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Agronomie (1998) 18, 45–59

Original article

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(Received 24 January 1997; accepted 12 February 1998)

Abstract – To plan out the needs for farm machinery, simulating the schedule of tasks might be welcome. Such schedules depend upon soil moisture conditions, and mechanistic models fitted to any local situations are not available. Thus, one has to request expert advice to design empirical models. Could expert advice come from farmers? To answer this question, we tested whether they have a homogeneous way of integrating soil conditions with regards the dates for seedbed preparation and sowing of a spring crop. Farmers were put in the situation of consulting experts and their decision making was investigated. Mathematical classification methods as well as discourse analysis were used to analyse the data. The study demonstrated that farmers: a) used common criteria for differentiating soil conditions; b) for a given soil texture, gave the same date allowing first day tilling operations; and c) chose a date in accordance with an agronomic criterium. Whether these conclusions could be extrapolated to winter gangs, to non-experienced farmers, and to farmers using reduced machinery for tillage is discussed. (© Inra/Elsevier, Paris.)

agriculture / decision making / expertise / workable days / tilling

Résumé – Les agriculteurs sont-ils des experts pour identifier les jours disponibles pour le travail du sol ? Pour raisonner les équipements des exploitations agricoles, il est utile de simuler le déroulement des travaux. Ce dernier est conditionné par l'évolution des états hydriques du sol. Des modèles mécanistes n'étant pas disponibles pour toutes les situations locales, on a recours à l'avis d'experts pour concevoir des modèles empiriques. Les agriculteurs peuvent-ils être de tels experts ? Nous avons cherché à répondre à cette question en testant si les agriculteurs évaluent de façon homogène les états du sol lors de la préparation du lit de semences pour une espèce cultivée au printemps. Nous avons placé les agriculteurs en position d'experts dans des conditions contrôlées expérimentalement, et réalisé des enqêtes sur leurs processus de décisions. Les données sont traitées en utilisant des méthodes de classification automatique et des analyses de discours. Notre étude permet d'établir que : les agriculteurs a) ont des critères communs pour différencier les états du sol, b) donnent une même date pour définir le premier jour où une intervention est possible pour une texture

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donnée, c) apprécient cette date conformément à des données recueillies lors d'une expérimentation agronomique. Nous montrons ainsi qu'il est possible de recueillir un avis homogène entre agriculteurs pour le premier jour disponible pour le travail du sol au printemps. L'extrapolation des conclusions aux chantiers d'hiver, à des agriculteurs faiblement équipés pour le travail du sol et à des agriculteurs récemment installés est discutée. (© Inra/Elsevier, Paris.)

agriculture / prise de décision / expertise / jours disponibles / travail du sol

1. INTRODUCTION

In the late 1980s, farmers working in arable cropping areas were eager to increase the power of tractors and the working efficiency of equipment. This was carried out in order to reduce dependence on climate uncertainty. Recent modifications of the European Agricultural Policy have called for a drastic reduction of overhead costs. This can be achieved by optimizing the choice and use of farm machinery. To promote such a process, computerized simulations of farming have been designed and are now available.

In Picardie, an arable cropping area of northern France, agricultural advisors use a computerized program called OTELO®, which yields a simulation of the working schedules. The program is based on the rules a farmer has developed for his own work organization and it tests these rules against a range of climatic scenarios [2, 14]. This program assesses the likelihood for a cultivation operation to be realized in the period the farmer planned to achieve his production objectives. Such analyses are possible only if the technical advisors can establish models for workable days fitting to any given farmer so as to determine, with an accuracy of ± 1 day, the days where cultivation operations can be optimally carried out. While the technical advisors find it fairly easy to collect data on the organization of work, an important factor in decision-making, they find it much more difficult to collect judgments on soil physical conditions, which are also determining factors in this setting. Thus, they would welcome methods that would simplify the collection of farmers' judgments on soil physical conditions. A study was undertaken to test whether farmers living in a same area could make homogeneous judgments on soil physical conditions in the perspective of a given cultural operation.

Although agronomists often have recourse to farmer judgment when they need to determine the possible day for carrying out a given task, they have not yet explored this aspect of decision-making. In former studies, the dates when farmers realized various tasks were systematically recorded [11] so as to establish the probabilities for defining optimal days for tilling. Such an a posteriori method did not indicate whether other days, not indicated in the study, would nevertheless have been considered as possible tilling days by the farmers. Similarly, in studies dealing with farmers' opinions on the possibility of carrying out cultivation operations in the best conditions, farmers' discourses were directly recorded during the whole period when these operations could be realized [16, 17, 22], but the farmers' judgments were aggregated regardless of their homogeneity.

Recent reports proceeding from two types of studies have shown that methods which merely aggregate farmers' opinions cannot be validated without preliminary controls. On the one hand, Cerf [7] showed that the way farmers perceive the physical variables of soil condition is influenced by the combination of implements they intend to use in order to realize a seedbed preparation and sugar beet sowing. Thus, since the combination of implements used during tillage depends on the agricultural equipment of the farms, one cannot consider without preliminary control that opinions issued by farmers on possible days for tilling are identical with reference to the variables of soil physical conditions.

On the other hand, Sebillotte and Servettaz [20] showed that in the setting of agricultural operations, farmers modify and reduce their requirements concerning the quality of tillage towards the end of cultivation operations. Thus, opinions issued at the beginning of a tillage period cannot be assimilated to opinions issued at the end of the same period.

