RELATIONSHIPS BETWEEN METEOROLOGICAL STATISTICS
AND GRASSLAND PRODUCTION

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SUMMARY

For appropriate grassland management precise forecasting of production is required and for this a similar precise forecasting of meteorological conditions becomes necessary. In general, however, long term prediction of meteorological conditions of more than three months, for example, is almost impossible so that a method which will circumvent this impossibility is required. One substitutive method is to construct several hypothetical types of meteorological seasonal changes based upon accumulated data and to choose one or two most probable for a given area over a given year instead of attempting to forecast actual meteorological conditions.

In this study, year-to-year variations in the 10-day mean of daily air-temperatures, measured at Nishinasuno, are classified into several meteorological patterns and grassland production for each of these patterns is predicted.

At the National Grassland Research Institute (36°55'N, 139°58'E and 320m asl) in Tochigi Prefecture, the mean of daily air-temperatures has been recorded for 10-day intervals since 1944. In this report, several statistical characteristics of seasonal and annual changes in these meteorological data and relationships between these meteorological changes and the herbage production of grazing grassland are discussed.

The results are summarised as follows: 1) the year-to-year variations in the 10-day mean of daily air-temperatures are slight during May and from August to November, and extensive from December to March and from June to July.

2) Principal component analysis and a clustering technique (k-means) were applied to the 42 years of plant growing season meteorological data, six different seasonal meteorological change types were classified and changes in grassland production for each of these types were simulated using Shiyomi's mathematical model. These results may contribute to forecasting grassland biomass production.

1. Introduction

For appropriate grassland management precise forecasting of production is required and for this a similar precise forecasting of weather conditions is necessary. In general, however, long term prediction of meteorological conditions extending over more than one month is almost impossible so that a

Key words: Clustering; Meteorological data; Grassland production; Principal component analysis

method which will overcome this difficulty is required. One substitutive method is to construct several hypothetical types of meteorological seasonal changes based on accumulated data and to choose one or two most probable for a given area in a given year, instead of attempting to forecast actual meteorological conditions.

2. Materials and Methods

Meteorological data have been recorded since 1944 at the site of the present National Grassland Research Institute

Table 1. Year-to-year variations of the 10-day mean of daily air-temperatures, °C, calculated from records covering 42 years

Month		Mean	Range	Variance	Skewness	Kurtosis
Jan.	F	1.1	-2.0, 4.6	2.34	0.01	2.39
	S	0.7	-2.1, 4.2	2.21	0.23	2.50
	T	0.8	-3.8, 4.2	3.53	-0.27	2.29
Feb.	F	0.9	-4.2, 5.2	3.79	0.02	2.96
	S	1.5	-2.7, 6.2	4.37	0.23	2.60
	T	2.1	-2.0, 6.5	4.39	0.07	2.21
Mar.	F	3.1	-2.0, 7.2	3.67	-0.28	3.00
	S	4.3	-0.1, 8.1	3.79	-0.10	2.32
	T	5.9	2.1, 8.4	2.63	-0.41	2.34
Apr.	F	8.6	4.8, 12.1	3.46	-0.19	2.24
	S	10.4	5.6, 15.5	3.74	0.22	3.21
	T	12.3	8.2, 15.5	2.82	-0.12	2.68
May	F	14.0	10.2, 17.0	2.39	-0.40	3.02
	S	15.2	10.7, 17.5	1.76	-0.96	4.65
	T	16.4	13.9, 18.6	1.13	-0.03	2.32
Jun.	F	17.7	14.8, 20.5	1.90	-0.34	2.39
	S	18.8	15.0, 23.0	2.78	-0.09	3.03
	T	19.8	17.3, 24.0	2.55	0.55	2.88
Jul.	F	21.2	18.4, 25.0	3.17	0.23	2.04
	S	22.7	18.8, 25.8	2.96	-0.21	2.53
	T	24.4	19.5, 27.3	2.31	-0.90	4.36
Aug.	F	24.7	20.0, 26.8	1.54	-1.36	5.95
	S	24.6	21.6, 27.0	1.42	-0.60	3.20
	T	23.4	19.8, 25.3	1.73	-0.78	2.95
Sept.	F	21.9	18.7, 25.2	2.35	-0.05	2.29
	S	20.3	17.2, 23.7	1.93	0.43	2.87
	T	17.9	15.5, 21.0	1.58	0.25	2.92
Oct.	F	16.0	13.8, 17.9	1.20	-0.23	2.07
	S	14.4	11.4, 17.9	2.03	0.26	2.88
	T	12.6	10.0, 14.9	1.54	-0.16	2.19
Nov.	F	11.0	7.8, 13.7	2.33	-0.19	2.45
	S	8.4	5.5, 11.6	1.70	0.16	2.93
	T	6.8	3.9, 10.0	2.30	-0.02	2.14
Dec.	F	4.9	1.3, 9.1	2.39	0.12	3.05
	S	3.4	-1.3, 7.2	3.84	-0.31	2.53
	T	2.3	-1.3, 6.0	3.36	0.33	2.06

