# THE SWOM MODEL: A TOOL FOR THE CORRECT CHOICE AND USE OF THE DIFFERENT SOIL TILLAGE TYPES

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## SUMMARY

SWOM is a real time computer model for determining soil workability condition based on soil water balance of a field under different canopy status (barren soil, residue cover soil and crop cover soil). The effects of tillage and weathering on the tilled layers of the soil are analyzed. In fact, SWOM simulates the changes on soil bulk density and storage capacity of the soil surface during the time.
The model's output provides information about the soil workability, according to the type of implements used in working. The implements are grouped into five categories defined on soil engaging mechanism basis.
For determining of soil workability condition "fuzzy set theory" is used.
The Agrometeorology Department of Veneto Region is going to be used the model, when its calibration will be completed, for drawing up the agrometeorological bulletins in which indications to the farmers about the time and the implements more suitable to perform and complete the soil tillages are supplied.

## 1. INTRODUCTION

Current trends in agriculture aim to reduce the environmental impact of the various farm practices. As far as soil tillage is concerned, while the specific objective is to produce a layer of soil suitable for correct plant growth, it is important that the operations do not damage the soil, but rather encourage the formation of a structure whose stability, porosity and organic content ensure the natural biotic processes necessary to keep it vital, impeding polluting pheomena, such as erosion and leaching of organic and inorganic compounds that cause serious damage to the surrounding area.
In this light a fundamental role is played by both the choice of the type of implement and the field performance time of agricultural machinery. These are difficult decisions even for the most experienced farmer, as various factors are involved, implying valuations of a qualitative nature and risks that are not easy to quantify and which also influence agricultural production. Such choices are all linked above all with the soil workable state.
The term workability is used to indicate the possibility of performing soil-engaging operations, without causing damage to its structural aggregates (or limiting such damage to an acceptable minimum) which might compromise normal biotic processes (14, 8, 6, 12).
Workability is the major feature of the equipment/soil relationship and is highly influenced by pedological aspects such as the soil texture, moisture content, temperature and organic matter content (25).
If the operations are carried out on the soil in a workable condition, structural damage of the soil is avoided and at the same time the following operations (particularly sowing) are facilitated with potential gains in timeliness and quality. Conditions of optimal workability generally arise with moisture values close to the point where the cohesion and plasticity curves cross; only within this range does the working merely cause disaggregation, rather

than smearing, of the structural aggregates. The values of this range are connected with the soil texture and the range is all the wider, the greater the stability of the soil structure (8, 26).

It is important to emphasise that a soil workability state varies according to the type of operation to be undertaken with the machinery: for example, overturning the layer by ploughing allows for a higher water content than tillage by means of scarification or hoeing.

A methodology has been designed for determining, at field level, the workability of agricultural soil. It is based on determination in real time of the soil water content, a criterion of workability which defines the range of workability for different types of implement and on local weather forecasts. Application of this methodology provides useful indications regarding the times and modes of performing soil tillage and farmers may be duly informed through appropriate information channels.

Although we feel that there is no more reliable method than personal, subjective judgment in deciding whether to undertake a specific agricultural operation, the most experienced farmer will surely benefit from using this type of information as a support for his decisions.

## 2. THE SWOM MODEL

Analysis of the favourable moments for performing soil operations - especially those related to sowing a crop - has been the subject of many studies and is based both on mathematical models and empirical data deduced from field studies (see for example 1 ,2 ,3 ,4 ,5 ,9 ,10 ,11, 16, 18, 20, 21, 22, 23, 27, 28, 29).

Unlike research based on field observation, the use of mathematical simulation models allows one to save on the time that would be necessary to undertake exhaustive experiments in the wide range of situations that may occur in agricultural contexts (diversity of climate, soil, equipment used, etc.) and once the calibration phase has been completed, answers may be obtained quickly, even for forecasting purposes. In the specific case of analysing workability conditions, application of such models to a land with specific pedoclimatic features allows one to obtain immediate information, even at a distance, regarding the workability of a soil to be tilled and, especially, to check a priori the result of an operation undertaken with a given implement.

In 1989 the Agrometeorological Department of the Veneto Region decided to include this type of information in their meteorological bulletins, providing farmers with indications regarding soil tillage; the Department thus began to work together with Department of Land and Agro-Forestal Environments of the University of Padua where studies were being undertaken on the determination of soil workability by means of simulation models. On examination of the models available and the methodologies reported in the literature, the feasibility analysis led to the decision to set up and implement a model ex novo. SWOM (Soil Workability Model) is the fruit of this collaboration. The first version, completed in March 1991, was followed by a second one, available from C.S.I.M., Teolo (PD), currently being calibrated.

