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Agron. Sustain. Dev. 26 (2006) 215–225

DOI: 10.1051/agro:2006018

Research article

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(Accepted 25 July 2006)

Abstract – Farmers are increasingly required to justify their practices and to change their technical management approach due to the development of integrated production, new regulations and private standards. The feasibility of these changes can be assessed by analysing the practices of farmers. Here, we analysed the practices of farmers in apple orchards from an agronomic viewpoint, focusing on irrigation and N fertilisation. Our study is based on interviewing farmers about their practices and factors that influence their decisions. Interviews were supported by model-generated irrigation and fertilisation schedules related to the considered plots. Fertilisation data recorded over a two-year period were compared to data from interviews. Our results show that (1) irrigation practices were highly dependent on pest control practices; (2) chemical spraying against the codling moth strongly influenced irrigation frequency; (3) irrigation practices were dependent on irrigation devices; and (4) fertilisation practices were highly dependent on the conceptions that farmers had about the role of N fertilisers. These conceptions were associated with timing, fertiliser formula and modulation rules. Based on data recorded by farmers over a two-year period, fertilisation practices were highly variable. Likewise, these data also differed from data collected during interviews. Overall, our findings underline the importance of considering interactions between cultural practices and farmers conceptions in order to understand farmers practices. It also stressed the need to consider data recorded by the farmers themselves only as a partial source of information and to design better interviewing procedures with farmers.

apple orchard / farmers' practices / farmers' conceptions / interviews / data recorded by farmers

1. INTRODUCTION

Agriculture is facing new challenges, including the development of integrated production and the introduction of new regulations or private standards. Agriculture is also concerned by sustainable development trends that make it necessary to minimise the environmental impact of cultural practices. Such a situation calls for changes in technical management. Research can assist farmers involved in these changes by analysing their current practices, a necessary step to assess the feasibility of changes (Papy, 2001; Orr et al., 2002). Such analyses are drawn up from the viewpoint of a description (Fujisaka, 1990; Fujisaka et al., 1993) or an evaluation (Chen et al., 2004; Helander and Delin, 2004). They may be based on viewpoints corresponding to different fields of science, such as cognitive ergonomics (Cerf et al., 1998), anthropology (Darré, 1996) or management (Ondersteijn et al., 2003). From an agronomic viewpoint, a practice is a cultural operation carried out by a farmer that has an impact either on the field itself or on its biophysical environment and that can be considered as a driving force of the soil-cultivated plant system. Several authors have focused on the interactions between practices at the plot or farm scale, and on their origins (Sebillotte and Soler, 1988; Aubry et al., 1998; Papy, 2001; Dounias et al., 2002). In this case, two main sources of information can be used: interviews with farmers and recorded data. Recorded data exist since farmers are increasingly required to record their practices, e.g., in the guidelines defining integrated production. The question of the coherence between these two sources of information is debatable. However, although some research has been done on farmers' records (Mazé et al., 2004), we found no published paper on the coherence between data from interviews and data recorded by farmers.

In this study, we analysed farmers practices in apple orchards from an agronomic viewpoint, with particular emphasis on the categorisation and scheduling of cultural operations (Girard et al., 2001). We focused our study on two practices that play an important role both in apple production and environmental issues: irrigation and nitrogen fertilisation. In orchards, irrigation practices have a major influence on fruit growth and quality (Génard and Huguet, 1996, 1999) and may be a source of groundwater pollution. Moreover, in the case of water shortages, they may be a major environmental concern. Nitrogen has a strong effect on tree vegetative development (Lobit et al.,

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2001) and thus on tree management (Lauri, 2002). N fertilisation, particularly in the case of irrigated orchards, may also be a source of groundwater pollution (Merwin et al., 1996). In fruit tree cropping systems, the cost of fertilisation is very low compared to the cost of labour. The management of such techniques seems difficult for apple growers, as can be seen by the high variability in the quantities of water or N applied (Nesme et al., 2003). Therefore, specific studies were needed to better understand the difficulties farmers faced when adopting new guidelines, such as those involved in integrated production systems.