This implies that the conditions under which the judgments of different farmers can be considered as really equivalent must be checked beforehand. The present study intends to demonstrate that farmers really have homogeneous judgments when they have to define the first possible day allowing a given cultural operation to be performed, provided their judgments are summed up and considered as a function of the variables they integrate when determining rationally the modalities of the cultural operation.

We have designed two studies to test this hypothesis. The first study aimed to i) identify the way farmers integrate those variables which, from an agronomic point of view, determine the choice for an optimal working day; ii) analyse the extent to which these variables are homogeneously taken into account by different farmers. The second study intended to investigate decision-making by farmers concerning the first possible day for a given cultivation operation and to establish an agronomic criterion accounting for the presumed homogeneity of farmers' decision.

Results of these studies will be presented successively because the data obtained in the first study were used to decide how data would be collected in the second study.

2. MATERIALS, METHODS AND RESULTS

Both studies have focused on decision-making during tillage and sowing of sugar beet (*Beta vulgaris* L.). Sugar beet was chosen because it requires demanding seedbed conditions [6, 18] as it must be established within a short lapse of time and because the duration of its growing cycle must be optimal [5, 9]. In brief, for sugar beet seedbed preparation, the question of the possible days for tilling is crucial.

We collected data by selecting two groups of farmers[1] willing to participate in the trial and working in the Picardie area (northern France). We limited the size of the groups to eight and six farmers, respectively, because we had to analyse their discourses thoroughly before processing the data concerning knowledge readily used by farmers in the setting of a decision on seedbed preparation. Working on large groups in order to use conventional statistics was beyond reasonable costs and lapse of time. To counter the drawbacks due to the small size of the study groups and to determine the conditions which would allow a generalization of the results, some hypotheses had to be made on the factors which could potentially generate differences in the representation and immediate availability of knowledge utilized by farmers; we considered a wide range of variations of these factors as they appeared from the two groups of farmers (*table I*). Factors potentially influencing the acquisition of knowledge (i.e. variables dependent on the farmer himself and variables dependent on the limitations induced by the field pattern within the tilling area) were considered, as well as other conditions influencing the way knowledge is acquired (competition between diverse spring tillage, duration of seedbed preparation for sugar beet).

2.1. Study 1

Sebillotte and Servettaz [20] showed that farmers use a great number of criteria when they decide on sugar beet sowing, but these authors gave no indication about the relative weight farmers allocate to these criteria during the decision-making process. These authors however drew relevant informations directly from on-farm work, which warranted that the criteria were really utilized during the decision-making process, but made comparisons difficult between individuals which face de facto different and personal situations.

2.1.1. Materials and methods

Experimental tasks were designed which mimicked as closely as possible real working situations so as to determine whether farmers really use similar criteria when deciding on tilling and sowing sugar beet. An on-farm follow-up of tilling and sowing techniques was realized in 1990 [7] which validated the experimental methods described in the present paper.

Experimental tasks were constructed using a set of 26 photographs which had been taken at the end of the winter, a time when sugar beet is sown in the cropping area under study (end of March). The land had been

[1] The choice of two different groups is contingent to the partnerships developed during the study.

Table I. Characteristics of farmers and working situations during the sugar beet sowing period.

Study 1								
Farmer code	A1	A2	A3	A4	A5	A6	A7	A8
Competition between different production activities	+	+	0	+	+	+	++	+
Field pattern constraints	+	+	+	+	0	++	++	+
Time required to carry out the work	++	0	++	++	+++	+	++	0
Number of years' experience as head of holding	< 10*	> 10	> 10	> 10	> 10	< 10*	> 10	< 10*
Initial agricultural training	yes	yes	yes	yes	no	yes	yes	yes
(year of higher education)	4	–	4	4	–	4	4	2
Technical and economic integration	++	+	+++	+++	+	+	++	+++
Study 2								
Farmer code	E1	E2	E3	E4	E5	E6		
Competition between different production activities	+++	+++	++	+	+	+		
Field pattern constraints	0	+	+	0	+	++		
Time required to carry out the work	++	+++	0	++	0	+		

* These farmers had worked on their fathers' farms for several years before taking over as head of holding. Competition among tasks, constraints due to field pattern and time required for sowing sugar beet: 0, slight; +, moderate; ++, considerable; +++, very considerable. Technical and economic integration: +, well integrated in socio-technical networks; ++, has a professional responsibility off the farm; +++, has more than one professional responsibility.

ploughed between mid November and early February. The 26 photographs revealed soil textures found on the farms and in the very area where farmers have their activities. A photograph reveals less than on-site observations: only visual criteria are available; furthermore their interpretation is biased by the quality of the photograph. Photographs were taken at a 1.5-m distance above ground level under a 45° angle of incidence to bring out the relief. This cannot give information on the appearance of the whole land. In spite of these limitations, these documents were useful since they forced the farmer to formulate all the criteria he used in order to construct a representation of the situation beyond the sole visual indications. A few situations are illustrated in *figure 1*.

