SIMULATION-BASED EVALUATION OF AGRICULTURE STRATEGIES UNDER UNCERTAINTY OF WEATHER FORECAST

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KEY WORDS

Simulation, model, agriculture, operation, efficiency.

ABSTRACT

The paper represents of results of farmer's agricultural operations efficiency based on the analysis of the developed discrete stochastic simulation model. The aim of the model is to obtain quantitative estimation of farmer's choice of agricultural operation strategy efficiency under unanticipated fluctuation of weather conditions. According the model farmer's strategies are described by two main parameters: 1) agricultural operation start time and 2) intensity of the operation.

The model deals with the influence of random changes of weather conditions, affecting operation efficiency. The resulting atmospheric influence is modeled as random changes to agricultural function start time and duration of favorable period for performing an agricultural operation. The agricultural function value on a given day determines the future yield value gathered from the respective area [1].

The goal of simulation experiments with different input parameters of the model is finding the parameters of the optimal farmer strategy provided known average statistical weather forecast inaccuracy. The secondary aim would be suggesting a more efficient strategy under conditions of changing weather forecast statistical error with initially known error range.

In order to influence harvest final value, the farmer could use a different culture, combination of other soil preparation procedures, pesticides and other chemicals, as well as affect other factors [2, 3]. In a general case, the parameters of the related agricultural functions could be modified in order to depict the factors mentioned above. The present paper, however, concentrates on two main numerical parameters of farmer's strategy, namely:

- Agricultural operation start time
- Intensity of the operation, i.e. number of days to be spent on processing the given plot of farmland.

The structure of the model for simulation runs of farmer strategy efficiency (meaning total harvest value of the area) is illustrated on Figure 1 in the next section.

MODEL DESCRIPTION

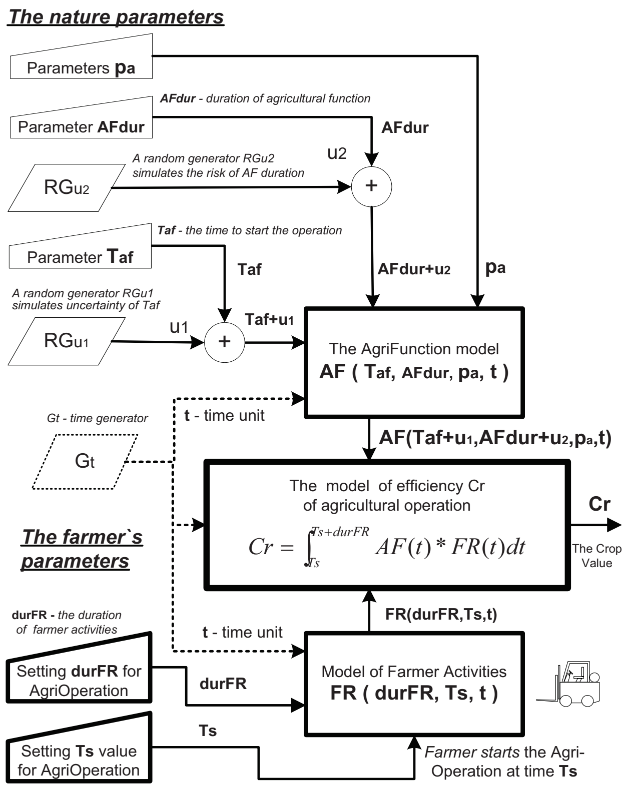

Figure 1. Overview of agricultural operation model

The structure of the model as per **Figure 1** includes the following general sub-models and blocks:

- Sub-model of agricultural function **AF**, start time input block **Taf**, **AF** duration **AFdur** input block and additional parameters input block **Pa**;
- sub-model of farmer activity, operation intensity input block **durFR**, and farmer's start time input block **Ts**;
- convolution of agricultural function **AF** and farmer activity function **FR**, yielding the total crops from the given farmland plot;
- random generators **RGu**$_i$ of random values u_1, u_2, that deliver time uncertainty **Taf** of agricultural function start time **Taf-U$_1$min<=Taf<=Taf+U$_1$max** and randomly change duration of agricultural function **AFdur** over value range **AFdur-U$_2$min<=AFdur<= AFdur+U$_2$max**;
- chronometric generator **Gt** of time counts t.