F, S and T denote the 1st, 2nd and 3rd 10-day periods of their respective months.

(NGRI) (36°55'N, 139°58'E, 320m asl). In this report, records of the 10-day mean of daily air-temperatures are used for the analysis. For these records, first, the means over the 42 years and then their year-to-year variation are calculated, and second, the 42 years are classified by a clustering method (k-means by Mahalanobis' distance) and by principal component analysis. Prediction of grassland production is made using a model previously developed by Shiyomi et al.(1983).

Table 2. Clustering of years by their 10-day mean of daily air-temperature from March to October

Pattern	1	2	3	4	5	6	Overall Average
# of years	8	4	3	9	5	13	
Year	51,53,66 74,76,79 80,82	45,47 54,57	49,70 84	56,58,60 68,69,72 77,81,83	44,63 65,71 78	46,48,50,52 55,59,61,62 64,67,73,75 85	
Month	°C						
Mar. F	4.7	1.8	-0.1	3.2	1.8	3.5	3.1
S	5.4	3.3	1.3	5.6	3.4	4.1	4.3
T	5.5	6.2	2.8	7.2	5.8	5.8	5.9
Apr. F	8.4	9.2	6.1	7.8	7.1	10.3	8.6
S	9.3	11.1	8.4	10.7	9.5	11.4	10.4
T	12.2	10.9	11.4	13.4	10.8	12.8	12.3
May F	13.4	12.4	14.5	14.6	12.7	15.1	14.1
S	14.9	14.0	15.6	14.7	16.2	15.5	15.2
T	17.0	15.5	17.0	16.0	16.6	16.4	16.4
Jun. F	18.4	15.7	17.0	17.9	17.9	17.9	17.7
S	19.1	16.8	18.8	18.4	19.8	19.0	18.8
T	20.2	18.1	18.5	19.7	21.5	19.9	19.8
Jul. F	19.8	20.2	19.9	21.1	22.7	22.1	21.2
S	21.1	20.5	23.8	22.6	23.5	23.8	22.7
T	24.1	23.1	25.3	24.3	23.8	25.1	24.4
Aug. F	23.6	24.6	24.4	25.0	25.4	24.9	24.7
S	24.1	25.2	25.0	24.0	24.5	25.1	24.6
T	23.2	23.9	23.5	22.1	23.8	24.0	23.4
Sept. F	21.7	20.6	22.0	22.6	19.8	22.8	21.9
S	19.6	21.0	20.0	20.3	19.5	20.8	20.3
T	17.5	17.7	18.0	18.1	17.7	18.1	17.9
Oct. F	16.4	15.2	14.8	16.3	14.9	16.6	16.0
S	15.8	13.1	14.9	14.0	13.0	14.6	14.4
T	13.0	12.4	11.4	12.7	13.0	12.4	12.6

Remarks: Pattern 1= high temperatures in the 1st and 2nd 10-days of March, low in July and August and high in the 2nd and 3rd 10-days of October;
Pattern 2= low in the 1st and 2nd 10-days of March, low from the 3rd 10-days of April to the 1st 10-days of August;
Pattern 3= extremely low until the end of April;
Pattern 4= a little high in March and April;
Pattern 5= low until the 1st 10-day period of May, high from the 2nd 10-days of May to the 2nd 10-days of July and low from the 3rd 10-day period;
Pattern 6= high throughout whole season, especially in April, July and September