2.1.1.1. Experiment A

For each photograph, farmers[2] were asked how they would prepare a seedbed with respect to the soil condition shown in the picture. In practice, photographs were laid out in front of the farmers who were told that each picture was representative of one field and that it had been taken at the beginning of the sowing period. Farmers were allowed to consider the pictures in a random order and to modify the order whenever desired. For each photograph a set of information (see *table II*) was supplied by the investigator whenever farmers requested help to make their decision. The information included the reaction of clods to hand or foot pressure as well as the reaction of soil to spade or heel strokes; the investigator had checked the reactions as he took the photographs because they are commonly used by farmers when they have to issue a judgment about the physical state of soil [20]. Finally farmers were asked to describe, aloud, how they would work out the soil to prepare a seedbed using the materials and manpower available on their own farms. Both conversations and remarks were tape-recorded by the investigator.

Though this experiment was designed to be as close as possible to real working conditions, two kinds of limitations should not be overlooked: i) the experiment dealt with decisions concerning one field, while farmers normally have to make their decisions for all the fields under the same crop [1]; ii) in spite of the complementary data supplied by the investigator, the information which farmers had at their disposal was mainly visual.

[2] Farmer A7 was not avalaible while this experiment was conducted.

Figure 1. Pictures shown during the experiments covered different texture of soil (i.e. clay loam for pictures 1 and 2, silt loam for picture 3), different friability of soil (i.e. friable for picture 2 and not friable for pictures 1 and 3), different degree of eveness, clods size and soil moisture.
Visual signs allowed farmers to infer some variables such as soil moisture.

Transcripts of interviews of every farmer participating in the trial were analysed using a grid (see *table III*) establishing correspondences between the expressions used by the farmers to specify the situations they have to deal with, and the variables used by agronomists. When several terms were considered as equivalent, they were associated in the form of sets called attributes (for instance: crusted, slaked down). These attributes were associated in the form of variables (for instance: results of soil textural behaviour). For continuous variables (for instance soil texture) different terms were clustered as a single attribute referring to the order built up from the intervals differentiated by each farmer; thus, terms such as 'clayey loam' and 'very clayey' were associated under the heading 'clayey' which finally grouped the terms corresponding for the farmers to the most clayey of the textures yielded by the set of photographs. Thus we identified the combined variables which farmers use when deciding about the modalities of tilling and sowing. We also identified the variables which would actually lead to the application (or non-application) of the same combination of tilling and sowing tools for different soil conditions illustrated on the photographs [7].

2.1.1.2. Experiment B

In a second phase, using the same set of photographs, farmers were put in a situation far from their usual cultivation practice so as to determine on which criteria they aggregate or differentiate soil conditions when they build a classification of the photographs independently of defining modalities for seedbed preparation. We aimed to assess the homogeneity of the farmers' classifications.

Using the same set of photographs as used in experiment A, the investigator first asked two questions: 'Is this similar to your own land?' 'To what extent is it similar or different?' These questions were intended to check that the experimental material enabled the farmers to have a clear representation of the situation illustrated by the photographs. Then he asked a series of questions: 'This is the *n*th photograph. Would you clas-

Table II. Additional information provided at farmers' request.

Additional information	provided on request	Range of variation
Weather at time photo taken	wind direction	north/northeast
	presence of wind	yes/no
	insolation	fog/clear sky
Reaction of clods	to handling	breaks into small clods[1]/hard to break up/can be kneaded
	to treading	breaks into large clods[1]
		breaks into small clods[1]
Reaction of soil	to spade	drained[1]/wet[1];
		block[1]/large clods[1]
	to heel	hard/soft; heel leaves print/heel does not leave print
Winter frost	presence	yes/no
	intensity	slight/hard[1]
Winter rain	abundance	slight/normal/abundant
Date ploughed		November/December / January/February
Condition when ploughed		good[1]/wet[1]
Date of photograph**		25th March/15th April
Weather on following days **		Scenario 1*/Scenario 2*

[1]At the end of the experiment, the farmers were systematically asked what significance they attributed to the words marked with this symbol. *Scenario 1: no rain expected in next 4 days, no persistent fog forecast, temperatures steady. Scenario 2: rain forecast in 2 days' time, with subsequent deterioration, moderate north-westerly wind, temperatures steady. **As far as possible, each alternative is envisaged systematically on each photo (if the farmer agrees to play the simulation game).

sify it together with the previous ones? Why if Yes? Why if Not ?'. The farmers could freely build and modify categories while categorizing the different photographs, but were asked to allot a given photograph to only one category. Finally, after all the pictures had been dealt with, the farmers were asked to i) assess, name and describe the categories they had established and (ii) specify which photograph, in their opinion, was the most representative of every one of the categories they had built. At the end of the experiment, we had at our disposal categories as built by each farmer and a transcript of the interviews collected during the process of categorization. This method has been drawn by using methods built up by psychologists studying natural classification and is based on results obtained by these psychologists (for synthesis see Van Mechelen et al. [21]).

The data were processed using a statistical analysis of the categories produced by the farmers so as to identify the overlaps between farmers' individual knowledge. A comparative analysis of their discourses during the categorization process was simultaneously carried out. The statistical analysis of categories used in the present study aims to construct a classification of the photographs such as to reflect the way farmers did associate the pictures. Distance (d) used to establish this classification is an index of similarity between pictures. This is the number of times any two photographs are found to be associated within the farmers' categories (minimum index = 0; maximum index = 8). From this index and using the topological properties of a mathematical tree, 'scores' can be calculated[3]. Indeed the method allows

[3] The computerized program used in this study was designed by Barthelemy and Guenoche (1988) and generously made available to us. This is gratefully acknowledged by the authors.