DEFINING AGRICULTURAL FUNCTION

It would be logical to assume that performing an agricultural operation performed by a farmer at specific point of time would positively affect the expected harvest value.

It is assumed with some extent of precision that it is possible know what would be the harvest value if the given operation is performed on k^{th} day, $k+1^{th}$ day, etc. For instance, let us consider operation of sowing. If the crops are sown too early before specific point of time, the harvest value would be rather low because of low soil temperature. On the other hand, if crops are sown too late, the coming up would be retarded, which in turn will again adversely affect the harvest. Thus, there is a specific time interval when sowing would yield the maximal harvest.

Agricultural function **AF(t)** is a formal representation of future harvest value dependency on performing operation at a specific time *t*, all other parameters held unchanged. Thus, in the given framework for every operation there is a related agricultural function which depicts efficiency of performing the operation at time *t*. Since a technological chain of crop growing includes several operations, the final harvest value would represent a function of operation-related agricultural functions. Each separate j^{th} agricultural function $\mathbf{AF_j}(t_{ij})$ determines quantitative dependency between the time point t_{ij} of performing specific operation and the value of the future harvest, all other things being equal. Each separate value of agricultural function $\mathbf{AF}(t_{ij})$ represents the maximal attainable harvest value $\mathbf{AF_{max\ ij}}$ from a single plot of farmland, after completing a specific operation at point t_{ij}, provided all other operations remain unchanged. For explanatory reasons, the values of agricultural functions can be obtained by sowing equal areas of crops at different points of time t_i , like illustrated on **Figure 2** below.

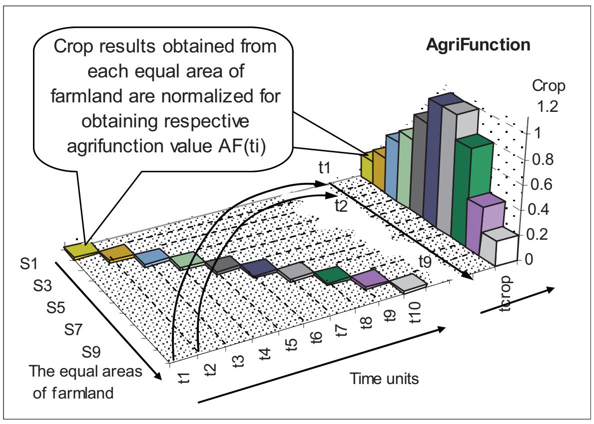

Figure 2. Estimating influence of sowing start time on the value of harvested crops (obtaining sowing agricultural function values)

Let us introduce the following variables:

Taf – agricultural functions start time (in this article a hypothetical fixed moment at time **Taf**=10);

Ts – agricultural operation start time by the farmer, subject to farmer's personal choice;

durFR – duration (days) of agricultural operation, mainly depends on farmer's choice of technology to affect the speed (duration) of agricultural operations, is influenced by technological constraint allowing farmer to accelerate agricultural operations;

$\mathbf{U_i}$**, i=1,2** – random values, uniformly distributed over time range $\mathbf{U_i min}$**<=**$\mathbf{U_i}$**<=**$\mathbf{U_i max}$ with given lower boundary $\mathbf{U_i min}$ and upper boundary $\mathbf{U_i max}$;

Pa – agricultural functions internal parameters that define the original form of the agricultural function, its start time **Taf** and its duration **AFdur**.

Uncertainty of beginning of agricultural function is modeled as a sum of initially given value **Taf** and a random value u_1.

The uncertainty of **AF** duration is similarly modeled as a sum of a fixed value **AFdur** and a random value u_2, uncorrelated with random variable u_1.

FORMAL MODEL DESCRIPTION

The efficiency of agricultural operation is estimated through the efficiency criterion **Crop**:

$$\int_{Ts}^{Ts+durFR} AF(T_{af}+u_1, AFdur+u_2, p_a, t) * FR(durFR, T_s, t)dt$$

The following function possesses relatively large degree of flexibility yet being simple enough for the purpose of the research above:

AF($\mathbf{T_{af}}$**+**$\mathbf{u_1}$**, durAF, t) =(UnitStep[t-Taf+dur1AF]-UnitStep[t-Taf])/(dur1AF)*(t-Taf+dur1AF) + (UnitStep[t-Taf] -UnitStep[t-Taf-dur2AF]) + (UnitStep[t-Taf-dur2AF] - UnitStep[t-Taf-dur2AF-dur3AF])/(dur3AF)*(Taf+dur2AF+dur3AF-t)**

It should be noted that **UnitStep(x)** represents the unit step function, equal to 0 for $x<0$ and 1 for $x>=0$.

