Working Paper

Impact of Semi-Arid Weather Conditions on Wheat and Maize Yield

Andrea Harnos

WP-94-17
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Contents

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Abstract

In recent years the need for assessing land capability and planning production has grown. In this paper we try to describe the impact of the weather on crop yield in semi-arid regions where weather variability and uneven distributions of precipitation strongly influence the yield. We tried to describe the relationship between the variations in the yield and the weather parameters. We give an introduction to plant phenology, and the analysis of yield time series. The applied model is $\eta(\xi,t) = y(t) + \nu(\xi,t)$, where η denotes the yearly yield, t is the time, ξ represents the weather, $y(t)$ expresses the effect of agrotechnological and genetic development, and ν is the effect of weather on yield. To describe the effect of the first factor, a logistic time evaluation can be used. Soil moisture has a big role in crop production, mostly it determines the size of the yield. We describe a simple soil moisture model and using this model we analyze the relationship between yield and soil moisture. Instead of monthly data we used phenophase data because the phenophases are not equally sensitive to the water and temperature conditions. Finally we show a more developed model for maize which starts from the relationship between relative yield decrease and relative evapotranspiration deficit:

$$\left(1 - \frac{Y_a}{Y_m}\right) = k \cdot \left(1 - \frac{ET_a}{ET_m}\right),$$

where Y_a means the actual yearly yield, Y_m is the potential maximum yield, ET_m is the maximum evapotranspiration and ET_a is the actual evapotranspiration.

1 Introduction

In recent years the need for assessing land capability and planning production has grown. Decision making in agriculture at every level must begin with the estimation of production circumstances. This includes the assessment of predictable hazards (droughts, floods etc.) in order to be able to prepare for them.

In this paper we try to describe the impact of the weather on crop yield. Hungary is located in the so called semi-arid region. A large part of the world is semi-arid, meaning that the annual precipitation is not more than 600 mm. Weather variability and uneven distributions of precipitation strongly influence the yield. Above all, Hungary is located at the border of maize and wheat belts so the yield is very sensitive to the weather. Consequently productivity is quite variable.

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Figure 1: Hungary

For the purpose of minimizing the risk of production (in the sense of minimizing the variability and maximizing the income [4]) we tried to describe the relationship between the variations in the yield and the weather parameters. We developed two region level methods. The first was applied to wheat and the second to maize. Both methods can be applied to any crop.

These methods use two weather parameters, the daily precipitation and the daily average temperature which are available in almost every farm. To validate the models we used average yearly yields (1951-1989) of whole counties. In Hungary the size of one county is about 5000 km. We illustrate the two methods with the case of Szolnok county located in the middle of the Great Plain. (Figure 1.) This is a relatively homogeneous territory from the viewpoint of soil and other natural and agrotechnological conditions. It is the driest county in Hungary.

In chapter 2 we give an introduction to plant phenology. The third chapter deals with the analysis of yield time series, and the fourth describes a simple soil moisture model. In chapter 5 we analyze the relationship between yield and soil moisture using the model described in chapter 4. Finally we show a more developed model for maize in chapter 6.

2 The relationship between weather and plant growth

2.1 Phenophases

We define the visible changes during a plant's life as phenophases [8,11]. For example, these may be: flowering, graining, ripening, shooting, etc. The intervals between the phases are not equally sensitive to the water and temperature. We can examine the relationship between the

- length of these phases and the meteorological variables and

- the developing rate and the meteorological variables.

The developing rate is the reciprocal of the phase length, it gives the ratio of the development per day. The length of the phases is more or less determined by the so-called temperature sums. Plants develop faster when it is warm and slower when it is cool. These temperature sums are actually the sums of those parts of the daily temperature that are effective according to the plant:

$$\text{temperature sum} = \sum_i (t_i - \text{const}). \tag{1}$$

t_i denotes the daily average temperature. Naturally, different temperature sums belong to different phenophases and the constant may depend on the given phenophase.

2.2 Maize

Maize is one of the most important cereals both for human and animal consumption and is grown for grain and forage [2,8,11]. This crop is grown in climates ranging from temperate to tropic during the period when mean daily temperatures are above 10-12 $°C$ and frost free. The adaptability of the crop varieties to different climates varies widely.

Maize is produced in almost all parts of the country. Hungary is located on the upper part of the region where maize can be grown. Due to this fact and the variability of weather, the yearly yields are highly variable. For optimal growth, an average temperature of 22-25 $°C$ is suitable.

