USE OF SIMULATION TECHNIQUE TO DISTINGUISH BETWEEN THE EFFECT OF SOIL AND WEATHER ON CROP DEVELOPMENT AND GROWTH

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Abstract. Environmental factors significantly influence the development and growth of plants. The main factors are soil and weather conditions. In real world it is not possible to segregate these influences. Using simulation models there are ways to analyse the effects of the changes of soil characteristics or weather elements separately. This way all the soil characteristics and weather elements can be changed one by one or different combinations of them can be used as input series.
In this study real Hungarian soil and weather scenarios were used that are significantly different from one another. Maize and wheat – the two main crops of Hungary – as well as field pea were used. Pea is known as a sensitive crop to weather. 4M-simulation package was used as a modelling tool. Our group at RISSAC based on CERES and CROPGRO models has developed it.
The results showed that the weather differences caused more significant changes in yields then soil differences though soils could moderate the effects of the extreme weather scenarios. The measure of reactions is meaningfully different depending on the species and cultivars. Analysis of separated effects of soil and weather factors has not only theoretical and methodological importance, but useful for the practice, too. When new plant species or cultivars are introduced in a country the optimal habitats can be found. The optimal structure for crops (where to seed different crops, and what sequence should be applied) and technology for crops (sawing time, fertilizer application and timing, etc.) can be estimated.
Keywords: *crop models, soil, weather, plant development and growth*

Introduction

The development and growth of plants in a given habitat is controlled by the soil and weather conditions as the main environmental factors. In real world it is not possible to segregate the influences of the soil and the weather on the crop production.

Many aspires were made but few attain has been achieved to separate the effects of the soil from the weather factors on crop yields. Statistical analysis failed to lead us a conclusion. Simulation modelling of weather–soil–plant is the proper means to analyse the effects of the changes of soil characteristics or weather elements separately. This way all the soil characteristics and weather elements can be changed one by one or different combinations of them can be used as input series. A more practical approach is when the role of local soils and weather are compared by a series of runs applying observed weather data from different years and real soil profiles from different fields of the selected farm.

The models of the two main crops of Hungary – maize and wheat – were applied, plus the model of pea crop as an addition. Weather – as many authors has shown – is the

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most obvious controlling factor of the development and growth of a given year at a changeable temperate climate [2, 4, 7, 9, 11], but pea is known as one of the most sensitive crop to weather [10, 12, 13, 14]. In this paper the environmental demands of crops and varieties were evaluated using real and simulated weather data.

Materials and methods

The DSSAT simulation model families (CERES and CROPGRO) have been adapted at our Institute for the Hungarian conditions. PEAGRO [9] model has been developed by our research group at RISSAC based on CROPGRO models [5] and CERES models [6]. These made us able to analyse the effects of the changes of soil characteristics or weather elements separately.

The data observed

For the simulation experiments several selected weather data observation series were used from Hungary. Each of these included maximum and minimum temperature, rain and radiation. The selected weather data sets were the followings: Nagyhörcsök (1976, 1988), Újmajor (1993-1996), Tápiószele (1993, 1995), Kompolt (1993, 1995). The selected soil data sets were two series of loam from Nagyhörcsök and Debrecen, two series of clay loam from Újmajor and Kompolt, a silty loam series from Tápiószele.

Conditions of simulation experiments under controlled environment

Controlled environment were simulated as follows: two levels of temperature as: T_{min} = 22 °C, T_{max} = 34 °C and T_{min}= 16 °C, T_{max} = 25 °C, four levels of radiation as 20, 25, 30, 35 $MJ{\cdot}m^{-2}$, four levels of precipitation as 5, 10, 20, 40 $mm{\cdot}day^{-1}$ given in a sequence of 5 days.

Crops included

Three traditional food and feed crops of Hungary were included in the simulation experiments: winter wheat, maize and pea. These species were selected since they have different demands concerning soil and climatic conditions. Some of the reasons of the divergent reactions (influences on the development and growth) of the used species to the environmental conditions are as follows:

- Different climatic demands (i.e. base temperature 2 °C for wheat, 4 °C for pea and 8 °C for maize).
- Different length of life (winter wheat and summer crops like maize and pea).
- Different CO_2 assimilation types (C3 like maize and pea, and C4 like wheat).
- Different transpiration coefficients (250–300 $l{\cdot}kg^{-1}$ for maize, 500–600 $l{\cdot}kg^{-1}$ for wheat, 700–800 $l{\cdot}kg^{-1}$ for pea).
- Different demands to soil conditions (i.e. pea has nitrogen absorbent capability while the other two species do not, but as a result pea is more sensitive to soil moisture conditions).