We focused our analysis on a small region in south-eastern France. The situation was particularly interesting for our purposes because farmers' practices were highly variable, although the physical characteristics as well as farm-related economic and extension conditions appeared relatively homogeneous (Nesme et al., 2003). Our analysis was based mainly on interviews with farmers about their practices and determinants. Interviews were based on the comparison between farmers' practices and model-generated irrigation and N fertilisation schedules. Farmers were therefore encouraged to comment on these theoretical schedules and to thus explain their own practices (Nesme et al., 2006). Fertilisation data recorded on a mandatory basis over two contrasted and subsequent years were compared to data from interviews. The major aim of this paper is to understand farmers' practices. It also focuses on the reliability of collecting data on farmers' practices, on the basis of interviews and data recorded by the farmers themselves.

2. MATERIALS AND METHODS

2.1. Study area and farmer sampling

The studied apple orchards were located in the Mauguio-Lunel plain, between Nîmes and Montpellier (43.66°N, 4.11°E, south-eastern France). This 20 × 10-km Mediterranean region, where vineyards and apple orchards are dominant, has been classified as a Vulnerable Zone according to the European Nitrate Directive (91/676/EEC). All apple growers adhered to the same guidelines that required mandatory recording of irrigation and fertilisation practices (Ceafl, 2000). A sample of 21 farmers belonging to three co-operatives was selected. The sample included nearly all the members of one co-operative, and 3–4 members of each of the other two co-operatives, selected on the basis of the diversity of the size of the farm and technical skills, identified by interviews with local extension workers.

2.2. Data collection

Data collection concerned four apple varieties harvested from August to November: Gala, Golden, Granny and Cripps Pink^{cov}-Pink Lady®. Mandatory data recorded by the farmers concerning irrigation and fertilisation were collected for the years 2002 and 2003. They described the amount and time of water and N supply for each plot on each farm, for a total of 154 and 143 plots, respectively.

Interviews were conducted in July 2003 and March 2004 with each of the 21 farmers. Interviews with farmers were assisted by model-generated irrigation and fertilisation schedules. The Epistics model (Nesme et al., 2006) was used. Epistics is a biophysical model representing water and N dynamics in orchards, linked with a decisional model made of agronomic decision rules able to trigger irrigation or N fertilisation events. A presentation and evaluation of Epistics can be found in Nesme et al. (2006). For each of the farmers' plots, Epistics generated theoretical irrigation and N fertilisation schedules for the years 2002 and 2003. For each plot, agronomic decision rule parameters were user-defined in order to generate schedules corresponding to high, low or no water and N crop stress. Schedules corresponding to the plots of a given farmer were then presented to that farmer who was asked to comment on them with reference to his own practices of the previous year. Farmers were therefore supposed to express the reasons why they eventually diverged from generated schedules and, thus, further justify their own practices. Farmers also criticised crop modelling choices as presented in Nesme et al. (2006). Each farmer was asked to describe his practices with special emphasis on timing (beginning and end of irrigation, irrigation frequency, and timing of N fertilisation). Other important topics, which were proved relevant during a previous interview with eight farmers in February 2003 (data not shown), were irrigation device, beginning of irrigation, interaction of irrigation with pest control practices and modulation of N fertilisation between plots. Interviews were semi-structured (Blanchet and Gotman, 1992) since the interviewer first clearly asked the farmer to comment on the schedules and then made sure that all of the farm plots, and all of the interview topics had been discussed.

2.3. Analysis of interviews on irrigation and fertilisation practices

Farmers' practices were described on the basis of modalities that emerged from farmers' testimonies during interviews, when commenting on model outputs. Interview-based modalities describing irrigation and fertilisation practices were analysed by means of two separate correspondence analyses (Escofier and Pagès, 1988). We previously showed (Nesme et al., 2006) that the irrigation practices of the 21 farmers were highly differentiated according to the irrigation system (overhead or underhead sprinkler, gravity or drip system). Each farmer had one to three different systems. Accordingly, the statistical unit of the correspondence analysis (CA) of irrigation practices was the group of plots with the same irrigation system within a farm. Since only three farmers used drip irrigation, the corresponding groups of plots were removed from the analysis. For fertilisation, the statistical unit was the farmer, the corresponding modalities describing his decisions and conceptions, including N fertilisation modulation between plots.