Maize makes efficient use of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate.

The sowing date of maize may be from the middle of April until the beginning of May, because at least 10-12 $°C$ is needed for emergence. Shooting can be expected between 1st and 20th of May. If the temperature is increasing, the length of this phase decreases. This interval is 10-15 days long. The development of the plant is strongest between shooting and flowering. Shooting starts at the beginning of May, and flowering between 1st and 20th of July. The average length of this interval is 60-70 days. The time between flowering and silk production is very short, roughly 3-10 days. Maize ripens 55-75 days after silk production. It can be expected between the middle of September and the beginning of October.

2.3 Wheat

Wheat is grown in different temperate climates, in the subtropics with winter rainfall, in the tropics near the equator, in the highlands with altitudes of more than 1500 m and in the tropics away from the equator where the rainy season is long and where the crop is grown as a winter crop [2,8,11]. The length of the total growing period of spring wheat ranges from 100-130 days while winter wheat needs 180-250 days to mature.

In Hungary mostly winter wheat is cultivated. Wheat is sown in the second half of October depending on weather and location. Emergence can be expected from the end of October until the middle of November. The length of this interval is between 12 and 22 days depending first of all on the temperature. Usually 5 $°C$ is enough for the emergence if there is sufficient water in the soil. Sometimes the wheat emerges only in the spring due to the cold weather and late sowing. Tillering can be expected between 10th of April and

10th of May. Usually 25-50 days pass from emergence to tillering. After tillering the head development is usually 35-45 days long depending strongly on the temperature. Winter wheat is the most sensitive to temperature changes in this period. Approximately 35-45 days pass until flowering and 35-50 days pass from yield formation until maturity. The harvest date is between the end of June and the middle of July.

3 Analysis of time series of average yields

3.1 Yield growing trajectories

We used a generally accepted simple hypothesis to analyze yield time series [5]. Accordingly, two factors influence the yield:

- genetic and agrotechnological development and
- the weather.

The applied model is

$$\eta(\xi,t) = y(t) + \nu(\xi,t), \tag{2}$$

where η denotes the yearly yield, t is the time, ξ represents the weather, $y(t)$ expresses the effect of agrotechnological and genetic development, and ν is the effect of weather on yield.

To describe the effect of the first factor, a logistic time evaluation can be used because:

1. we can assume that before the fifties the yields either did not change or hardly changed (lower asymptote),
2. in the fifties and sixties there was a real growth in yields due to the agrotechnological development and new species,
3. we assumed that the average yields would grow slowly after the nineties (upper asymptote).

Figures 2 and 3 show the fitted curves to the wheat and maize yield time series in Szolnok county. The logistic trend is plotted by a solid line and yearly yields are plotted with squares.

$y(t)$ can be divided into two parts:

$$y(t) = C + \tilde{y}(t), \tag{3}$$

where C is the yield before the growth and $\tilde{y}(t)$ describes the growth due to the agrotechnological and genetic development. After the earlier assumptions, we can suppose that $\tilde{y}(t)$ is the solution of the following differential equation:

$$\begin{aligned} \frac{d\tilde{y}(t)}{dt} &= \alpha \cdot \tilde{y}(t)\left(1 - \frac{\tilde{y}(t)}{K}\right), \\ \tilde{y}_0 &= N_0. \end{aligned} \tag{4}$$

The analytical form of $y(t)$ is

$$y(t) = C + \frac{e^{\alpha t}}{1/N_0 + (e^{\alpha t} - 1)/K}. \tag{5}$$

where α is a growth factor, $C + K$ is the upper limit of the growth, C is the yield in the past, and $C + N_0$ is the initial yield. The values of the parameters were determined from a nonlinear regression analysis of the yearly data.