Modeling farmer activity (which is assumed constant) performing agricultural operations involved the following expression:

FR(t,Ts,durFR)=(UnitStep(t-Ts)-UnitStep(t-Ts-durFR))/durFR

Thus, intensity is the inverse value of the duration **durFR** of the operation.

PURPOSE OF THE RESEARCH

How does the average crop volume change as the farmer applies different strategies for agricultural function **AF**(T_{af}+u_1, **durAF**, t), where the real value u_1 uniformly randomly distributed within the three intervals in ascending order, namely $-1 <= u_1 <= 1$, $-2 < u_1 < 2$, $-3 < u_1 < 3$.

ANALYZING FARMER STRATEGY

The degree of adequacy of model considered is impossible to verify using direct methods. In order for the model to be verified, indirect estimation should be applied. One of these methods is studying model for contradictions with expected behavior of the object of the research in certain boundaries. Should clear contradictions be discovered, no further verification of the model would be necessary.

Given that, let us start studying efficiency of farmer strategies and harvest value-related risks by considering a typical agricultural function. As an example, let us consider a trapezoid function, relatively well describing most of the farming cultures. By changing the duration **dur1AF** of velocity of the front of agricultural function, we might affect the approach of the most favorable time for performing a specific operation. The duration **dur2AF** of the most favorable time span of performing the operation will be referred to as the duration of the agricultural function with start time **Taf** (see **Figure 3**).

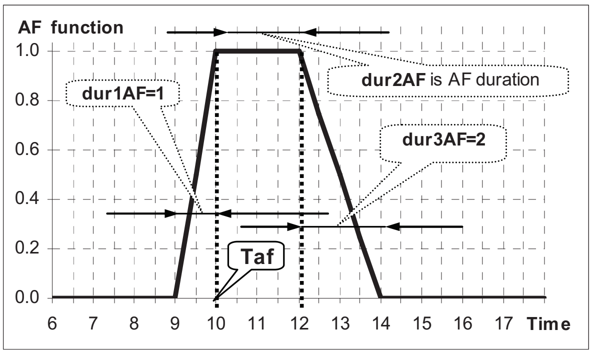

Figure 3. Typical agricultural trapezoidal function chosen for research, **Taf**=10.

First, three cases of uncertainty (or forecast errors) of agricultural operation start time for uniformly random distribution within intervals 9<=**Taf**<=11, 8<=**Taf**<=12 and 7<=**Taf**<=13. The duration of the function remains unchanged: **AF** duration = 2 days.

The area of uncertain values of agricultural trapezoidal function will be altered as intervals increase. The areas of uncertainty of the agricultural functions appear on **Figures 4a** and **4b** as shaded regions.

The area of the uncertainty of agricultural values at 7<=**Taf**<=13 represents the shaded from of **Figure 4b**, expanded one day in both directions of x-axis.

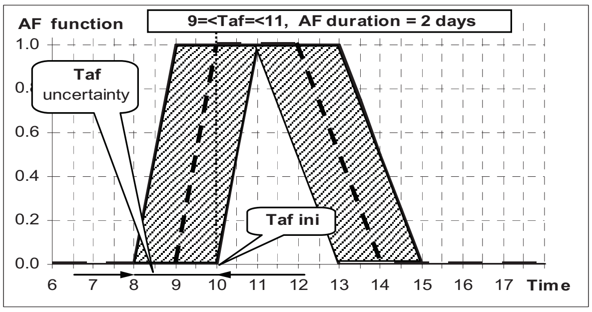

Figure 4a. Area of uncertainty of agricultural function at 9<=**Taf**<=11.