After each correspondence analysis, the statistical units were described by their coordinates on the first two factors since other factors were not easily interpreted and made a poor contribution to data variance. Correspondence analysis factors were interpreted according to the association of modalities on the factorial planes. Statistical units were then classified using the k-mean method, based on the calculation of the centroid of

Table I. Variables and modalities describing irrigation practices from farmers' interviews.

Subject	Variable	Modalities
Management features	Surface per irrigation block (ha)	<2; 2 to 5; >5
	Minimal time to irrigate the block (day)	2 to 5; >5
	Mean duration of irrigation round (day)	6 to 10; >10; No planned irrigation round
	Possible variability of irrigation round (day)	2; >2
	Amount of water for each irrigation round in summer (mm)	40 to 60; >60; Unknown
	When does irrigation occur?	Day; Night; Night and day
	Why irrigate during the day (*or* night *or* night and day)?	Objective; Constraint
	Does irrigation occur on a given plot just after the end of the previous plot?	Yes; No
Relationship with pest-control practices	Beginning of irrigation after end of primary scab contamination?	Yes; No
	Time lapse between irrigation and next chemical spraying in summer (day)	1; >1; Independence
	Does irrigation depend on pest control?	Yes; No
Adaptation options	What happens in the event of summer rainfall?	Next water amount modified; Next irrigation date delayed; Both next amount and date
	What happens in the case of summer drought?	Increase in water amount; Decrease in irrigation round duration
	Difference in water amount for each irrigation round between spring and summer?	Yes; No

each cluster (MathSoft, 1999). Three groups were created and projected on the corresponding factorial plane. They were represented by variance ellipses that included 95% of the units of the considered cluster. The irrigation system was projected as an illustrative variable on the F1 × F2 factorial plane.

2.4. Analysis of mandatory recorded data and comparison with interview-based descriptions of practices

This analysis was restricted to fertilisation because recorded irrigation data lacked precision about irrigation frequency or pump flow rate. It concerned 18 of the 21 farmers for whom recorded data from both 2002 and 2003 were available. Since time is an important dimension for understanding interrelationships between practices and since the survey mainly focused on timing, we described the recorded fertilisation schedules by their timing: for each of the five periods of the year emerging from interviews with farmers, namely winter (January–February), spring (March–April), May, June and summer (July–August), a first index was computed as the amount of N applied, divided by the total annual amount of N. Since all farmers had very similar fertilisation schedules on their different plots, we computed the mean index value among all plots for each farmer and time period. The index was then transformed into a Boolean value (0: no fertilisation; 1: fertilisation) by comparing the original index to a threshold (0.1). Since interviews indicated the presence/absence of N fertilisation for each of the five periods, this transformation made it possible to compare data from recordings to data from interviews. Three 18 × 5 binary tables describing the presence/absence of fertilisation by 18 farmers over five periods from data recorded in 2002 and 2003 and from the interviews were built in this way. Tables compiled from recorded data were submitted to a Correspondence Analysis. Farmers, described by their coordinates on the first three factors of the Correspondence Analysis, were classified using the k-mean method, each class depicting an N fertilisation timing profile. The independence between classifications was tested using a Fisher's exact test (Scherrer, 1984). N fertilisation timings as described (a) by recorded data (2002 or 2003) or (b) by interviews, were compared by computing the proportion of farmers "doing the same thing" from both sources of information, i.e., supplying (or not supplying) N from (a) and (b), for each period. Data analysis was conducted with S+2000 software (MathSoft, 1999).

3. RESULTS AND DISCUSSION

3.1. Irrigation practice analysis

3.1.1. Codification of irrigation practices

After the interview, irrigation practices were codified a posteriori as modalities describing the management of water supply, its relationship to pest control practices, and adaptation options (Tab. I).