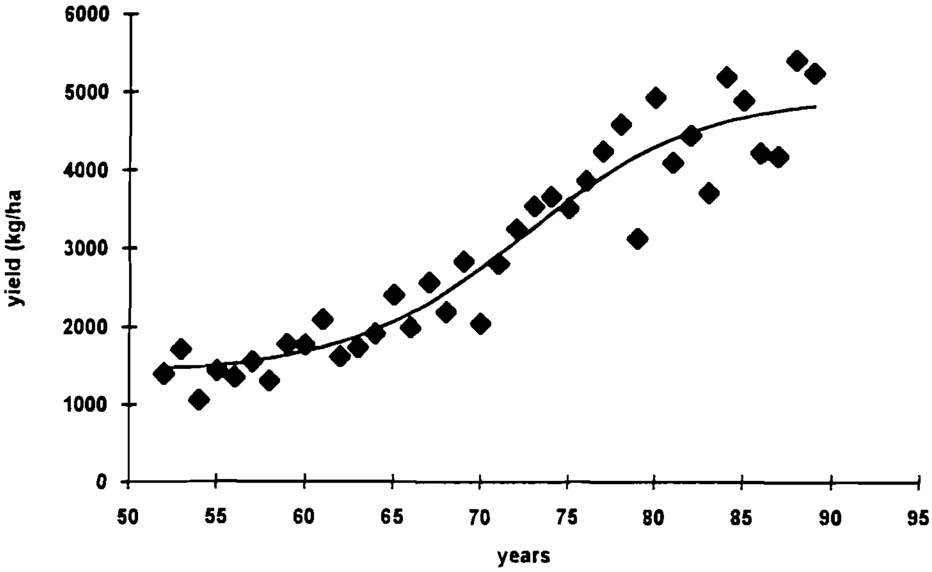

Figure 2: Yearly variation of wheat yield (Hungary, Szolnok county, 1951-1989)

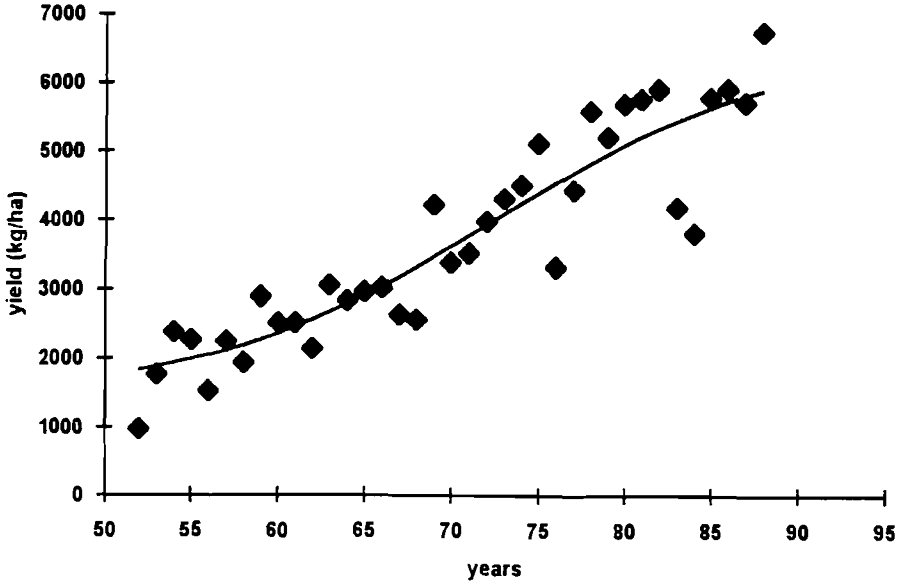

Figure 3: Yearly variation of maize yield (Hungary, Szolnok county, 1951-1989)

3.2 Analysis of the residuals

We assumed that the agrotechnological trend gives the expected value of the yield, and the difference between the measured and the expected yield is the effect of weather. These differences, called residuals ($\nu(\xi,t)$), give us an opportunity to compare different areas from the viewpoint of crops. Thus we examined three questions:

- Are the residuals time independent or not?
- Are the observations independent within one sample?
- What is the distribution of the residuals?

To answer the first question in the case of maize, we examined if the rate of the residuals is growing or not in time by a simple regression analysis of the absolute residuals. We determined that the slope of the fitted lines is zero, so the residuals are time independent. The residuals also turned out to be independent and normally distributed. The parameters of the normal distribution are $\mu = 0kg$ and $\sigma = 400kg$ (μ denotes the expected value and σ denotes the standard deviation).

In the case of wheat, using the same methods, we found that the residuals were time dependent (they grow in time), but the relative residuals ($\nu(\xi,t)/y(t)$) were not time dependent and, in addition, the relative residuals were independent and normally distributed. The parameters were $\mu = 0$ and $\sigma = 0.12$. We tried to do a multiple regression analysis between the residuals and the pure weather variables, but we could find only weak correlations.