The SWOM model simulates the hydrological behaviour of the soil layers subject on tillage, in different conditions of crop canopy condition and following the evolution, in the course of the agricultural season, of a number of the hydrological parameters which undergo substantial modifications according to tillage and weathering. In this way it is possible to estimate a priori the effects of different tillage operations on the soil (7).

Given the peculiarity of its final use (preparation of agrometeological bulletins), SWOM has a number of innovatory features with respect to previous models, making it more suitable for this application.

First of all, the model distinguishes between different types of soil tillage. A distinction is made especially between various types of implements (moldboard plough, scarifier, harrow, hoe, etc) which act differently on the soil and hence have different effects on the parameters involved by the action, above all the soil density and the roughness of the soil surface. Moreover, analysis of the workability condition characterising the types of operation allows one to identify the effect that the use of a specific implement may have on the soil structure (for example one may forecast the probable smearing of the soil aggregates caused by a hoe used on soil that is too wet). SWOM thus provides the opportunity of supplying indications regarding the most suitable type of implement for undertaking a given operation in specific pedoclimatic conditions, acting as a support when taking decisions in relation to the soil water content.

Given the need to proceed with simulation of the hydrological pattern over the entire agricultural season, SWOM allows one to differentiate between the possible conditions of canopy status that may be found on a field to be tilled; for this purpose evapotranspiration was estimated, using different methods according to whether the surface was barren soil, residue cover soil or crop cover soil.

Finally, SWOM simulates evolution over time of the pedological parameters that may be subject to modifications due to tillage or weather agents. In particular, the model simulates the changes in the soil bulk density and storage capacity over time, given the important repercussions of variations in these parameters on the field water balance and hence on the simulation of its workability.

As far as simulation of the soil water balance is concerned, it was decided to divide the soil into two layers (12 and 18 cm) corresponding to the depths of tillage operations, in accordance with the remarks that will be made later when illustrating the "workability criterion". For a more exact simulation of the hydrological behaviour of these two layers, a third layer was examined, below the former at a depth of 20 cm and having an influence on the layers above.

The model is structured in sub-models, including five models simulating some components of the water balance and one analysing workability. A flow-chart of the SWOM model with the sub-models and the major components is shown in figure 1.

With regard to simulation of the water balance, the most important components of the SWOM model are:

1 - DENSITY Sub-model (Sub.RHO)

Estimation of changes in the soil bulk density of a field subject to tillage is based on studies by Porter and McMahon (17).

The following factors were included:

- Tillage
- Raindrop impact
- Variations in water content
- Other weathering effects

The original algorhytms were adapted to the conditions in which SWOM is normally employed: with respect to the environment considered in the original studies, in our agriculture other types of implements are used and the depth of tillage is greater. Moreover, there are frequent situations in which deep working (e.g. ploughing) is followed by a more surfacing operation (e.g. harrowing and sowing). This is why SWOM differentiates simulation of changes in density over time of both the surface and the deeper layer.

With regard to the type of implement used, a sub-division was made according to the classification shown below and the sequence of machinery actually used in the field; the available options are:

1. Ploughing
2. Scarification
3. Harrowing and sowing
4. Rotary hoeing and sowing

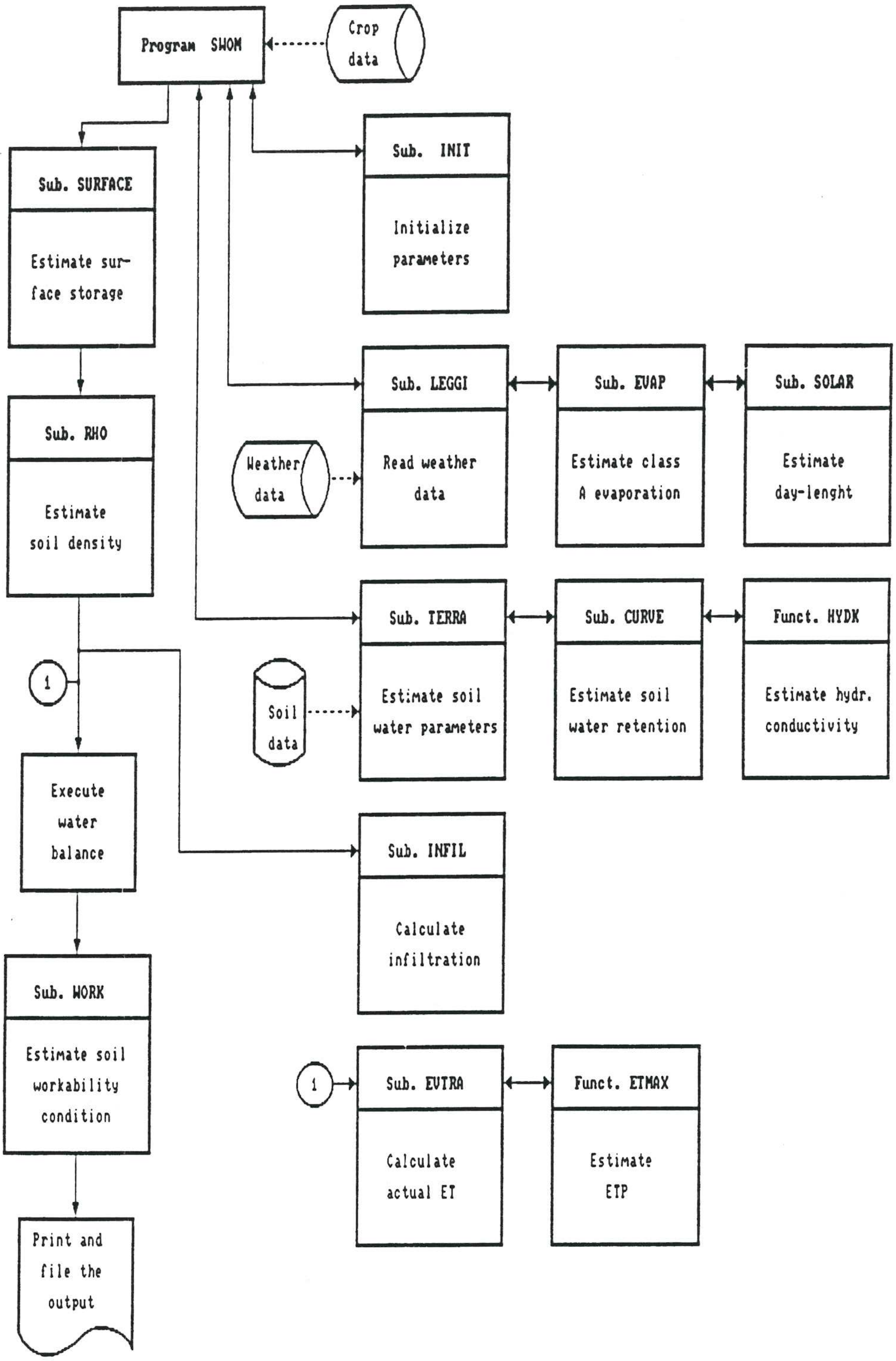
5. Rolling

2 - SURFACE STORAGE sub-model (sub. SURFACE)
The storage capacity of the soil surface is the volume that may be occupied by water during a meteorological event before runoff occurs. Tillage increases the soil storage capacity (and surface roughness), although these induced changes tend to reduce due to the action of various weathering agents.
In SWOM simulation of the variation of this parameter over time is influenced by two distinct factors: tillage and weathering. Based on Porter and McMahon's model, some modifications were made to the sub-model to make it more suited to Italian agriculture, taking account of the five options used in the DENSITY sub-model.

3 - WATER CONDUCTIVITY sub-model (Sub. CURVE)
The sub-model simulates the water conductivity and soil water retention curves in various types of soil.

4 - INFILTRATION sub-model (Sub.INFL)
The sub-model simulates the phenomenon of infiltration considering some peculiar features of a tilled soil such as clods and surface seal. It is based on a model by Moore and Larson (1980) which considers two layers (tilled and untilled or sub-soil) and the surface crust or seal.

Figure 1 - Main components of the SWOM model.



5 - EVAPOTRANSPIRATION sub-model (Sub. EVTRA)

The sub-model simulates evaporation and/or evapotranspiration from the soil, distinguishing between the various canopy states during the agricultural season (barren soil, residue cover soil and crop cover soil). Different algorhythms are used according to the state of the soil:

1) Barren soil: evaporation from the soil is regulated by the state of the water and its suction value on the soil according to the formula proposed by Lauciani and Tombesi (15).

2) Residue cover soil: the phase following the harvest; crop residue has a strubble-mulching effect influencing the loss of water from the soil surface. To estimate this effect, a corrective factor was applied to soil evaporation, considering the amount of residue present on the surface.