In most cases, a group of plots could be identified as being equipped with a unique irrigation system, a unique pump delivering water for several plots, as in the case of arable crops (Labbé et al., 2000). We defined this group of plots as the irrigation block. The block surface and the pump flow rate determined

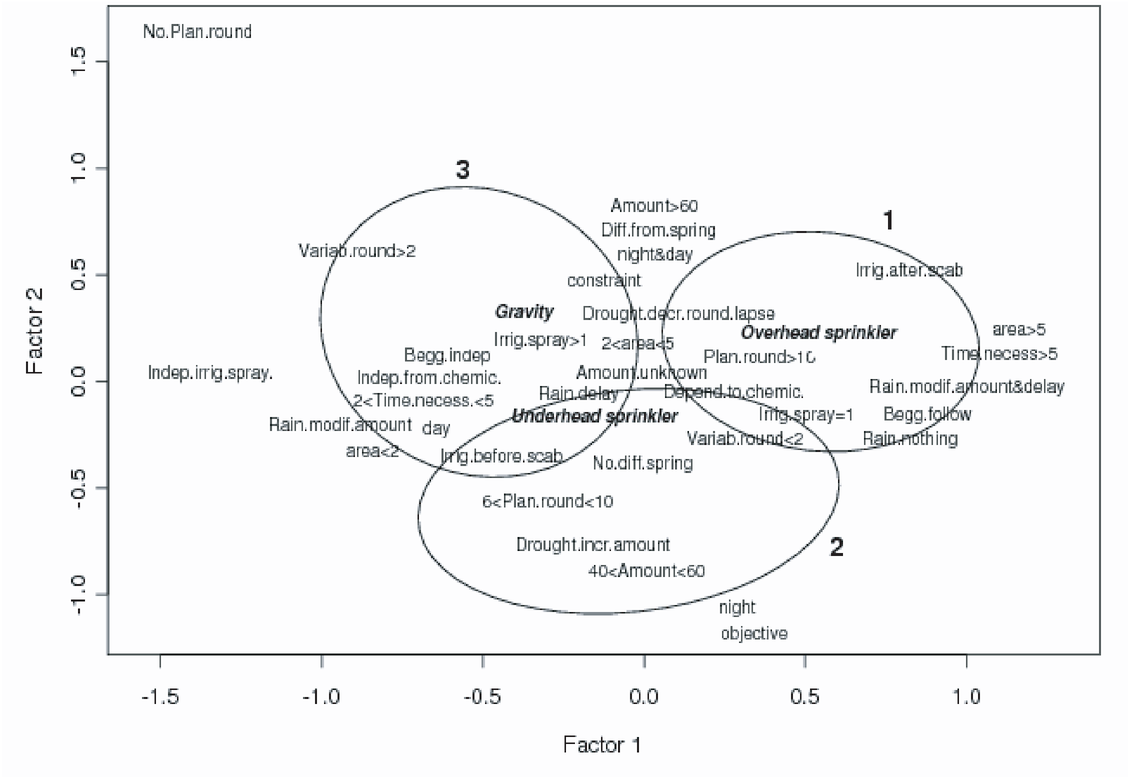

Figure 1. Irrigation practices (projection on the plane formed by Factors 1 and 2 of the Correspondence Analysis). Clusters based on coordinates of the statistical units on the first two factors are represented by variance ellipses (confidence level: 95%). The letters located next to the ellipses refer to the cluster numbers used in the text. *Area* = block area (ha); *Time.necess* = time necessary to irrigate the whole block (day); *Begg.follow* or *Begg.indep* = beginning of irrigation of a plot just after the end of irrigation on a previous plot or independence between plots; *Irrig.after.scab* or *Irrig.before.scab* = beginning of irrigation after or before end of primary scab contamination; *Plan.round* = planned irrigation round duration (days); *Variab.round* = variability of planned round duration (day); *Amount* = amount of water applied at each irrigation round (mm); *Diff.from.spring* or *No.diff.spring* = is the amount of water of each round different before spring and summer conditions?; *Irrig.spray* = time lapse between irrigation and next chemical spraying (day) or independence between both; *Depend.to.chemic.* or *Indep.from.chemic* = dependence or independence between irrigation and pest-control practices according to the farmer; *Night*, *day* and *night&day* = irrigation carried out during the night, day or night and day; *Objective* or *constraint* = is this night/day irrigation period an objective or a constraint?; *Rain.delay* or *Rain.modif.amount* or *Rain.modif.amount&delay* or *Rain.nothing* = rain postpones next irrigation round, modifies its amount of water, both postpones it and modifies its amount of water or does not change anything; *Drought.incr.amount* or *Drought.decr.round.lapse* = summer drought leads to increase in water amount per round or decrease in round duration.

the minimum time required to irrigate the whole block. Irrigation of all the plots of a block was referred to as an irrigation round. This round was carried out in several days, with basic periods of about 12 h to irrigate an elementary plot area (generally 0.5 ha). Large plots were thus irrigated in several days. The duration of the irrigation round, defined by its mean value and variability, was greater than the minimum time mentioned above. It could be shortened when irrigation of a given plot occurred just after the end of the previous one or when irrigating day and night (instead of day or night).

Some farmers preferred irrigation only during the night because of the absence of wind and a lower evaporation rate. They thus increased water distribution homogeneity or limited lime deposition on fruits in the event that the pumped water was calcareous.