4 Soil moisture model

In this chapter we present a simple soil moisture model and its application. Using this model we could establish closer connection between the yield and the meteorological parameters. Because of the weak relationship mentioned at the end of the previous chapter, we started to think about a descriptor variable that is better than the pure weather variables. From the literature the soil moisture seemed to be the best choice [1,6,7].

Soil moisture shortage is a limiting factor for plant growth. Soil moisture has a big role in crop production, mostly it determines the size of the yield. If there is too much moisture, the land cannot be cultivated, and if there is not enough, the plants cannot develop well. The yield loss depends on the degree and the duration of the water shortage. The developing phase in which water shortage occurred is very important because these phases are not equally sensitive to the water deficit. This model uses only the average yields, temperature, precipitation and soil moisture of Szolnok county, so the model cannot be applied to one plot of land.

4.1 The water balance equation

The soil moisture can be determined by the following differential equation:

$$\frac{dSW(t)}{dt} = R(t) - E(t) - I(t) - RO(t), \tag{6}$$

where SW denotes the soil moisture in the examined layer (in this case it is the upper $100cm$), R is the rainfall, E is the amount of the evapotranspiration, I is the infiltrated

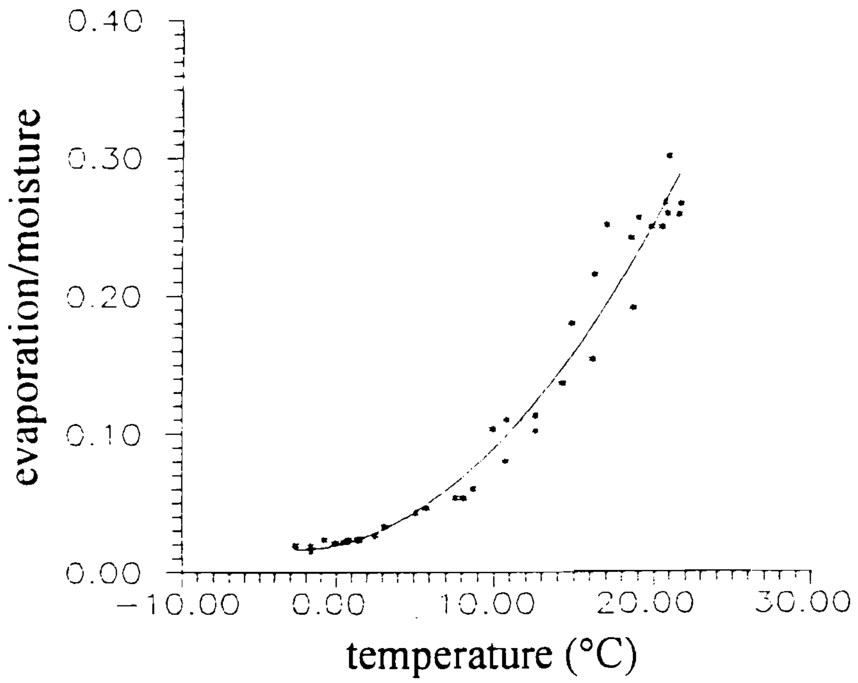

Figure 4: Loss/moisture ratio as a function of average temperature

water and RO is the runoff. All of the variables are in mm [1,10]. We used the discrete form of the equation because we had only daily data:

$$SW_{i+1} = SW_i + R_i - E_i - I_i - RO_i, \tag{7}$$

where i denotes the i^{th} day. Usually only temperature and rainfall data are available. For this reason we wanted to find a relationship between the variables included in the equation and the data we have. The runoff (RO), the infiltration (I) and the evapotranspiration (E) are combined in the variable $L(t)$, the loss function. This turned out to be proportional to the soil moisture for the case of Szolnok county. The infiltration and the runoff can be neglected in the summer half of the year and we had average data for evaporation, so it was possible to determine this loss function by regression analysis (Figure 4.)

This function is:

$$L(T, SW) = SW \cdot (0.01995 + 0.002423 \cdot T + 0.00045 \cdot T^2), \tag{8}$$

where T denotes the temperature.

We used a constant for the winter half of the year, because evaporation does not play a big role when it is cold. The soil moisture formation for 1974 is shown in Figure 5.

