I(.,.) values corresponds to the entropies, H(.,.). In communication theory, the following expressions are used (Reza 1966):

H(X) – the entropy of the source,

H(Y) – the entropy of the receiver,

H(X,Y) – the entropy of the entire communication system,

H(X|Y) the source-related entropy which indicates how precisely the content of input can be determined if the output is known, this is the mean of the mutual information.

H(Y|X) is the receiver-related entropy if the transmitted symbol is known; this is the mean of the equivocation (the noise in the channel). By multiplying H (.,.) values with n, I(.,.) values can be obtained. Equivocation, E(X;Y), is minimum (zero) if I(X,Y) - I(X;Y) = 0, that is if joint information and mutual information are equal, and it is maximum if I(X,Y) is maximum and I(X;Y) = 0, the lack of mutual information denotes that the source and the receiver are independent of each other. When every symbol of the source is admitted by the receiver with the same probability, equivocation is maximum and the coherence coefficient equals zero. When a given symbol of the source corresponds to a single symbol of the receiver, equivocation is zero and the coherence coefficient yields one.

Results

Information values show increasing tendencies from spring to autumn. The same is true for the values of equivocation, coherence coefficient and the entropies (Table 4). The source information increased the least in the case of Ca. For P and K, the increase of joint information, I(X,Y), and mutual information, I(X;Y) from spring to autumn was large, while in the case of Ca changes could hardly be observed. The value of mutual information increased by more than 100% for K and P (186%; 124%). The enhancement of equivocation, E(X;Y), was also the smallest for Ca. A similar phenomenon could be observed in the case of the coherence coefficient. The most probable explanation of the differences in the three elements is that in the case of Ca much less fluctuation can be expected in the plant's requirement during the growing season than in the case of K and P.

Since the sources and receivers may contain different number of symbols, the potential maximum of equivocation varies. Therefore, we calculated the relative equivocation by expressing the actual equivocation in the percentage of the maximal one. The values of relative equivocation are presented in Table 5. In all three cases, similar percentages were recorded in spring and autumn (Table 5). The relative equivocation underwent very little variation.

Discussion

The increasing joint information from spring to autumn (Table 4) can be explained. In autumn, one symbol of the source is admitted by the receiver in many cases with approximately the same (often small) probability. Ecologically, this phenomenon may have connection with the abundance of the P and K resources. The latter has to do with the fact that for P and K the numbers of classes increase in autumn. Although mutual information also increases, the coherence coefficient hardly reaches 0.4. This indicates that only very uncertain conclusions can be attained about the behavior of the receiver on the basis of the source and visa versa, as suggested by the high value of the noise, H(X|Y)

Table 1. Frequency of symbols of the source X (phosphorus in the soil, mg/100 g) and the receiver Y (dry weight of 10 shoots in g) and their sum. (A) Spring sampling. (B) Autumn sampling.

A

X\Y	0.2495*	0.3495	0.4495	0.5495	0.6495	total
1.125*	6	16	8	2	1	33
2.185	5	7	4	3	1	20
3.245	1	4	1			6
4.305					1	1
total	12	27	13	5	3	60

B

X\Y	0.2495*	0.3495	0.4495	0.5495	0.6495	0.7495	total
2.185*	1	1	4	1	1		8
3.245	1	3	6	1	1	1	13
4.305	2	2		2	2	2	10
5.365	3	6	11	1	2		23
6.425		1	3	2			6
total	7	13	24	7	6	3	60

* mean values of classes

Table 2. Frequency of symbols of the source X (potassium in the soil, mg/100 g) and the receiver Y (dry weight of 10 shoots in g) and their sum. (A) Spring sampling. (B) Autumn sampling.

A

X\Y	0.2495*	0.3495	0.4495	0.5495	0.6495	total
2.86*	5	16	7	3		31
4.09	6	8	6	2	3	25
5.32	1	3				4
total	12	27	13	5	3	60

B

X\Y	0.2495*	0.3495	0.4495	0.5495	0.6495	0.7495	total
2.86*		2	1				3
4.09	1	2	6	2	2		13
5.32	4	6	10	4			24
6.55	1	2	2		1		6
7.78	1	1	3	1	3	2	11
9.01			2			1	3
total	7	13	24	7	6	3	60

* the mean values of classes for X and Y

Table 3. Frequency of symbols of the source X (calcium the soil, mg/100 g) and the receiver Y (dry weight of 10 shoots in g) and their sum. (A) Spring sampling (B) Autumn sampling.