There was a strong interaction between irrigation and pest control practices. Firstly, since primary contamination by apple scab (*Venturia inaequalis*) lasts from March until the end of May, irrigation, which may favour scab development (Olcott-Reid et al., 1981), was often avoided during this period. Secondly, irrigation may be constrained during summer (from June to August) because of control measures against the codling moth (*Cydia pomonella*) that consist of chemical spraying every 10–12 days. During this period, overhead irrigation may leach chemicals from tree foliage (Howell and Maitlen, 1987).

Information on water stress indicators was not included in the table because it could not differentiate farmers, e.g., all the farmers used tree vigour as a long-term indicator and leaf shape and soil shrinkage cracking as short-term indicators.

3.1.2. Characterisation of irrigation practices

The first factor of the Correspondence Analysis (Fig. 1, 15% of total variance) opposed blocks of plots with the highest area (*area*>5), the highest minimum time to irrigate blocks (*Time.necess*>5) in which a given plot is irrigated just after the end of the previous one (*Begg.follow*) and with irrigation beginning after scab contamination (*Irrig.after.scab*), on the right, to blocks with the lowest area (*area*<2) and the lowest minimum time to irrigate the block (2<*Time.necess*<5), on the left. This factor was highly determined by the block area. The second factor (13% of total variance) opposed blocks of plots with the highest amount of water per round (*Amount*>60), irrigation night and day (*night&day*) or without any planned irrigation round (*No.plan.round*), at the top, to blocks with the lowest amount of water per round (40<*Amount*<60), irrigation during the night (*night*), which was an objective for the farmer (*objective*), at the bottom. This factor was mainly determined by the amount of water delivered at each irrigation round.

Cluster 1 included blocks of considerable area (more than 5 ha) that required a minimum of five to 11 days to be irrigated. Individual plot irrigation often occurred just after the end of the previous one, and the planned irrigation round lasted from 10 to 15 days; in some cases, a round began in a given plot just one day after the end of the previous round. Variability of round duration was very small (less than two days). Since these blocks were irrigated with overhead sprinklers, farmers avoided irrigating before the end of primary scab contamination. Irrigation and pest control practices depended on each other: irrigation took place the day before chemical spraying to avoid leaching of chemicals from trees and, in some cases, chemicals were sprayed each day on a different plot to fit the irrigation practices. Irrigation took place during the day and night to shorten the round duration. Amounts of water per round were high (greater than 60 mm) but varied between the beginning and the end of the irrigation period. In such a constrained system, a few farmers did not change their irrigation plans in the event of rainfall in summer, in order to postpone the irrigation round as little as possible, but others modified water amounts in the event of rainfall greater than 30 to 50 mm.