5 The analysis of the relationship between the soil moisture and the yield by regression analysis in the case of wheat

5.1 Functional relationship between the developing rate and temperature in the case of wheat

Simple functional relationships have been determined between the developing rates and temperature [11]. These were calculated by a simple regression analysis for the winter

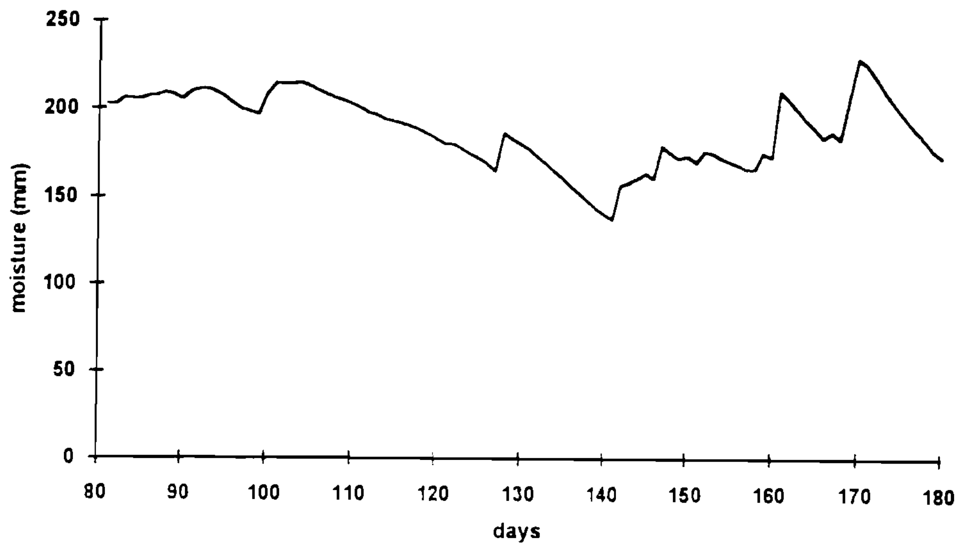

Figure 5: Soil moisture during the vegetation period in 1974.

wheat produced in Kompolt (Hungary). These relationships are:
for the sowing-shooting interval:

$$a(T) = 0.0353 \cdot 1.0745^T \qquad r = 0.77,$$

for the shooting-earing interval:

$$a(T) = 0.009 \cdot 1.0947^T \qquad r = 0.88,$$

for the earing-ripening interval:

$$a(T) = 0.0089 \cdot 1.0506^T \qquad r = 0.73.$$

T denotes the average daily temperature, $a(T)$ is the growth rate, and r is the correlation coefficient. Of course for other regions and other wheat species these relationships are not correct, but the differences turned out not to be large. The relationships are not very strong (as one can see from the correlation coefficients). Despite this fact we could apply these functions fairly well (chapter 4.).

Using the method described above, we could determine the starting dates of different phenophases (including the harvest date). These dates are shown in Table 1, in days starting 1st of January.

We calculated the moisture sums, the temperature sums and precipitation sums and the averages for one day of these quantities for every interval. Then we selected the significant variables by stepwise regression analysis. The dependent variable was, of course, the updated yearly yield. Updating the yields was necessary because there was an increasing trend. We determined earlier that the relative residuals were normally distributed and time independent, so we multiplied the yield predicted in 1990 by these relative residuals. Thus we were able to update the yields.

Most of the weather variables have an optimal range in which the plant develops optimally. In the case of the temperature, precipitation and soil moisture, the values of these variables are not so good below and above this interval and are sometimes certainly bad for the plants. For example, if the temperature is too high, the plant is damaged.

year	shooting	earing	ripening
52	115	136	182
53	113	142	183
54	124	149	189
55	122	150	192
56	121	147	189
57	108	138	179
58	122	138	181
59	107	135	180
60	111	138	181
61	96	129	172
62	106	135	181
63	106	131	171
64	107	136	174
65	114	140	183
66	101	124	170
67	105	131	174
68	97	119	162
69	107	130	174
70	108	137	178
71	98	122	167
72	85	118	161
73	102	126	169
74	89	123	170
75	94	117	162
76	99	124	167
77	90	115	160
78	95	126	172
79	92	118	157
80	104	133	177
81	83	115	157
82	101	122	165
83	83	106	150
84	91	118	163
85	88	113	161
86	83	107	150
87	87	118	158
88	87	113	155
89	69	101	148