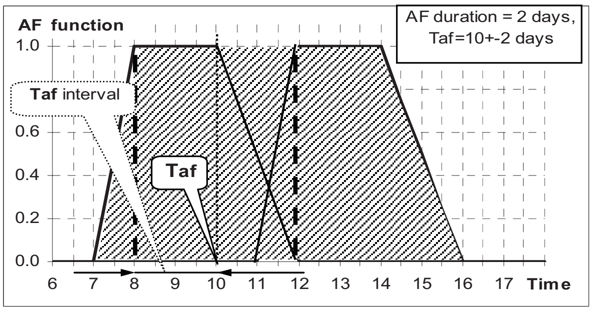

Figure 4b. Area of uncertainty of agricultural function at 8<=**Taf**<=12.

All of these agricultural functions have their maximum value of 1.

ANALYZING DEPENDENCE OF FARMER'S STRATEGY EFFICIENCY ON AGRICULTURAL FUNCTION START TIME UNCERTAINTY

Let us consider that the time of function start **Taf** is unknown to the farmer and he empirically tries to discover efficiency of his efforts, which in this case is determined by intensity of farmer's operations. The change in crop volume is explained by the farmer's start day **Ts** and a different duration of performing agricultural operation **durFR** (illustrated in **Figure 5**).

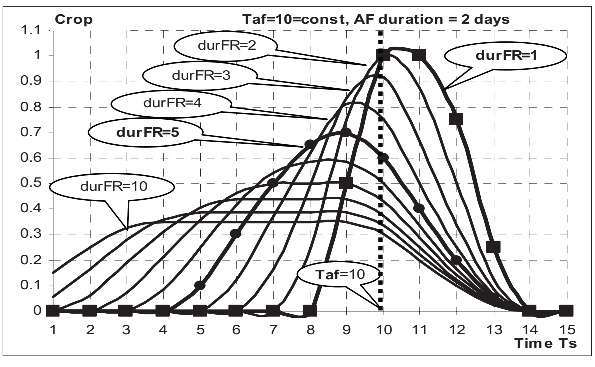

Figure 5. Dependence of operation duration **durFR** on the harvested crop value. The agricultural function starts on the **Taf**=10th calendar day with duration **AFdur**=2.

Figure 5 illustrates efficiency of farmer strategies for a determined trapezoidal agricultural function represented on **Figure 3**. If a quick-to-act farmer (**durFR**=1 day) can gain a maximum yield beginning the operation on 10th as well as 11th day. On the other hand, an average-response-farmer (**durFR**=5 days) can obtain the maximum yield only if he starts the agricultural operation earlier, i.e. on day 9. In this case his maximum yield would result 70% of that of the fast-to-act farmer. In three-dimensional space of parameters of farmer strategies {**Ts**, **durFR**, **Crop**} their efficiency is represented by a concave surface as in **Figure** 6.

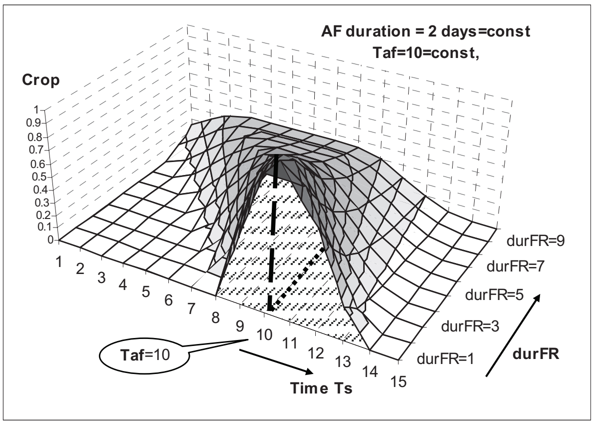

Figure 6. Efficiency surface of farmer strategy parameters in 3D coordinates **Ts**-**durFR**-**Crop**

Thus, under determined parameters of agricultural function, a maximum crop volume can be gathered by the farmers who are capable of processing their plots within the time frame of the agricultural function. Let us consider efficiency of possible farmer responses under uncertainty in forecasting the beginning of agricultural function (equally random distributed with plus-minus one day interval). Now the start of agricultural function is equally probable to start on days 9-11. The average efficiency of farmer responses is illustrated on **Figure 7**.