Cluster 3 included blocks for which irrigation management was far less constrained. These blocks were mainly irrigated either by gravity systems or underhead sprinklers. Blocks were quite small (less than 5 ha and even less than 2 ha) and required a short time to be fully irrigated (between two to five days). The planned round lasted six to 10 days, with a variability of duration greater than two days. Irrigation was triggered independently for each block. Since some blocks were irrigated by gravity systems, the time lapse between irrigation and chemical spraying ranged from one to four days, in order to have sufficient soil-bearing capacity for tractor practicability. In other cases, since irrigation was carried out using underhead sprinklers, the farmer considered it to be independent of pest control practices. For example, irrigation generally began independently of scab contamination. Irrigation was carried out during the day only or during the day and night (2 × 12 h) due to work organisation simplification. The amount of water per round was either high (greater than 60 mm) or unknown for gravity systems. In the case of a rainy event, the water amount applied per round was modified or the next irrigation round was postponed.

In Cluster 2, the planned round duration was 6–10 days, which was intermediate between the two previous clusters. The variability of the planned round duration was low. The blocks were generally irrigated with underhead sprinklers. Water was mainly applied during the night, which was an objective for the farmer. Amounts of water per round were comprised between 40 and 60 mm but did not vary between the beginning and the end of the irrigation period. However, in the case of severe drought during summer, farmers increased water amounts per round instead of decreasing the round duration.

Therefore, Clusters 1 and 3 represented blocks of plots highly and poorly constrained by management features, respectively. Cluster 2 represented blocks of plots somewhat constrained but where emphasis was placed on irrigation efficiency.

3.1.3. Importance of constraints on irrigation practices

Elements hampering farmers' practices and preventing farmers from applying water at the moment they judge optimal for crop uptake can be qualified as constraints. Interviews showed that irrigation practices were constrained by the irrigation device used and management features (designing and managing blocks of plots and irrigation rounds). This is in accordance with the findings of other authors on annual crops (Puech et al., 1997; Bergez et al., 2001).

Results also showed considerable constraints on irrigation practices as a result of pest control practices that had not yet been identified in published papers, to our knowledge. This constraint varied between blocks of plots according to the irrigation system: underhead water supply led to partial independence between irrigation and pest control practices but overhead irrigation was highly constrained because of the risks of leaching chemicals from foliage. The flexibility of irrigation plans was thus considerably limited. Improving water use efficiency and gains of flexibility on irrigation practices could be related to an improved design of irrigation management or, in some cases, to a change in pest control practices. For instance, for overhead sprinkler-irrigated orchards, male codling moth confusion could be an efficient way of dissociating irrigation and pest control practices.

Identifying the set of constraints on cultural practices is important to understanding them. This includes not only the interactions between practices stressed by Sebillotte (1978) and the management constraints caused by devices described above, but also the problems of work organisation (Aubry et al., 1998; Labbé et al., 2000). Considering these constraints, it should be helpful to study the conditions under which technical tools or changes could be adopted (Papy et al., 1988). For instance, we can wonder whether the subtle use of decision-making tools based on soil or plant water status and designed to optimise fruit tree irrigation (Huguet, 1985; Huguet et al., 1992; Boland et al., 1993; Bussi et al., 1999; Jones, 2004) is consistent with the general constraints of tree irrigation described here.

During the interviews, farmers easily described effects of these constraints by means of "rules-of-thumb". Such rules, once clearly formalised, could be a first step towards a decisional model (Shaffer and Brodahl, 1998) that could be used to optimise the set of farmers' rules-of-thumb, as proposed by Bergez et al. (2002) for constrained irrigation devices. Such a decisional model should not include rules that may be incompatible with agronomic knowledge. The decisional model could also be linked to a biophysical model (Chatelin et al., 2004) to evaluate the possible technical changes in constrained environments by means of simulations.