3) Crop cover soil: the method adopted is based on studies by Ritchie (19) which correlate evapotranspiration with the index of leaf growth, LAI, making a sub-division between evaporation and transpiration.

A more detailed description of the various components of the water balance simulated by the SWOM model is reported in (7).

The WORK sub-model analyses a field state of workability according to the type of instrument used for tilling.

As well as distinguishing between the different implements used for tillage operations - which, as is well known, are suited to different conditions of soil moisture - the corresponding workability ranges are introduced. From this point of view, SWOM is differentiated from other similar models: in fact, in general only a maximum value of soil moisture is employed (and often the choice of this value is at the programme user's discretion), beyond which the use of agricultural machinery is discouraged; no reference is made, on the other hand, to a minimum threshold, i.e. a minimum of soil moisture below which it is not advisable to carry out a given operation. With low values of moisture, in fact, the high cohesion among the single particles of soil leads to an undesirable formation of clods often associated with a certain degree of dustiness while, in some cases, the operation may not be feasible as the implement is unable to penetrate the soil. This phenomenon is unfortunately rather frequent in our farms characterised by long dry spells and fine texture soil where the difficulties and negative consequences of tilling unworkable soil are certainly greater.

The criterion of workability adopted in SWOM is based on the comparison between soil water content at a given time and the values associated with optimal workability. The comparison is made for two different layers of soil whose depth was chosen on the basis of the depth at which the various operations are carried out: the first is 12 cm deep and is subject to more superficial operations such as harrowing, hoeing, rolling and sowing; the second is 30 cm deep and is subject to ploughing and scarification. We felt that, in the light of more modern mechanisation, tillage should not be undertaken below 30 cm depth. This value may be modified, however, if required.

Five categories of implements were grouped together according to the soil engaging mechanism basis, as shown below.

I Moldboard plowing (soil cutting and overturning)
II Scarification (deep scarification)
III Harrowing (surface harrowing or scarification)
IV Rotary hoeing (soil break-up and mixing)
V Sowing and rolling (surface compressing)

Instead of water content expressed as a percentage of moisture, we preferred to use the relative value of capillary suction, expressed as cm of water column. It is only by referring to this value that one can conclude that the workability of different types of soil (sandy, loamy, clayey, etc) is comparable over an approximately similar range. As far as the well-known phenomenon of hysteresis is concerned, on the basis of which the ratio between the soil water content and suction value differs according to whether the soil matrix is becoming wetter or drier, the drying phase alone is considered for the purpose of determining workability.

On the basis of field experiments carried out to define tendential values, for each category of implement it was possible to identify three different moments associated with the result obtainable from the operations: optimal, possible and inadvisable. A range of capillary tension was thus assigned, within which the operation produces an optimal result; upper and lower suction limits were then set, within which a given type of operation may be carried out without causing irreparable damage to the soil structure, while it is never advisable to carry out operations beyond these limits.

The workability test is only carried out on the upper layer of soil (to 12 cm) for categories III, IV and V, whereas for categories I and II, the test is undertaken on both layers (to 30 cm) and, should the results be conflicting (one workable and one unworkable layer), the more unfavourable condition prevails, conditioning the answer given by the model.

These ranges were defined on the basis of the first tests undertaken, and taking account of the indications reported in "La façon en travail du sol", Etudes du CNEEMA (1979). This illustration of the ranges may be considered as the common definition of workable soil. The values of capillary suction for the five categories of operation, referring to loam, are reported in figure 2.