Table III. Grid of analysis of farmers'discourse

Attribute	Variable	Encoded terms+
Loamy		*limon battant, limon*
Silt loam	texture	*limon argileux*
Clayey		*très argileux, argileux*
Sandy loamy clay		*type argilo-sableux*
Hydromorphy		*hydromorphe*
Stoniness	other permanent features of the soil	*petits cailloux, silex*
Crusting earth		*terre battante*
Non-crusting earth		*terre non battante*
No evening out		*très structuré, cahotique, pas nivelé*
Well evened		*absence de relief, pas de bosses*
Clod size*		*grosses mottes, blocs, petites mottes*
Amount of clods*		*beaucoup de mottes, pas de mottes*
Clods friability*		*mottes dures, mottes fissurées*
Wintered tilth	structure of the soil	*c'est hiverné, l'hiver a travaillé*
Non-wintered tilth		*pas d'hiver, pas hiverné*
Overwintered tilth		*destructuré*
Compacted ground		*tassé*
Fragmented ground		*fissuré*
Slaked down soil		*fermé*
Soil moisture*	Soil moisture	*humide, frais, vert, sec*
Spring tilth		*labouré au printemps*
Winter tilth	Tilth conditions	*labouré avant les gelées, labour hiver*
Good tilth conditions		*bien labouré, bonnes conditions*
Bad tilth conditions		*mauvais travail au labour, mauvaises conditions*
Intense winter frost		*il a gelé en hiver*
No winter frost	winter weather	*absence de gel sur ce labour*
High level of winter rains		*dégradé par les pluies hivernales*
Low level of winter rains		*structure conservée, absence de pluie*
Earth easy to till		
Earth not easy to till	tillage easiness	

+We leave these expressions in French to respect the terms used by the farmers. *For such an attribute, according to the low score of each expression, we associate opposite terms (i.e. big and small clods). For each photo we then checked that the different farmers did not appreciate the attribute with different evaluations (i.e. with opposite terms).

the calculation of 'scores' of a pair (x,y) of a set X^2 (where X = the set of 26 photographs), i.e. the number of pairs (z,t) of X^2- (x,y) so that $d(x,y)+ d(z,t) < d(x,z) + d(y,t) = d(x,t) + d(y,z)$. This is equivalent to the calculation of the strength of connection between two elements of X. In the present case, this method yields an approximate measure of the stability, within the group of farmers, of the associations made between any two photographs. The program provides a graphic representation of these distances in the form of a graduated tree, where the leaves are the photographs and where nodes are clusters of photographs observed either within the farmers' categories or constructed by the program.

The results of the analysis of the farmers' discourse carried out in parallel on the criteria they had used during classification were applied so as to characterize the stable clusters emerging from the analysis of scores. In this part of the study the criteria were encoded according to the grid of analysis previously used in experiment A (*table III*).

2.1.2. Results

After encoding the variables mentioned by the farmers on the photographs used during experiment A, a comparison of data derived from the farmers' opinions was carried out (*table IV.a*). It revealed that they all mentioned the variables which, for agronomists, are determining in the choice of a date for adequate cultivation. Only the weight attributed to the different variables varied between farmers. *Table IV.b* shows that farmers did not all quote the same variables for a given photograph. As a matter of fact the number of quotations for one variable was found to be always lower than the number of farmers participating in the trial (seven). Such heterogeneities can be put in relation to the different combination of implements mentioned by the farmers during the test, which in turn reflects the various combinations of implements they use on their own fields. In contrast, a great homogeneity is demonstrated between the farmers when the comparison rests on the variables mentioned to determine how to assign a specific combination of tools to a set of physical conditions of the soil (*table V*). Except for farmer A5, soil structure was found to be a prominent criterion when farmers had to choose combinations for tilling and sowing. Farmer A5 was an exception because his own material (a combined tillage tool) allowed him to obtain about the same seedbed whatever the soil structure may be. Therefore he did not pay attention to the differences between soil structure which were shown in the pictures.

Table IV.a. Total encoded terms and percentage of each variables quoted by farmers to identify a given soil condition during experiment A.

	A1	A2	A3	A4	A5	A6	A8
Soil texture	22	26	37	16	21	2	28
Other permanent features of the soil	20	26	11	7	55	23	22
Soil structure	31	35	26	40	24	36	34
Soil moisture	12	11	11	11	10	13	2
Tillage easiness	–	–	–	–	–	25	2
Total encoded terms	82	54	35	82	38	53	50

An analysis of the data collected from experiment B corroborated the apparent heterogeneity of judgments issued by the farmers on the soil physical conditions. Nevertheless when a mathematical approach using an 'analysis of scores' was carried out, overlaps between categories built by the farmers could be evaluated (*figure 2*) giving indications on the distances between photographs on the one hand, between clusters of photographs on the other. The study of distances demonstrates that: i) stable pairs can be defined among farmers, either because they frequently match some photographs (bold on *figure 2*) or because they frequently separate them (italic on *figure 2*); ii) a level of aggre-

Table IV.b. For each photo shown during experiment A. Total amount of farmers quoting a given attribute or a given variable.