Table 1: Dates of phenophases

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-3.130231E6	1.041575E6	-3.0053	0.0055
pre2	-5.562105	2.921918	-1.9036	0.0673
temp2	7603.916433	2495.691335	3.0468	0.0050
mois2*mois2	0.000025	0.000012	2.1154	0.0434
length2	-491.621723	567.022731	-0.8670	0.3933
avprel	674.802882	292.69404	2.3055	0.0288
avtempl	-48.014674	50.907281	-0.9432	0.3537
avtemp2	-1287.820833	1249.112393	-1.0310	0.3114
temp2*temp2	-4.543317	1.493726	-3.0416	0.0051
avpre2*avpre2	-158.819610	58.344571	-2.7221	0.0110
R-SQ. (ADJ.) = 0.5099 SE=441.804547 MAE= 302.436624				

Analysis of Variance for the Full Regression					
Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	9270337.	9	1030037.	5.27707	.0003
Error	5465355.	28	195191.		
Total	14735693.	37			
R-squared = 0.629108 Stnd. error of est. = 441.805					
R-squared (Adj. for d.f.) = 0.509892 correlation coefficient=0.793					

Table 2: The result of the regression analysis

This means it is not correct to use linear models to describe the relationship between these variables and the yield. A second degree model seemed to be better, so all of the squares of variables were included in the analysis.

As a result of the regression analysis, the following variables turned out to be significant: the average temperature (avtempl) and the average precipitation (avprel) of the shooting-earing interval, the moisture sum (mois2), the temperature sum (temp2), the precipitation sum (pre2), the length (length2), the average temperature (avtemp2) and the average precipitation (avpre2) of the earing-ripening interval. The result of the regression analysis is presented in Table 3. The predicted vs observed values are plotted in Figure 6.

From these results it turns out that the phenophases have a big role because the different phases are not equally sensitive to the water and temperature conditions. The soil moisture is very important in the second interval, which is the developing phase, and this corresponds with the experiments.

The correlation coefficient is very high comparing to the simple regression models.

6 The analysis of the impact of weather on maize yield

We tried to improve the method described in the previous chapters. For this reason we prepared a procedure to determine the amounts of yield decrease due to the weather [2,3].

It is possible to estimate the effect of water stress on yield if we calculate the relative evapotranspiration (ET_a/ET_m), so we can thus determine the relative yield loss. If the agrotechnological and weather conditions are optimal for plants and we are in a constraint free environment, the actual yield (Y_a) equals maximum yield (Y_m), $Y_a = Y_m$. If full water requirements are not met, $Y_a < Y_m$.

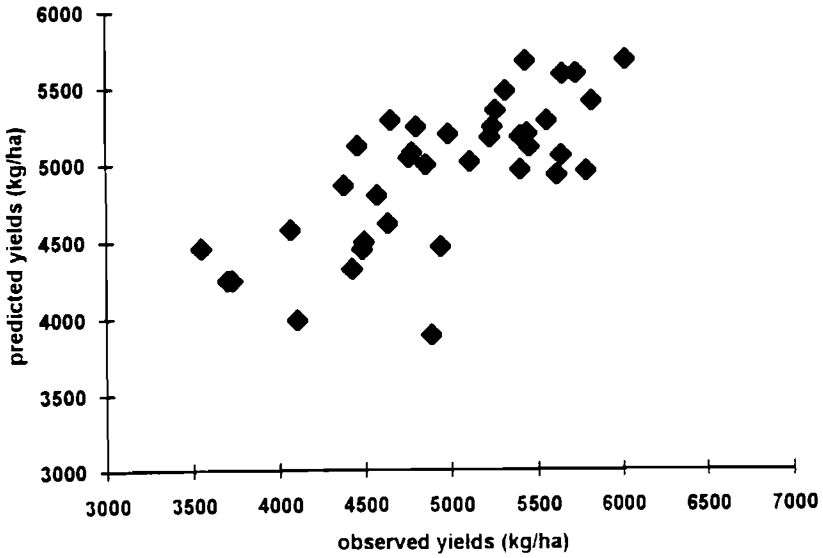

Figure 6: Observed vs predicted yields.