Hungarian varieties of these species were selected with different characteristics: e.g. breeding season in case of maize, cold resistance and food quality in case of wheat, leaf morphology in case of pea. At the decision of selection of varieties it was considered whether or not the variety played a role in the National Fertilizer Experimental Network, or the National Breeding Test or in our own experiments.

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Results and analyses

Simulation experiments using observed data sets

In field experiments it is not possible to separate the influence of soil conditions and weather conditions. One of the advantages of simulation modelling is that these conditions can be freely exchanged, and the cause and effect relationships can be studied. Applying the same soil and different weather scenarios can separate weather-generated changes. In the contrary, applying the same weather and different soils can separate soil-generated changes.

Pea development and yield was the most sensitive among the studied crops to extreme changes of weather. It is demonstrated by a combined field and simulation experiment in which the weather data came from observations at the corresponding experimental field. This way the reality of the simulation study was controlled by the field data. The main treatment applied was the amount of rain. Real soils (clay loam, loam, sandy loam) and weather scenarios were selected from the Hungarian region to compare the influences of the soil and weather on pea development and yields. The dry and the wet year treatments had 42% and 142% of the average rainfall respectively. The result showed 14–15 day difference in the maturity date and 2600–3000 kg·ha^{-1} yield difference caused by the weather. The effect of soil led to 800 and 1200 kg·ha^{-1} yield differences in dry and wet years respectively 6 to 1 days differences in emergence date and 7 to 8 days differences in maturity date (*Table 1*).

Table 1. *Simulated pea development and yield in dry and wet years on different soils.*

Soil types	Emergence after sowing		Maturity day after sowing		Yield (kg/ha)	
	dry year	wet year	dry year	wet year	dry year	wet year
clay loam	22	11	75	90	2072	5014
sandy loam	16	10	72	87	1224	3836
loam	16	10	68	82	1679	4831

Difference of emergence date showed correlation with initial soil water content (ISWC). The initial soil water content linearly decreased the required time for emergence. See the rate of ISWC/DUL at *Fig 1*.

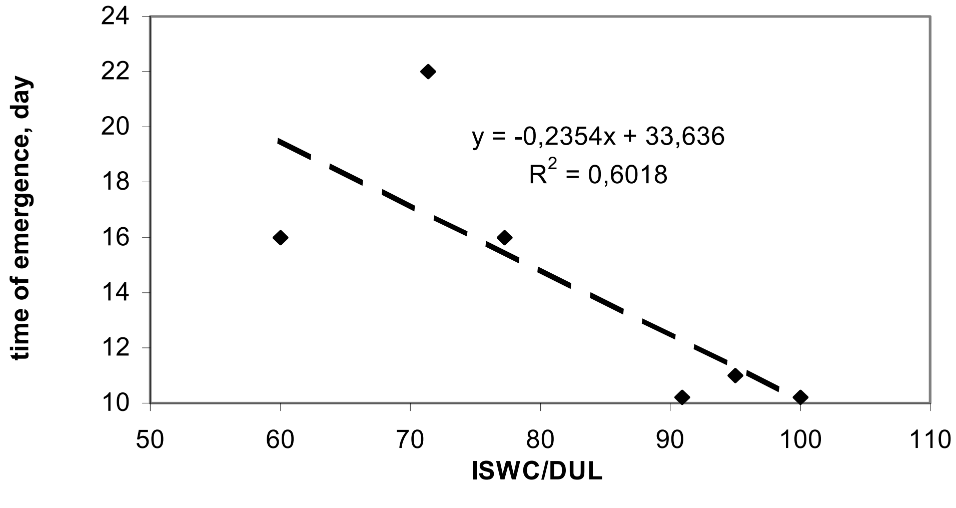

Figure 1. *Time of emergence vs. ISWC/DUL.*

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Simulation experiments under controlled environment

Yields of three crops were simulated using modified weather. The decreased night and daily temperature from 22–34 ^{o}C to 16–25 ^{o}C respectively and caused different changes of yield of pea and maize (*Table 2*). The yield of maize decreased and in the contrary the yield of pea increased by lowering the temperature. This shows the difference in optimum temperatures of the two crops. This is the way in which the effect can be singled out by simulation not only for the final yield but also for the dynamic of growth and development. Even the transpiration and nutrient uptake can be studied day by day. Since the operation of the system is very complex human brain cannot follow all the mutual effects of factors and processes on a daily time step. Using simulation a lot of hypothesis can be tested.