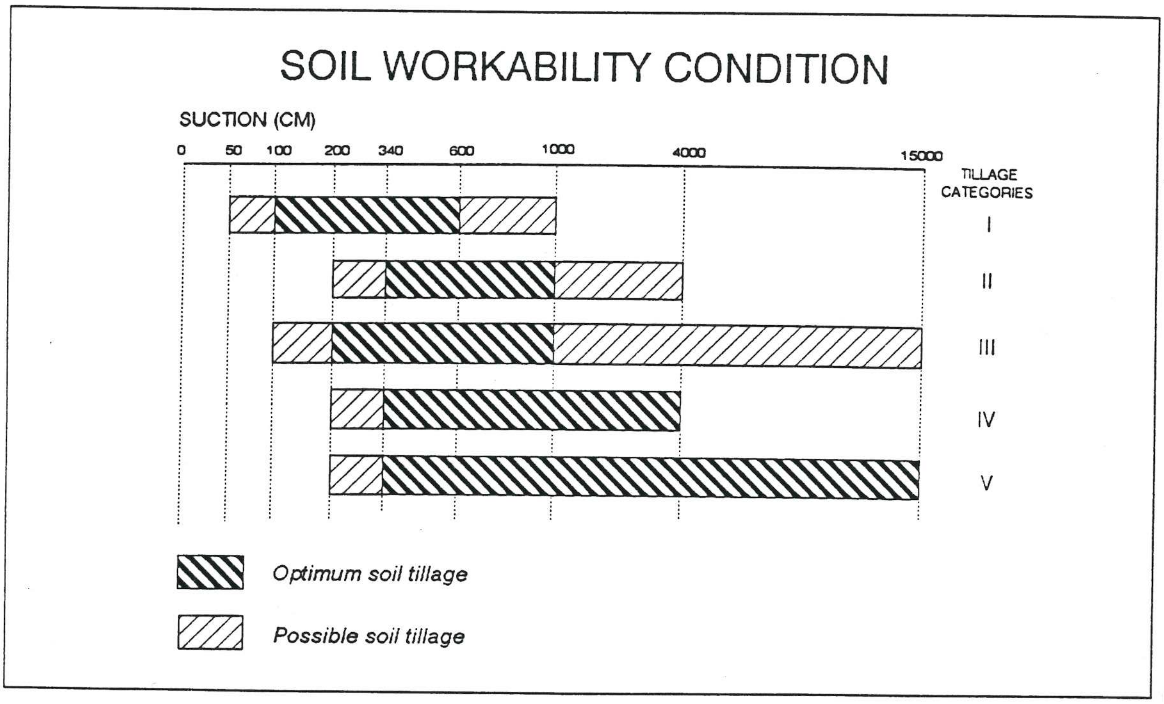



Figure 2 - Soil workability condition, defined as matric tension (cm), of the five tillage categories for loam soil (values in calibrating phase).

At present research is being executed with the aim of checking the values chosen for defining the workability range of the various implements used in operations in different pedological situations in the central and eastern Po Valley (Emilia-Romagna and Veneto).

Given that in reality the transition from workable to unworkable takes place progressively, i.e. a workability range does not have well defined boundaries, this difficulty was dealt with by adopting the fuzzy set theory formulated by L. Zadeh in 1965 (30,13). In this type of approach, rather than determining which of a series of values belong to a given set, what is

defined is the membership level of a fuzzy set. The moment of transition from belonging to non-belonging is thus indistinct (24).
Figure 3 shows the difference between the classical and the fuzzy approach with regard to the workability of a plough.