	T	C	U	D	E	F	H	I	J	K	L	M	N	O	P	Q	R	S	Y	W	X	Y	Z
Soil texture	4	2	3	5	2	3	4	3	4	1	4	2	3	2	6	3	3	5	4	5	6	3	4
Other permanent features of the soil	1	2	–	6	6	4	2	–	5	5	6	5	3	4	–	2	2	7	–	1	1	2	–
Degree of evenness	4	1	3	–	1	1	1	3	2	1	1	1	–	–	1	1	1	–	1	6	2	2	1
Clods size	1	–	1	–	–	–	–	2	–	1	1	–	–	–	–	–	1	–	–	–	–	–	1
Clods friability	1	–	3	1	2	2	1	2	–	1	1	2	–	1	1	3	1	1	1	2	1	1	1
Result of a textural behaviour	2	2	2	4	3	1	2	1	3	3	6	3	6	1	2	2	2	3	2	2	3	–	1
Soil moisture	–	1	–	–	2	3	1	3	1	3	2	5	–	–	–	1	1	3	–	2	–	2	1
Tilth conditions	1	1	3	–	3	–	–	3	–	1	1	1	2	–	1	1	2	–	3	3	–	2	2
Winter weather	–	–	–	1	2	1	1	–	1	1	2	1	1	1	–	1	–	1	–	1	–	2	–
Tillage easiness	–	1	–	–	2	1	1	–	1	1	1	1	1	1	–	1	–	1	–	–	–	1	

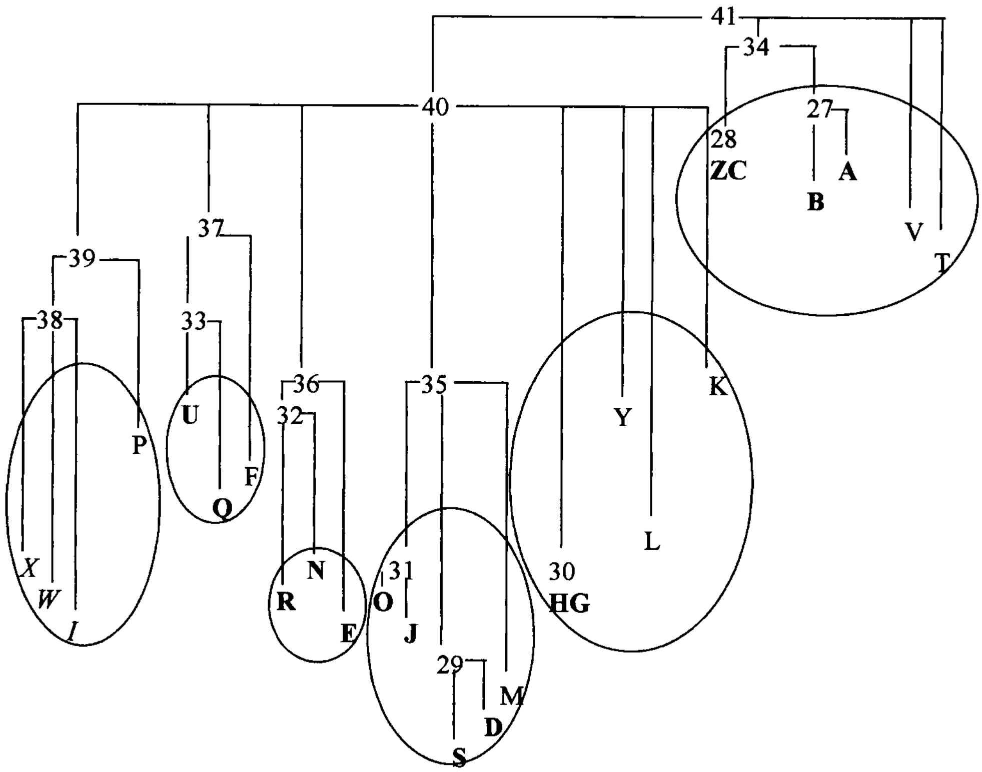

Figure 2. Result of the application of 'score' analysis to the 26 photographs used in experiment 1.
Key: no. number of nodes resulting from 'score' analysis (27–41); letter: code of an actual photograph (A–Z). Stable pairs are indicated in bold type where farmers frequently class the photos together. Stable pairs are indicated in italics where farmers frequently dissociated these photos from the others. Maximum groups taken into account are encircled. The length of each line respects the mathematical distance between two photographs as calculated by the program.

Table V. Total amount of variables quoted by farmers to justify their choice of applying a specific tools combination to a given soil and percentage of each variable (experiment A).

	A1	A2	A3	A4	A5	A6	A8
Soil texture	–	27	37	16	50	–	40
Other permanent features of the soil	–	–	–	–	–	–	–
Soil structure	70	53	37	53	–	75	60
Soil moisture	30	13	20	31	–	25	–
Tilth conditions	–	7	6	–	50	–	–
Total quoted variables	10	15	14	19	2	8	5

gation can be defined which is relevant for the analysis of the most important clusters (circled on *figure 2*). These clusters more or less reflect the way each farmer built his categories since, on average, they cover up 60 % of the farmers' categories with variations between 33 and 100 %.

When these clusters were compared with the variables obtained from the interviews collected during experiment B, the variables giving the best account of the separation between clusters appeared to be texture, susceptibility to crusting and stoniness (*table VI*), i.e. the permanent features of the soil. It should be further pointed out that the pairs of photographs found to be stable among different farmers were characterized by variables independent of yearly contingencies. These are the variables which are actually used by agronomists when they do a first degree classification of fields. The differences in the degree of overlapping (33–100 %) found between individual categories built by the farmers and the clusters produced by 'analysis of scores' could actually be explained by the different weights allocated, during the process of categorization, to variables inde-

Table VI. Variables characterizing the clusters formed by analysis of the 'scores'.