Table II. Variables and modalities describing N fertilisation practices from farmers' interviews.

Subject	Variable	Modalities
1st supply	Period	Winter (Nov. to Feb.); Spring (March to April)
	Why this period?	For fertiliser solubilisation; Corresponds to blossoming; Because of constraint
	Role of N	For tree reserves; To help beginning of vegetative development; For crop uptake
	Is this supply only for N?	Yes; No
	Modulation of N amount according to…	P fertilisation; Present crop load; Previous crop load; Tree vigour; No modulation
2nd supply	Period	Spring; May; June
	Why this period?	Blossoming; Physiological fruit drop; Fruit growth; Because of constraint
	Role of N	To help beginning of vegetative development; For crop uptake; For tree vigour; For fruit load; For fruit growth; For fruit growth, colouring and sugar content
	Is this supply only for N?	Yes; No
	Modulation of N amount according to…	Fruit load; Tree vigour; Tree vigour and fruit load; Varieties; No modulation
General management	Is the total amount of fertiliser determined at the beginning of the year?	Yes; No
	According to the farmer, is there a relationship between fertilisation and tree vigour management practices?	Yes; No
	How is N fertiliser applied?	Broadcast; Roughly localised; Precisely localised
	Does inter-row grass represent significant N uptake?	Yes; No
	Fruit counting to estimate crop load?	Yes; No

3.2. Analysis of fertilisation practices

3.2.1. Codification of fertilisation practices

Since all of the farmers supplied fertiliser at least twice (always in granular form), fertilisation practices were codified as modalities describing the first two fertiliser supplies (Tab. II), according to their period, the reason for applying the fertiliser during this period (plant phenology or constraint) and the role of N. According to farmers' conceptions, the range of N roles was quite large, from very basic (to fit crop uptake) to very "specialised" (to increase fruit growth or colour). Fertiliser modulation between plots was determined by annual (crop load) or pluriannual observations (vigour, previous crop load).

N fertilisation was also codified by the way N was applied (localised or not) and its interaction with tree vigour management practices (branch pruning, root pruning, fruit load management, tree shape, etc.). It also took the way fruit load was estimated and inter-row grass N requirements into consideration, as well as when the total amount of fertiliser was determined (Tab. II).

3.2.2. Characterisation of nitrogen fertilisation practices

The first factor of the correspondence analysis (Fig. 2, 16% of total variance) opposed the first supply during winter (*winter*1), corresponding to the assumed time for fertiliser solubilisation (*solubilis.*1), and the second supply in spring (*spring*2), corresponding to blossoming (*blossom*2), on the right, to a second supply that was supposed to enhance fruit growth, red colouring and sugar content (*for.fruit.growth.colour.sugar*2), on the left. The second factor (13% of total variance) opposed the first supply, supposed to help tree reserve reconstitution according to farmers (*for.reserve*1), second supply timing corresponding to the physiological drop (*physio.drop*2), and a second supply to increase tree vigour (*for.vigour*2), at the top, to a second supply for fruit growth (*for.fruit.growth*2) and a second supply modulation according to fruit load (*Mod.load*2), at the bottom.

Variables related to inter-row grass N requirement estimation, annual forecast of fertiliser amount per plot and localisation of applied fertiliser did not make it possible to discriminate between clusters.

Cluster 1 included farmers who first supplied fertiliser in winter (from November to February) so that solubilisation could be achieved for the beginning of crop uptake. This first supply was often carried out with complete fertiliser and was supposed to help tree reserve reconstitution. It was modulated between plots and years according to the previous crop load or to fit the phosphorous crop requirement. The second supply was carried out in spring (from March to April), at blossoming. It was made of N fertiliser only (generally calcium ammonium nitrate) and was assumed to sustain crop load or crop N uptake. It was either modulated according to plot vigour or not modulated. Fertiliser was generally broadcast-applied and according