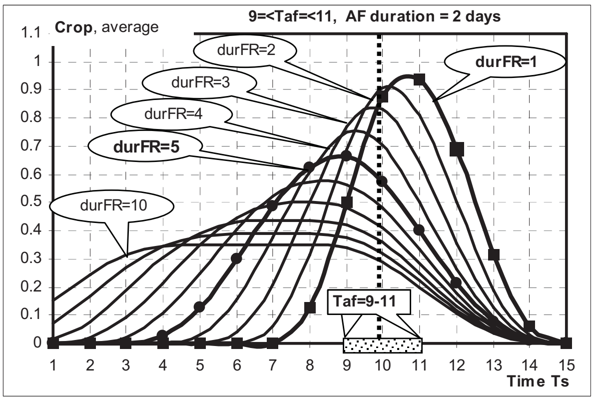

Figure 7. Influence of equally distributed in +/-1 day error in estimating agricultural function start on average efficiency of farmer response.

It would be logical to assume that the average efficiency diminishes for every possible farmer response.

Therefore, depicted in 3D space of parameters of farmer strategy the crop surface of crop difference values looks as in **Figure 8**.

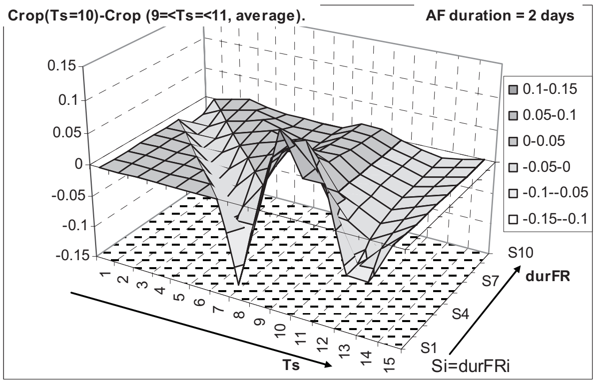

Figure 8. Difference in efficiency of parameters of farmer strategy in 3D coordinates **Ts**, **durFR**, [crop (**Ts**=10) - average crop (9=<**Ts**=<11)].

As follows from **Figure 8**, there can be noted significant changes in farmer strategy efficiency on maximum curvature areas illustrated in **Figure 6**. In order to analyze the effect let us broaden the boundaries of uncertainty interval of beginning of agricultural function from day 8 to day 12.

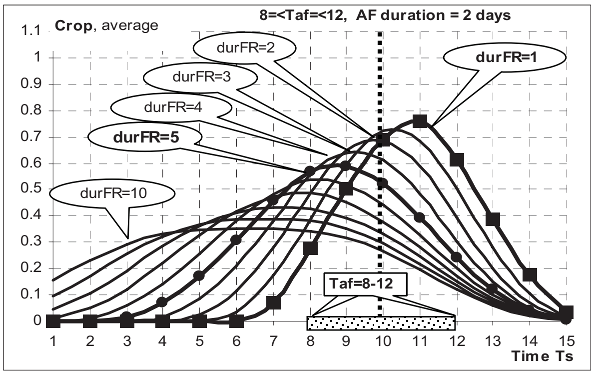

Figure 9. The agricultural function start uncertainty equals plus-minus two days: 8=<**Taf**=<12, **AF** duration = const= 2 days.

In 3D space of parameters of farmer strategies the resulting surface will take the form as per **Figure 10**.

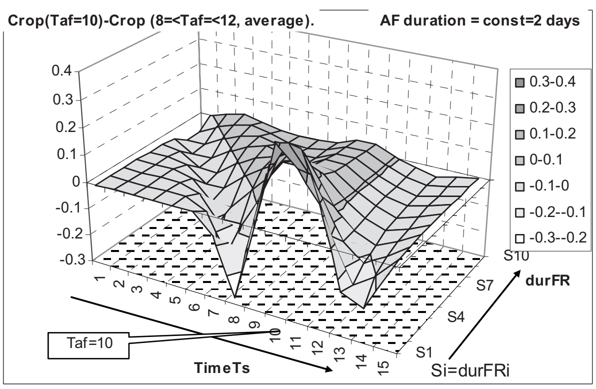

Figure 10. Surface of differences in efficiency of parameters of farmer strategies in 3D coordinates **Ts**, **durFR**, [crop (**Ts**=10) – average crop (8=<**Ts**=<12)].

Thus, practical conclusions would be that a more fast-to-respond farmer must start working already on day 11 in order to obtain maximum average crop of 0.75 (75%) under given uncertainty conditions, whereas under deterministic conditions he would have had a chance to start working on day 10 or work for two days with lower intensity. The crop volume would remain maximum attainable at 100%.