Groups resulting from score analysis	Texture	Susceptibility to crusting	Stoniness	Soil structure	Result of textural behaviour	Tilth condition
W, X, I, P	X (73)					
U, F, Q	X (54)	X (67)				
E, R, N	X (35)		X (100)			
O, J, D, S, M	X (72)	X (94)				
G, Y, K, H, L	X (50)				X (84)	
C, Z, B, A, T, V	X (54)			X (64)		X (61)

X: Variable mentioned for characterizing all the photos in the group in question. (73): % agreement among farmers on one mode of the variable.

pendent of yearly contingencies. Classifications best represented are those where the farmers only take into account permanent characteristics of the soil (for instance farmer A4). In contrast, classifications least represented are those where the farmers, when building categories, take into account variables referring to soil structure conditions (farmers A2 and A3).

In conclusion, this first study suggests that farmers decide about the modalities of tilling by structuring a set of variables which are also determining factors for agronomists in decision-making about seedbed preparation. Though the weight allocated to each variable changes among the farmers when they have to decide how to till, the soil structure is a prominent variable taken into account by the majority of farmers. Whenever the farmers have to differentiate between diverse physical conditions of soil in the absence of any working constraints, permanent characteristics of soil come out as a central point.

Soil moisture, a variable only occasionally mentioned during both experiments, was also investigated considering its potential importance in decision-making. Because this variable is difficult to assess from photographs, this evaluation was carried out using on-field decisions. Comparison between farmers was warranted by means of an agronomic characterization of the fields (permanent characteristics and soil structure).

2.2. Study 2

This study was carried out with a second group of farmers and was designed to assess the homogeneity between judgments issued by farmers in the absence of working constraints but directed to the choice of a first possible day for tilling.

2.2.1. Materials and methods

Since the agronomic variables integrated into the farmers' judgments had been identified, a sample of fields was selected based on these variables. Fields were selected (*table VII*) in relation to their texture (silt loam and/or clay loam) and to the structure of the ploughed layer which was qualitatively characterized. The structure of the ploughed layer is evaluated by determining the levelling of tilth (measures in duplicate on 2-m lengths, one measure every 0.05 m) and by analysing structural conditions (five profiles having 1×0.4 m^2 distributed all over the field) according to Gautronneau and Manichon scale [10]. Type 'O' tilth is a fragmented structural condition of the soil, with no decimetric clods and no cavities. Type 'B' tilth shows decimetric clods and cavities and very little fine earth.

Finally during the whole experimentation period, moisture was monitored in moisture profiles in the fields on which the farmers had to issue their judgments. These measurements allowed a comparison between the inquiry carried out among the farmers and an on-field experiment carried out in the same area [8, 19]. The latter experiment was taken as a reference when soil moisture (% w/w) had to be interpreted in terms of mechanical effects within the ploughed layer.

2.2.1.1. Farmers' interviews on the first day possible for tilling

From the beginning of March, farmers were asked to fill in diaries on the situation of sugar beet fields. They

Table VII. Characteristics of fields chosen for moisture monitoring.

Field code	Soil texture	Structure	Water-logging	Uniformity within field
P1E1	SL	B	no	wet patch
P2E1	SL; CL	B	no	yes (texture)
P3E2	CL	B	yes	no
P4E3	SL; CL	O	no	yes (texture)
P5E3	SL; CL	O	no	yes (texture)
P6E4	CL	B	no	no
P7E4	CL	O	yes	no
P8E5	CL	O	no	no
P9E5	CL	O + B	no	yes (structure)
P10E6	SL	B	no	yes
P11E6	SL	O + B	no	yes (structure)

P1E1: the last two symbols refer to the farm on which the field is located; CL: clay loam (> 18 % clay); SL: silt loam; O: type 'O' tilth (notation from Gautronneau and Manichon [10]); B: type 'B' tilth (notation from Gautronneau and Manichon [10]).

had to write down the reasons for the eventual postponing of work (rainy weather, soft ground, impenetrable ground, soil too cold, risk of frost, other farming tasks to fulfill). In parallel, during the follow-up carried out in the fields (see below), the farmers were asked to give their opinion on the possibility (or impossibility) to carry out a task. The data were processed so as to identify: i) the first day considered to allow tillage; ii) to explain deviations with respect to the days when the work had actually been performed.

2.2.1.2. On-field measurements of soil moisture

During the days preceding tilling and sowing, daily moisture profiles were established on field plots on which farmers based their decision-making (*table VII*) and the size of particles was analysed. Moisture was measured on samples collected at four depths (0–5 cm, 5–10 cm, 10–20 cm, 20 cm to bottom of plough layer). Six samples per level were taken so as to take into account the spatial variability of soil moisture within the ploughed layer [13].

2.2.2. Results

2.2.2.1. Farmers' interviews

Five out of the six farmers gave a similar appraisal on the first possible day for tillage (*table VIII*). A time-

Table VIII. First day regarded by farmers as possible for tilling fields in sample (1993).