3. Results and Discussion

1) Year-to-year variation of the 10-day mean of daily air-temperatures

Averages of the 10-day means of daily air-temperatures, their yearly variation over the 42 years and the shape of their distribution are shown in Table 1. Records of 10-day means of daily air-temperatures, which are 42-year averages, indicate a minimum of 0.7°C in the 2nd 10-day period of January and a maximum of 24.7°C in the 1st 10-day period of August. Variances around these temperature averages take small values from the 2nd 10-day period of May to the 1st 10-day period of June and from the 1st 10-day period of August to the 3rd 10-day period of October. On the other hand, they take large values from December to April and from the 2nd 10-day period of June to the end of July. The measures of skewness for the temperatures take 20 positive and 22 negative values. The frequency distributions of the temperature may be a symmetrical pattern around the averages. Kurtosis measurements take values over 3 from May to August and values under 3 from September to February.

2) Classification of seasonal changes in the 10-day mean of daily air-temperatures

Forty-two years were classified into six clusters by their annual differences from the 10-day mean of daily air-temperatures. Variables utilized in this analysis were the 10-day means of air-temperatures during the pasture plant growing season, specifically, from March to October. The results are shown in Table 2. In this table, Pattern 1 contains eight years, i.e., 1951, 53, 66, ..., 82, and the means for each 10-day period during these 8 years are shown. In the last column of Table 2, the overall averages for the 42 years are shown for comparing to each of the patterns, and distinctive features for each pattern are summarized at the bottom of the table.

Table 3. Eigen values and vectors in principal component analysis applied to 42 sets of monthly mean air-temperature records

	Principal component			
	1st	2nd	3rd	4th
Eigen value	2.604	1.604	1.332	0.981
%	28.9	17.8	14.8	10.9
Cummulative %	28.9	46.8	61.6	72.5
Variable				
March	0.311	-0.268	-0.396	0.522
April	0.344	0.325	-0.429	0.160
May	0.373	0.187	0.220	-0.125
June	0.241	-0.310	0.616	0.180
July	0.204	0.404	0.423	0.496
August	0.025	0.608	0.094	-0.091
September	0.411	0.203	-0.182	-0.264
October	0.457	-0.299	-0.030	0.064
November	0.409	-0.165	0.094	-0.571

Figure 1. Scatter diagrams of principal component scores covering 42 years. This analysis used correlation coefficients between monthly mean air-temperatures during the herbage growing season, i.e., from March to November. Small numbers in the figures denote year and the larger circled numbers indicate the patterns defined in Table 2.

For example, Pattern 3, including 1949, 70 and 84, has the feature of being extremely low until the end of April and normal after May. In this pattern, the mean daily air-temperature is about 3°C lower in March and about 2°C lower in April than the overall average. Such low early spring temperatures may cause serious delay of spring and early summer plant growth.

A principal component analysis for the given 42 years of data was made using as variables the monthly mean air-temperatures from March to November and their correlation coefficients. The eigen values and the corresponding vector for each principal component are shown in Table 3. The first three components contribute 61.6% of the variation. The first component may be concerned with temperatures for the whole season, excepting August, because all elements of the first eigen vector are positive and large. The second component may be concerned with summer temperatures because elements concomitant to July and August, of the second eigen vector, take large positive values, but this interpretation contains a little ambiguity since elements concomitant to April and June are also large.

The third component coincides with the features of a cold early-spring and a hot early-summer. Scatter diagram of 42 data sets in 3 dimensional principal component space are shown in Figure 1. Although variables used in this analysis are different from those in the previous clustering procedure, the two results resemble each other. That is, circled numbers in Figure 1 indicate patterns in Table 2, and years belonging to the same pattern in Table 2 may be located within a relatively close area in Figure 1.

3) Prediction of plant growth corresponding to the 6 seasonal air-temperature change patterns using a grazing pasture system model

As stated previously, a system model for predicting seasonal changes in plant and animal biomass has been developed. It contains many parameters concerning environmental abiotic conditions, and one of them is daily changes in air-temperature. In that model, air-temperatures have an important role in photosynthetic activity, growth and respiration or heat production. High temperatures cause activation of photosynthesis, growth of organisms and an increase of energy loss by respiration. Low temperatures cause inverse effects.