The difference in the estimated average crop volume between slow-to-respond and fast-to-respond farmers decreases. Thus, for example in a deterministic case the difference in maximum values between strategies with **durAF**=1 and **durAF**=5 makes up to 30%. Under uncertain beginning of agricultural function 8<=**Taf**=<12 this difference drops down to 22%. It should be noted that the maximum crop volume of strategy **durAF**=1 falls on day 11 (**Ts**=11), whereas crop volume maximum (0.59) of strategy **durAF**=5 falls already on days 8-9 counting from the start of agricultural operation.

It looks that a slower-to-act farmer should start operations even start ahead of beginning of respective agricultural function. Faster-to-act farmers should start working a little behind the mid-point of uncertainty interval. This is clearly seen in graphs of average crop volume obtained for 7=<**Taf**=<13 (see **Figure 11**).

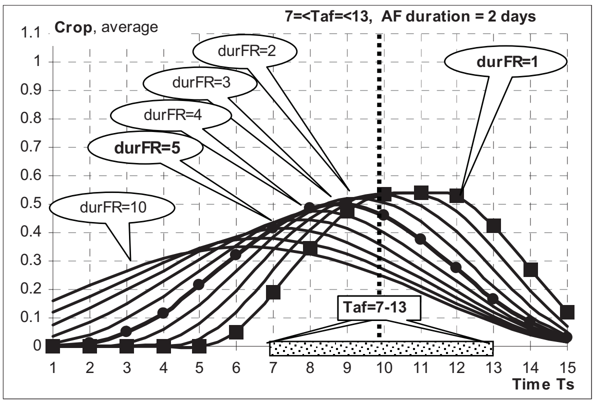

Figure 11. The agricultural function starts uncertainty equals plus-minus 3 days: 7=<**Taf**=<13, **AF** duration = const= 2 days.

Comparing trends in **Figures 5**, **7**, **9**, and **11** shows that increasing the uncertainty interval of beginning of agricultural function leads to the following changes:

- the maximum efficiency of short-term strategies (**durFR**<8) decreases much faster than the same for the longer-term strategies (**durFR**=>8). In other words, faster farmers adhering to strategy of maximum efficiency under uncertainty of agricultural function start time find themselves in bigger losses than the slower-to-act farmers.
- the peak values of maximum efficiency of short-term strategies are broadened whereas the respective peaks of longer strategies become more acute. In other words, around efficiency maximum value the short-term strategy sensitivity to shifts of start time of agricultural function falls, whereas the outcomes of longer strategies of slower-to-respond farmers become more sensitive to changes in **Ts** – start of agricultural operation.

INFLUENCE OF ERROR IN CHOOSING OPERATION START ON CROP VOLUME

The slower the agricultural operation is being performed, the smaller the loss in average crop volume (see **Figure 12**).

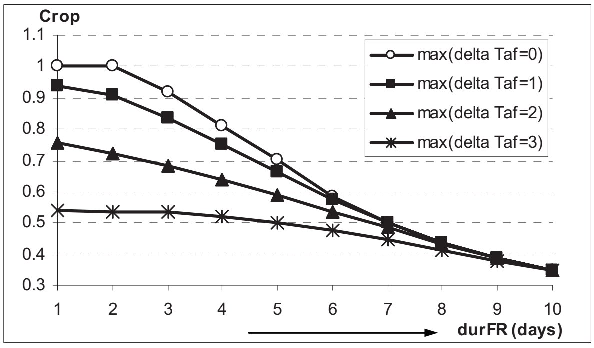

Figure 12. Dependence of maximum average crop volume on duration of agricultural operation, **Ts**=const=average of **Taf** =10.

Let us consider the the behavior of obtained crop volume depending on operation start time and uncertainty of agricultural function start time (see **Figures 13**-**15**).

The notation legend for **Figures 13**-**15** should be read as follows:

- **Taf10** defines the start of agricultural function at point **Taf** =10,
- **Taf7_13** stands for the uncertainty interval 7<=**Taf**<=13,
- **Taf8_12** standing for 8<=**Taf**<=12,
- **Taf9_11** standing for 9<=**Taf**<=11.

The duration of agricultural function remains constant and equals 2 days (**AF** duration = 2 days).