Table 2. *Temperature effect on yields of maize and pea.*

Temperature (^{o}C)	Crop yield (kg/ha)	
	maize	pea
16/25	11042	7520
22/34	12230	4000

Water demands of maize and pea crops and radiation were compared in the next simulation experiment. The interdependency of the photosynthesis and transpiration is demonstrated by this simulation. Higher radiation increases the water demand and decreases the soil moisture content (*Fig. 2*).

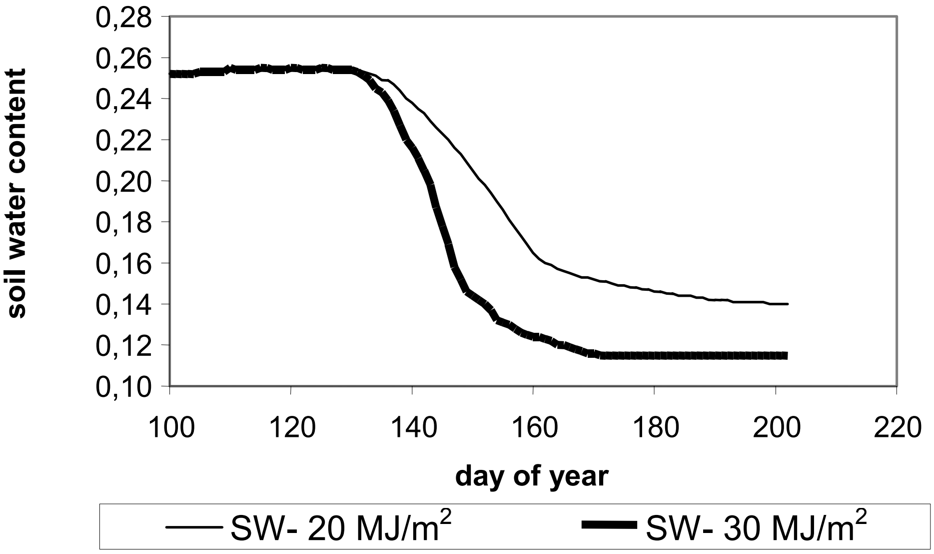

Figure 2. *Influence of radiation on the soil water content.*

Practical application of simulation

Irrigation technology can be developed for any soil and weather combination by optimisation via model application (*Table 3*). Then economic analysis can be added to help the farmers to choose the irrigation amounts and timing and other agronomic treatments according to the risk acceptability level of the given farmers.

Table 3. *Simulated pea yields with different plant densities and irrigations in dry and wet year.*

Plant density effect			Irrigation effect		
Plant/m^2	Grain yield (kg/ha)		Irrigation dose (mm)	Grain yield (kg/ha)	
	dry year	wet year		dry year	wet year
50	2270	4141	0	2072	5014
60	2203	4567	20	2520	5207
70	2180	4842	40	3594	5207
80	2129	5014	60	4053	5207
90	2072	5053	80	4823	5207
100	2031	5115	100	4946	5207
110	1985	5165	120	5040	5207
120	1978	5207	140	5200	5000

Important question of production technology is the sequencing of crops. A lot of field experiments were done to investigate the best combinations of crops according to their vegetation periods, water and nutrient demands, etc. Long term, more than 30 years, Hungarian National Experimental Network (OTK) has proven that pea is a better pre-crop of maize than wheat. We used simulation to figure out the reasons of this experience. We applied the local soils and weather data, as well as the genetic parameters of the original plant materials to regenerate the water status of the soils at each year of the experiment (*Table 4*). It has become obvious that the reason of the favourable effect of pea was that more water had remained in the soil after the harvest.

Table 4. *Simulated soil water content after pea and wheat.*

Soil layer (cm)	Soil water content (v%)	
	After pea	After wheat
0-5	27.1	17.4
5-15	27.1	25.3
15-30	29.7	26.7
30-45	30.5	26.9
45-60	31.2	26.6
60-90	31.0	25.2
90-120	29.0	24.1
120-150	27.1	23.3
150-170	26.2	22.5

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