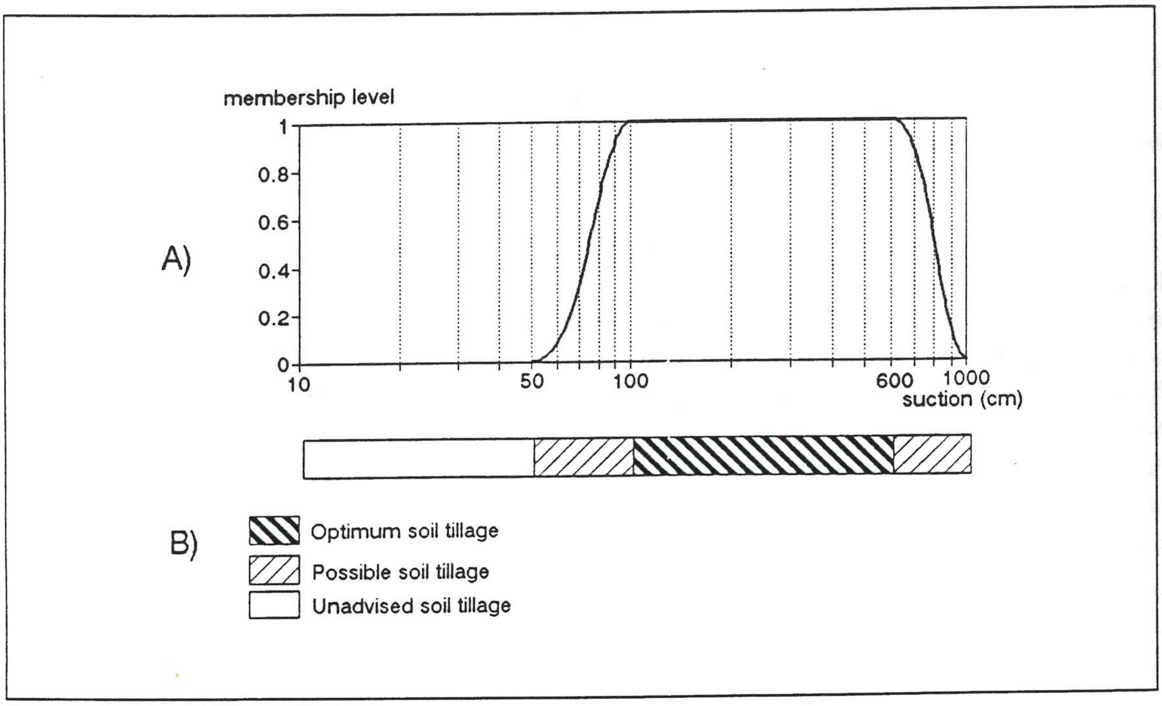



Figure 3 - Exemplyfing comparison, for moldboard plowing, between fuzzy set theory (A) and binary or classic set theory (B).

As an illustration of the answer supplied by the model, an output file is reproduced. It refers to the simulation conducted in 1991 using the data collected on the "Valier" farm at Borsea (RO) where soybean was cultivated. Weather data were supplied by the nearby agrometeorological station at Concadirame. Rainfall between June 15 and 19 had caused a signficant variation in the water content, i.e. in capillary suction. The answer given by SWOM for June 19 indicated optimal workability as far as moldbaord plowing was concerned, while scarification would be negatively affected by the high humidity rate in the workable layer. In this case the model warns that the use of a scarifier might produce undesirable results, such as compressing and destruction of the structural aggregates affected by the operation. Given the high water content of the surface layer SWOM also discouraged to carry out other operations that day involving crumbling of the structural aggregates (soil break-down and mixing) or compressing the surface (sowing and rolling). With regard to operations similar to harrowing, the value suggested that, in the right conditions (good weather forecast and/or available work days), such work should be postponed, so that the operation could be performed in conditions of optimal workability. Especially in the last case, the decision whether to carry out the operation or not might be taken bearing in mind the weather forecast for the area supplied by the Regional Agrometeorological Service.

## 3. CONCLUSIONS AND FUTURE TRENDS

Estimation of the soil workability is an extremely interesting, though rather delicate, aspect concerning management of a very important part of a farm's patrimony (soil and machinery). This problem calls for a solution that is both reliable and widely applicable. The SWOM model, with the criterion of workability adopted, is an attempt in this direction.

When appropriately interpreted, the results of the simulations carried out using local weather data, and taking account of the forecasts supplied by regional agrometeorological services, may be used at field level by technical assistance services as a support for farmers in chosing and planning the various agricultural operations.

The final purpose of this research is to provide farmers and agricultural operators with an instrument that can give indications regarding both the mode of execution of operations and the most suitable equipment or machinery to adopt. As well as bearing in mind the work time required to complete the operation, the decision should take account of the pedoclimatic environment concerned, using only those implements that respect the soil structure in order to maintain, if not to improve where necessary, its fertility and biological vitality.

LEGEND
I - MOLDBOARD PLOWING
II - SCARIFICATION
III - HARROWING
IV - ROTARY HOEING
V - SOWING AND ROLLING

| ** TILLAGE CATEGORIES ** | | | | | |
|---|---|---|---|---|---|
| DAY | I | II | III | IV | V |
| 6/16/91 | .0000 | .0116 | .9216 | 1.0000 | 1.0000 |
| 6/17/91 | .0000 | .0003 | .9103 | 1.0000 | 1.0000 |
| 6/18/91 | .0000 | .0000 | .8801 | .0000 | 1.0000 |
| 6/19/91 | 1.0000 | .0000 | .8251 | .0000 | .0000 |
| 6/20/91 | 1.0000 | .0000 | 1.0000 | 1.0000 | 1.0000 |
| 6/21/91 | .8174 | .0052 | 1.0000 | 1.0000 | 1.0000 |
| 6/22/91 | .0533 | .0576 | 1.0000 | 1.0000 | 1.0000 |

Figure 4 - Example of output of the WORK.RIS file: the daily value is refered to the membership level ($\mu$) of soil tension value (x), for each tillage categories, to the optimum soil workability condition ($\gamma$) in according to "fuzzy set theory"

$\mu_\gamma (x) = 0$ unadvised soil tillage

$0<\mu_\gamma (x)<1$ possible soil tillage

$\mu_\gamma (x) = 1$ optimum soil tillage

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