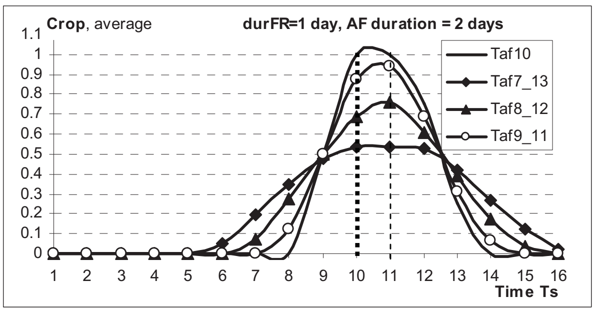

Figure 13. Dependence of crop volume on start of operation **Ts** for different intervals of uncertainty **Taf**.

The duration of agricultural operation equals 1 day, **durFR**=const=1 day.

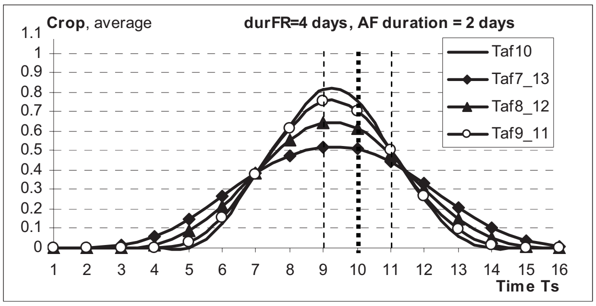

Figure 14. The duration of agricultural operation is fixed, **durFR**=const=4 days.

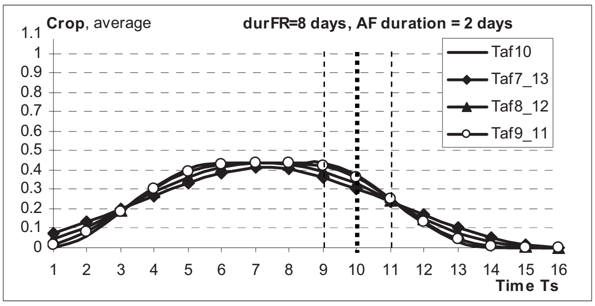

Figure 15. The duration of agricultural operation is fixed, **durFR**=const=8 days

The graphs allow quantitative estimation of average farmer losses in case of insufficient information on s start time of agricultural function. Possible reasons of uncertainty of agricultural function start could be weather forecast errors, as well as improper mathematical description.

CONCLUSIONS

The paper has illustrated application of simulation modeling for quantitative analysis of farmer strategy efficiency for operation one to ten days long with beginning uncertainty of plus/minus one day, of plus/minus two days and of plus/minus 3 days.

All of the cases studied implied a 'what if' approach, where the weather condition uncertainty was modeled.

The set of farmer strategies is determined by two parameters:

- start day **Ts** of performing the operation, and
- duration of the operation **durFR** (number of days)

Taking into consideration the delimitation of the research, a number of general conclusions can be made:

- the more uncertainty of beginning and duration of agricultural functions there is, the less average crop value is obtained
- the more uncertainty in estimating beginning and duration of agricultural functions, the earlier and less intensively one should perform respective operations in order to obtain a relatively stable level of crop.
- a slower-to-act farmer should start operations a little in advance of agricultural function start. Faster-to-act farmers should start working a little behind the mid-point of uncertainty interval.
- Farmers capable of faster farmland processing should decrease the operation intensity under larger uncertainty intervals

In cases considered above performing an operation in 3-4 days appears the least risky strategy with agricultural function uncertainty interval of **Taf**=10+/-3 days. The average crop volume for farmer with **durFR**=1 is basically the same as for the farmer with **durFR**=3. However, low crop risk for the first farmer (**durFR**=1) is significantly higher (on average equals ca. 0.5), where in half of the observations the crop volume will reach 100% with 0% for the other half. The average crop volume would then yield 50% as it follows from comparing **Figures 13** and **14**.

The quantitative estimates with regard to specific agricultural functions of a farming culture can be obtained through estimation by agricultural experts in respective areas.

The model presented in this article leads at quantitative estimation of farming risks.

The format of the given article leaves other researches arising of weather condition uncertainty beyond the scope of this work.

The simulation model described in the article allows flexible analysis of diverse combinations of weather condition uncertainty, agricultural functions, and farmer strategies.

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