In order to evaluate the effect of water shortage, it is necessary to derive a relationship between relative yield decrease and relative evapotranspiration deficit:

$$\left(1 - \frac{Y_a}{Y_m}\right) = k \cdot \left(1 - \frac{ET_a}{ET_m}\right), \tag{9}$$

where Y_a means the actual yearly yield, Y_m is the potential maximum yield (which could be produced under optimal circumstances). Maximum evapotranspiration (ET_m) refers to conditions that exist when enough water is available for optimal growth. ET_m denotes the rate of maximum evapotranspiration of a healthy crop, grown in large fields under optimal circumstances. ET_a is the actual evapotranspiration. This is equal to maximum evapotranspiration when available soil water is adequate. k is an empirical yield response factor which varies under different growing conditions and also during the plant's life.

As we described in chapter 3, the yield of maize steadily increased between 1951 and 1989. It would have been very difficult to determine the maximum potential yield for every year, so instead we updated the actual yields. This means that we estimated the yearly yields to have been produced under the conditions of 1990 agrotechnology. We have found that the difference between the actual yield and the technological trend (the expected value of the yield) is normally distributed and independent of time. Consequently, the residuals are independent of the expected yield, so we simply added the residuals to the expected yield in 1990, which is 6400 kg/ha. In the later investigation we used these data.

6.1 Maximum yield

Maximum yield of a crop (Y_m) is defined as the harvested yield of a high-producing variety, well adapted to the given growing environment, including the time available to reach maturity, under conditions, where water, nutrients, pests and diseases do not limit the yield. The maximum yield can be determined from experimental data, or from calculations (Wageningen method). In our case, this maximum yield was 9000 kg/ha.

Latitude	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21

Table 3: Mean daily percentage (p) of annual daytime hours for latitudes of Hungary

6.2 Maximum evapotranspiration

Crop water requirements are usually expressed as the rate of evapotranspiration in mm/day. The level of evapotranspiration is related to the evaporative demand of air. We can define a reference evapotranspiration (ET_0), which expresses the effect of climate on the level of crop evapotranspiration. ET_0 is the rate of evapotranspiration of an extended surface with 6 to 15 cm tall green grass cover, actively growing, completely shading the ground and not short of water.

The reference crop evapotranspiration ET_0 is 4-5 mm/day if the temperature is around 10 $°C$, 6-7 mm/day if it is around 20 $°C$ and 8-9 mm/day if it is around 30 $°C$. There are several methods to calculate ET_0 (i.e. Penman, Radiation, Pan Evaporation Methods, Blaney-Criddle method). We chose the latter, because this method uses only temperature data and is relevant to the conditions of Hungary. For a given climate, crop and crop development stage, the maximum evapotranspiration in mm/day is

$$ET_m = kc \cdot ET_0. \tag{10}$$

The crop coefficient (kc) is related to the crop development stage, in initial stage: 0.3-0.5, in development stage: 0.7-0.85, in mid-season stage: 1.05-1.2, in late season: 0.8-0.95, and at harvest: 0.55-0.6.

6.3 The Blaney-Criddle method

This method is used to calculate reference crop evapotranspiration using measured temperature data, general levels of humidity, sunshine and wind. The relationship is:

$$ET_0 = c[p(0.46T + 8)] + b, \tag{11}$$

where ET_0 is the reference crop evapotranspiration in mm/day, T is the mean daily temperature in $°C$, p denotes the daily percentage of total annual daytime hours (Table 3), c and b are adjustment factors that depend on minimum relative humidity, sunshine hours and daytime wind estimates. In Szolnok county these factors are:

- $c = 1.64$ and $b = -1.8$ if $RH_{min} < 20°C$,
- $c = 1.48$ and $b = -2.0$ if $20°C < RH_{min} < 50°C$,
- $c = 1.125$ and $b = -1.9$ if $50°C < RH_{min}$.

6.4 Actual evapotranspiration

ET_a is the actual evapotranspiration and is related to the water uptake by the crop from the soil. In order to determine actual evapotranspiration, the level of the available soil

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95% Confidence Interval	
			Lower	Upper
P3	0.4803398394	5498.6911591	-11162.389918	11163.350598
P4	0.6598551256	2179.7857124	-4424.514135	4425.833845
P5	0.9171944331	4200.2882493	-8526.070668	8527.905057

Asymptotic Correlation Matrix			
Corr	P3	P4	P5
P3	1	-0.740028357	-0.184567695
P4	-0.74002835	1	-0.220544509
P5	-0.184567695	-0.220544509	1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	3955022.4116	3955022.4116	15.528	0.0004
Error	36	9169392.7276	254705.35354		
C Total	37	13124415.139			