Table 4 contains results applied the system model to the 6 seasonal air-temperature change patterns defined previously. It is assumed in these simulations that seven young cows, whose total body weight is 1,837 kg, per 2 ha, are released for grazing on April 10 and that their grazing continues until October 30. Moreover, we assume that each cow consumes herbage amounting to a dry matter weight equivalent of 2.5% of the cattle body weight in live matter and that the body weight increase for each cow during the grazing period is 106.4 kg. As shown in this table, plant biomass on March 1 is fixed at 69.5 g/m² for each of the 6 patterns, and simulated plant growth (in some cases, negative growth or consumption) starts from that time point. Growth in Patterns 2, 3 and 5 is delayed until early-April but Patterns 2 and 5 recover their growth by

Table 4. Prediction of plant growth corresponding to the 6 seasonal air-temperature change patterns, defined in Table 2, using a grazing pasture model; units are in grams of dry weight/m²; see text

Pattern		1	2	3	4	5	6	Average
Mar.	1	69.5	69.5	69.5	69.5	69.5	69.5	69.5
	11	91.8	58.4	59.5	93.1	58.4	92.8	93.2
	21	111.9	62.3	44.9	113.5	64.8	114.2	114.6
	31	124.0	96.3	43.5	163.7	91.6	126.5	126.5
Apr.	10	163.8	154.1	75.2	193.6	145.4	167.8	168.7
	20	161.4	155.3	109.9	173.7	153.3	160.0	162.5
	30	152.7	150.3	129.0	155.7	150.5	150.0	152.3
May	10	184.3	185.3	175.3	183.4	185.1	181.3	183.4
	20	221.5	222.3	213.1	221.5	219.5	235.3	220.5
	30	278.5	279.7	262.8	286.2	274.3	281.1	280.5
Jun.	9	339.4	346.5	323.6	346.9	336.2	338.2	342.4
	19	407.3	422.3	391.6	416.7	402.3	405.4	411.4
	29	360.9	378.6	353.1	369.4	353.4	360.0	364.9
Jul.	9	232.6	241.3	231.2	234.5	223.7	229.0	232.4
	19	196.1	200.9	191.5	193.9	186.0	188.6	192.7
	29	180.7	185.0	174.5	178.1	173.8	173.4	177.2
Aug.	8	179.2	181.1	173.8	175.9	173.4	172.8	175.8
	18	185.3	184.0	180.6	182.6	180.1	179.3	182.0
	28	186.1	183.5	182.6	186.3	182.3	181.2	183.7
Sept.	7	169.5	169.2	167.3	169.3	169.9	165.1	168.0
	17	163.9	162.9	162.3	162.4	165.5	159.7	162.3
	27	166.8	165.0	165.0	164.8	167.4	163.1	165.0
Oct.	7	168.5	169.0	169.3	167.2	170.6	165.9	167.8
	17	156.1	160.4	158.7	157.7	161.6	156.2	157.7
	27	154.2	159.0	158.3	156.6	159.0	155.7	156.5
Nov.	6	181.1	184.4	184.8	182.7	183.8	182.5	182.8

the end of April and low plant biomass continues only in Pattern 3 until the end of July. As indicated in these simulated results, low air-temperature in the spring or a delayed spring causes serious loss of plant production.

In Pattern 6, mid-summer plant biomass is a little less than that of the simulated result obtained using overall average air-temperatures because high summer temperature accelerates energy loss by respiration and suppresses photosynthesis.

Amounts of rainfall and sunshine are also important for plant growth, but in the Kanto Area of Japan where NGRI is located the amounts available may be sufficient for plant growth. Incidentally, yearly rainfall and global solar radiation at NGRI in 1985 were 1,405.5 mm and 4,158.2 MJ/m², respectively. For this reason, these two amounts were not dealt with in this study.

Many system models have been developed for predicting crop yield (e.g., Horie, 1987), crop growth (e.g., Shiyomi et al., 1987), plant disease and insect pest dispersions (e.g., Shiyomi et al., 1982) and so on in agriculture. These models do, in most cases, contain weather influence factors, however, as present day long term prediction of meteorological conditions is still very difficult, the method described herein, i.e., patterning of meteorological seasonal changes, may offer greater effectiveness in agriculture production prediction.

4. Literature Cited

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