Farmer code	Field code	Texture of zone considered	Structure of zone considered	First day considered possible for tilling
E1	P1E1	SL	B	10–3
	P2E1	SL	B	10–3
E3	P4E3	SL	O	10–3
	P5E3	SL	O	10–3
E6	P10E6	SL	B	5–3
	P11E6	SL	O + B	5–3
E2	P3E2	CL	B	15–3
E4	P6E4	CL	B	15–3
	P7E4	CL	O	15–3
E5	P8E5	CL	O	15–3
	P9E5	CL	O + B	15–3

P1E1: the last two symbols refer to the farm on which the field is located; CL: clay loam (> 18 % clay); SL: silt loam; O: type O tilth (notation from Gautronneau and Manichon [10]); B: type B tilth (notation from Gautronneau and Manichon [10]); 10–3: 10t March 1993.

lag was found between appraisals concerning silt loam fields and clay loam fields. These results also suggest that the soil structure conditions have no role in the farmers' judgment about the first possible day for tilling.

2.2.2.2. Soil moisture measurements

For a given texture, a fairly homogeneous soil moisture level within the 5–10 cm ploughed layer was found for the days farmers judge as the first possible day (*table IX*). For silt-loam, for which the greater number of data was available, this corresponded to a soil moisture of 19.9 ± 1 %. Thus, the farmers selected independently from each other the same day for starting a cultivation operation. This suggests that the farmers are aware of a threshold effect concerning soil behaviour in spite of the fact that the drying sequence of the soil is a continuous phenomenon. This must be put in parallel with a set of previous experimental studies: when studying drying sequences, Lorre and Papy [12] found a break in soil behaviour when it was subjected to the pressure of tyres. As a matter of fact, during a drying sequence evolving in the form of a continuous process, soil compaction was shown to decrease abruptly for a

Table IX. Soil moisture (% weight) in fields in sample.

Field code	Texture of zone considered	Structure of zone considered	Moisture in 5–10 cm layer (% weight)	Date of measurement*	First day considered possible for tillage
P1E1	SL	B	**20.74**	10–3	10–3
P2E1	SL	B	**19.59**	10–3	10–3
P4E3	SL	O	20.84	17–3	10–3
P5E3	SL	O	20.76	17–3	10–3
P10E6	SL	B	18.88	15–3	5–3
P11E6	SL	O + B	21.40	16–3	5–3
P3E2	CL	B	**18.63**	15–3	15–3
P6E4	CL	B	**19.48**	16–3	15–3
P7E4	CL	O	**20.83**	16–3	15–3
P8E5	CL	O	**20.75**	15–3	15–3
P9E5	CL	O + B	20.85	18–3	15–3

P1E1: the last two symbols refer to the farm on which the field is located. CL: clay loam (> 18 % clay); SL: silt loam; O: type O tilth (notation from Gautronneau and Manichon [10]); B: type B tilth (notation from Gautronneau and Manichon [10]). 10–3: 10 March 1993. *As the study began only on 7 March, field measurements could not be taken from all the sample before the dates considered by the farmers to be the first days possible for tilling; the exceptional conditions of 1993 meant that sugar beet sowing began unexpectedly early. Bold: soil moisture (% weight) on first day considered possible for tillage.

given soil moisture level (17–20 %) and a given tyre pressure.

In parallel with the above described inquiries on farmers, another agronomic experiment was carried out on clay-loamy fields ploughed at the end of autumn. Relations were demonstrated between the pressure and type of tyres used in the setting of tilling, soil moisture of the 5–10 cm ploughed layer and soil compaction [19]. These relations were expressed in the form of a percentage of zero porosity within the ploughed layer. This percentage, which should be lower than 20 %, was obtained when soil moisture levels were in the range 17.5–22.5 % and when tyre pressures were between 220 and 70 kPa. Strikingly, the soil moisture level considered by the farmers to be adequate for tilling this kind of soil texture was found to correspond (± 1 %) to the mid zone of the range where soil moisture had been found to be adequate in the agronomic experiment. Moreover the range of tyre pressures studied in this experiment was within that which the farmers usually have to deal with.

In conclusion the farmers do indeed have a homogeneous appraisal of the first possible day for tilling. When a time-lag between dates is noted, it is related to soil texture and is in agreement with agronomic knowledge on water dynamics within silt loam and clay loam. In contrast, farmers do not seem to consider, for a given texture, that fragmentation for a type B tilth is more difficult than for a type O tilth.

As a consequence of the data acquired from study 1, it was hypothesized that farmers cope with the effects of soil structures by modulating their combination of implements. On-field data collected during study 2 would seem to confirm this interpretation. Whenever data are available from farms (see *table X*) it can be shown that the farmers adapt the combinations of tilling implements to the tilth structure. When coping with a type B tilth, they increase the number of passages or make use of more efficient tool combinations.

3. DISCUSSION

Decision-making by farmers is indeed difficult to analyse. The criteria they utilize are rarely quantitative, making any agronomic modelling hazardous. Moreover, their explicit knowledge (i.e. what they are able to express as individuals) is often incomplete and distorted when compared with reasoning actually used in the decision-making process. This has been demonstrated by several studies [4, 15]. When an individual decides about a task, knowledge appears incomplete because he (she) does not only and not always refer to conscious arguments. Knowledge also appears distort-

Table X. Differences in tillage tools combinations for sugar beet seedbed preparation according to soil structure and texture (data from 1993 surveys*).