A

X\Y	0.2495*	0.3495	0.4495	0.5495	0.6495	total
19.75*	2	2	1			5
27.35	6	8	3	2	1	20
34.95	3	11	6	1		21
42.55	1	1	2	2	1	7
50.15		4	1		1	6
57.17		1				1
total	12	27	13	5	3	60

B

X\Y	0.2495*	0.3495	0.4495	0.5495	0.6495	0.7495	total
19.75*	1	4	9		1		15
27.35	3	4	8	2	1	1	19
34.95	2	1	3	3	3	1	13
42.55		2	4	1	1	1	9
50.15	1	2		1			4
total	7	13	24	7	6	3	60

* mean values of classes for X and Y

Table 4. Information values.

	Phosphorus		Potassium		Calcium	
	spring	Autumn	spring	autumn	spring	autumn
I(X)*	59.6107	89.7880	53.1899	92.3239	89.3919	90.4310
I(Y)	82.1668	94.7539	82.1668	94.7539	82.1668	94.7539
I(X,Y)	136.4721	172.6459	130.2202	172.3613	162.0788	173.8860
I(X;Y)	5.3054	11.8959	5.1366	14.7165	9.4799	11.2989
E(X;Y)	131.1667	160.7500	125.0837	157.6448	152.5989	162.5871
r	0.2761	0.3648	0.2781	0.4043	0.3369	0.3546
H(X|Y)	0.0884	0.1983	0.0856	0.2453	0.1580	0.1883
H(Y|X)	2.1861	2.6792	2.0867	2.6274	2.5433	2.7098

Table 5. (A) Maximum equivocation.(B) Ratio of the actual to the maximal equivocation (relative equivocation).

A

	Spring number of Symbols		maximum E (X;Y)	**Autumn** number of symbols		maximum E (X;Y)
	source	Receiver		source	receiver	
phosphorus	4	5	179.7439	5	6	204.0718
potassium	3	5	162.483	6	6	215.0112
calcium	6	5	204.0718	5	6	204.0718

B

	Relative equivocation %	
	Spring	Autumn
Phosphorus	73	79
Potassium	77	73
Calcium	75	80

Table 6. Niche breadth of the receiver (plant) and the efficiency and relative redundancy of the channel (soil).

		Phosphorus	Potassium	Calcium
niche breadth	spring	0.9935	0.8865	1.4898
	autumn	1.4965	1.5387	1.5072
efficiency of the channel (evenness)	spring	0.7166	0.8068	0.8315
	autumn	0.9298	0.8588	0.9365
relative redundancy	spring	0.2833	0.1932	0.1685
	autumn	0.0702	0.1412	0.0635

(Table 4). Knowing the quantity of P, K and Ca in the soil does not or render the estimation of the dry plant mass, or inversely, knowing the dry plant mass does not lead to reliable inference about P, K and Ca in the soil. This is reflected in the low value of mutual information.

The theory of communication systems is closely connected with niche theory, since both use information theory. Niche width can be estimated based on the Shannon formula: the joint information I(X,Y) divided by n defines the niche width (if I(X,Y) is consistent with the Shannon formula). The diversity of the source divided by the logarithm of the number of the source symbols gives the evenness which is a measure of the efficiency of the channel (Table 6). The complement of evenness defines relative redundancy. It seems that the wider the niche, the larger the information-theoretical uncertainty of the entire system, the noise, in the channel.

Ecologically, wide niche indicates that a) the population is "generalistic" (Pielou 1975) for the (soil) factor in question in the given period (Précsényi et al. 1980) and b) the populations have flexible response which ensures survival and propagation in the seasonally changing environments (Pielou 1975). Furthermore, communicational aspects point to the importance to have the largest possible mutual information, i.e., when one symbol of the source corresponds to a single symbol of the receiver.

The increase in equivocation occurring on the receiver side from spring to autumn in the cases of P and K may be in connection with the nutrient enrichment of the soil, and also with the population entering another phenophase, after seed spreading in the autumn. The behavior of Ca differed from the two other elements, indicated by differences in information values in most cases, especially in the spring and their minor modification in Ca from spring to autumn.

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