Root MSE	504.68342	R-squar	0.3013
Dep Mean	6400.00221	Adj R-sq	0.2819
C.V.	7.88568	corr. coeff	0.549

Table 4: The result of the nonlinear regression analysis

Variable	DF	Parameter Estimate	Standard Error	T for H0:Par=0	Prob > $\|T\|$
INTERCEP	1	4778.307238	419.60606979	11.388	0.0001
P	1	0.222202	0.05638876	3.941	0.0004

Table 5: The result of the linear regression analysis

water must be considered. Actual evapotranspiration equals maximum evapotranspiration when the water available to the crop is adequate. When available soil water is less than the demand of water by the crop, $ET_a < ET_m$. Available soil water can be defined as the fraction (f) of ET_m by which the total available soil water can be depleted without causing ET_a to become less than ET_m. For a given crop, ET_a is determined by the evaporative demand of the air when available soil water does not restrict evapotranspiration. Beyond the depletion of the fraction (f) of total available soil water (Sa), ET_a will fall below ET_m will depend on the remaining soil water and on ET_m. Under these assumptions the following relationships hold:

$$\begin{aligned} ET_a &= ET_m \text{ where } St \geq (1-f)\cdot Sa \\ ET_a &= \frac{St}{(1-f)\cdot Sa}\cdot ET_m \text{ where } St \leq (1-f)\cdot Sa \end{aligned} \quad (12)$$

6.5 The calculations and results

First, we calculated the dates of the phenophases and the quantities of the variables for each phenophase as we described above. The original calculations ([2,3]) were given only for single months or ten day periods, so we had to determine what happens if there is a water shortage in two or more intervals. We derived a simple multiplicative model:

$$Y_a/Y_m = (1-P1\cdot x_1)\cdot(1-P2\cdot x_2)\cdot(1-P3\cdot x_3)\cdot(1-P4\cdot x_4)\cdot(1-P5\cdot x_5) \quad (13)$$

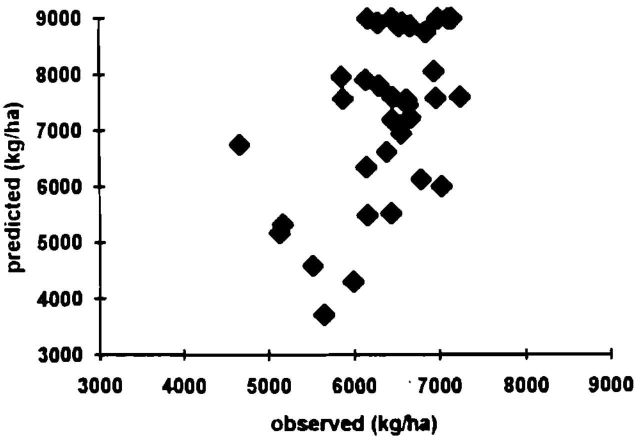

Figure 7: Observed vs predicted values

where $x_i = (1 - ET_{ai}/ET_m)$, i is the i^{th} phenophases. In the first two phenophases ET_{ai} turned out to equal ET_m so $ET_{ai}/ET_{mi} = 1$ and $P1$ and $P2$ were 0. We fitted this model by a nonlinear regression analysis, and the results can be seen in Table 4. After this we made a linear regression analysis for the predicted and observed values. The results are in Table 5., and the observed vs predicted values are plotted in Figure 7.

Unfortunately, using this method we could not get better results than with the first method described in Chapter 5. We don't know exactly what happens if water stress occurs in more then one phase. Nevertheless, the results in Figure 7 show that this approach is promising.

7 Conclusions

The necessity of assessing land capability and production conditions has grown recently. We dealt with only the weather impact on crops yield because it is the most important factor in semi-arid regions (Hungary is located in a semi-arid region).

Using only measured weather data turned out not to be effective for describing the relationship between the weather parameters and the yield. Calculating the soil moisture for every day resulted in a good descriptor variable and we could get a better regression model. Instead of monthly data we used phenophase data because the phenophases are not equally sensitive to the weather.

We tried to improve this model with determining the size of yield decrease due to the weather using a relationship between relative yield decrease and relative evapotranspiration deficit. With this method we could not get better results. We do not know what happens if water stress occurs in more than one phenophase. Nevertheless, the results are promising.

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