		Farm	Code*			
Soil texture	Soil structure	E1	E2	E3	E4	E6
CL	Type B	2 passes combination 1	2 passes combination 4	2 passes combination 5	1 pass combination 4 **speed < than with SL**	—
	Type O	2 passes **combination 2**	**1 pass** combination 4	**1 pass** combination 5	1 pass combination 4 **Depth >**	—
SL	Type B	2 passes combination 1	2 passes combination 4	2 passes combination 5	1 pass combination 4	2 passes combination 6
	Type O	1 pass **combination 3**	**1 pass** combination 4	**1 pass** combination 5	1 pass combination 4	2 passes combination 6

*Data not available for farm E5. O: type O tilth (notation from Gautronneau and Manichon [10]); B: type B tilth (notation from Gautronneau and Manichon [10]); CL: clay loam (> 21 % clay); SL: silt loam. NB: the combinations of tillage implements chosen by farmers are not described; the numbers (1–5) differentiate the various combinations observed within the sample. Bold: discrepancies between a farmer's practice and the basic mode he defined are marked in bold.

ed because the same individual may express notions which he(she) knows to be socially relevant to a given task though he(she) does not make use of these notions.

The present study has shown that criteria as used by the farmers in deciding about tillage operation can be made clear and compared with agronomic variables. Furthermore these criteria allow comparisons between individual farmers. However, such studies require careful experimental designs to collect and analyse the judgments of farmers: they must allow an adequate expression of the criteria used by each farmer in the study groups. Investigators have to check the situations in which the criteria are collected and they must carry out relevant analyses of the discourses to highlight these criteria. The relevance of the devices used in the present study was warranted by turning to models and methods derived from the sphere of ergonomic and cognitive psychology[4].

[4] Ergonomic and cognitive psychology deals with the study of knowledge and reasoning operators used to cope with working situations.

This study shows that in deciding about tilling operations, by means of their own and individual criteria, the farmers take into account agronomic variables such as soil texture, soil structure (friability, size of aggregates, degree of evenness, soil texture behaviour), moisture (superficial and within the ploughed layer). Though they may issue different judgments about similar soil conditions, a partial homogeneity can be disclosed by a statistical analysis of their judgments whenever these are issued outside the constraints imposed by the actual realization of tillage.

The soil structure was a prominent element in selecting a combination of tools, whereas soil permanent characteristics (texture and susceptibility to crusting) were capital elements for differentiating between fields and for decision-making on the first possible day for tilling. Farmers agreed in the appraisal of the first possible day for tilling for a given texture. Their judgments were also in accordance with measurement data of soil moisture levels found within the ploughed layer.

According to these conclusions, we propose that data be collected by the advisors and input into the OTELO® computerized program should be limited to the following: i) the rules governing the work organization, ii) temperature conditions (to avoid frost or to cultivate when the temperature of soil reaches a given threshold). Due to this study, advisors do not have to collect farmers opinions on the evolution of soil moisture. These data are directly loaded by the program from a modulus which is part of the program and which evaluates the evolution of soil moisture levels within the ploughed layer by processing data from raincharts and from potential evaporation and respiration/transpiration. The quality of the model included in this modulus has been assessed [19].

The limits of our study lie in the choice of the climatic scenario, of the season and in the kind of farmers and farms studied. The homogeneity of appraisals by farmers about the first possible day for tilling was tested in only one single climatic scenario (i.e. continuous desiccation). Our conclusions might need further assessments under different climatic conditions. But, it should be noted that the reaction of soil to alternating rain and desiccation periods is heavily dependent on the soil texture. Now, in so far as farmers have been shown to determine the first possible day for tilling according to texture, this indicates that they might integrate this criterion under other climatic conditions than those studied in order to decide about tilling operations.

Results were assessed during spring time when the soil undergoes desiccation after having been at field capacity. In so far as decision-making is concerned, farmers realizing spring cultivation are in a similar situation: they must sow as soon as possible in order to lengthen cultural cycles without taking the risk of crusting. One might ask whether such conclusions are valid for the autumn where weather conditions and decision situations are different [14]. During this latter season, when cultivation conditions can progressively hamper cropping or sowing, farmers have to operate as fast as possible. A simulation of the operations performed during autumn thus would call for an evaluation, given a quantity of rain, of how long a cultivation operation will be interrupted. Expected values would be heavily dependent on initial soil moisture conditions (less homogeneous in autumn than at the end of winter) and on farm equipment. Therefore, opinions issued by farmers under such conditions could not be expected to be as homogeneous as in spring. The question of possible days for tilling is less crucial in autumn than in spring; farmers undergo autumn conditions rather than grasping for opportunities.

The conclusions of the present study could also be questioned since they were drawn from small study groups. They must be modulated whenever the materials farmers have at their disposal do not allow the separation of the treatment of soil structure on the one hand and of soil texture and moisture on the other. Modern agricultural machinery makes fragmentation of cloddy soil possible so as to obtain a seedbed adequate for germination and shooting. Thus farmers may not take into account soil structure when deciding about the first possible day for tilling. As a consequence, soil moisture appears mostly as a determining factor in decision-making concerning field trafficability even when decision-making should rather deal with field workability. Conclusions might be questioned also in the case of recently established farmers who do not yet have a structured representation of their diverse fields.

Even if our results cannot be generalized without further studies, we were able to demonstrate the homogeneity within farmers' judgments for the first possible day for tilling, and we showed that such results can be used for building decision support. Furthermore this work demonstrates the necessity of checking the homogeneity between farmers' appraisals before using them as expert opinions.

Acknowledgments: Part of these studies was supported financially by a combined contract granted by the ministère de l'Agriculture et du Developpement rural and the Picardie 'Biopôle Végétal'.

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