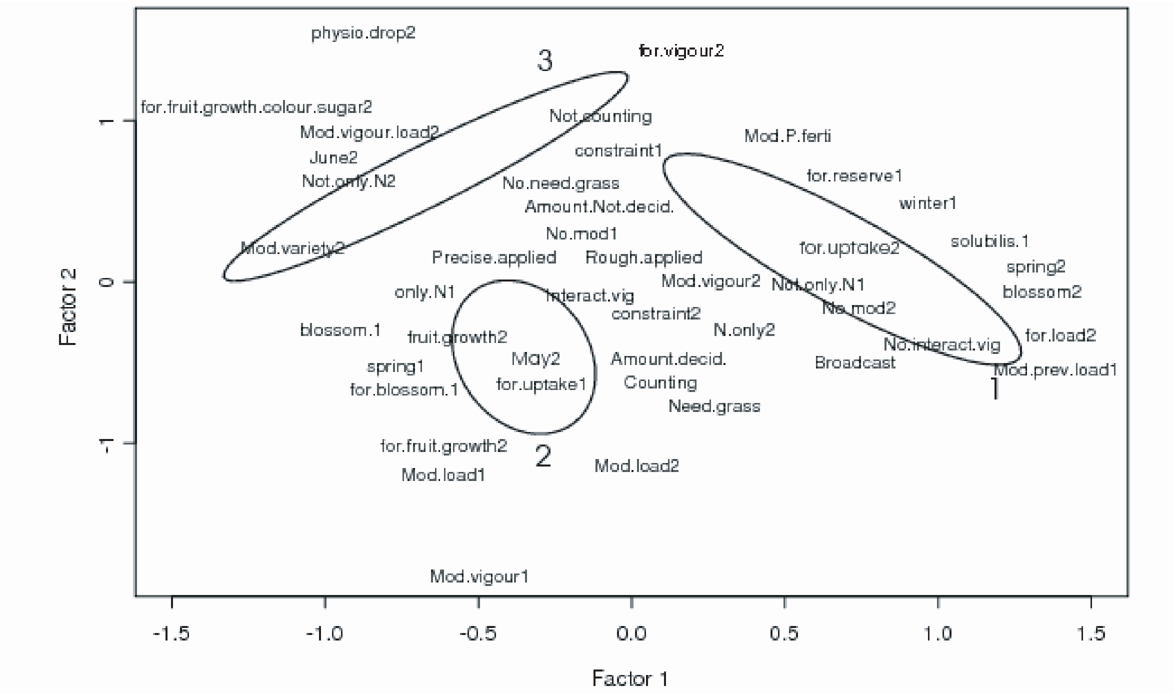

Figure 2. Nitrogen fertilisation practices (projection on the plane formed by Factors 1 and 2 of the Correspondence Analysis). Clusters based on coordinates of the statistical units on the first two factors are represented by variance ellipses (confidence level: 95%). The letters located next to the ellipses refer to the cluster numbers used in the text. Number after words (1 or 2) indicates the concerned (first or second) fertiliser supply. Season or month indicates the period of the fertiliser supply. *Blossom.*, *solubilis.*, *physio.drop*, *constraint*, *fruit.growth* = the period of supply corresponds to blossoming, to the time needed for fertiliser solubilisation, to fruit physiological drop, to an external constraint or to fruit growth period; *for.reserve*, *for.load*, *for.blossom*, *for.uptake*, *for.fruit.growth*, *for.fruit.growth.colour.sugar*, *for.vigour* = the fertiliser supply is supposed to sustain tree reserve, fruit load, blossoming, crop N uptake, fruit growth, red colouring and sugar content or orchard vigour; *Mod.P.ferti*, *Mod.prev.load*, *Mod.load*, *Mod.vigour*, *Mod.variety*, *Mod.vigour.load*, *No.mod* = fertiliser supply modulation between plots according to the P fertilisation, the previous fruit load, the present fruit load, the orchard vigour, the variety, the combined fruit load and orchard vigour or not modulated *Only.N* or *Not.only.N* = fertiliser made only of N or two elements; *Precise.applied.*, *Rough.applied*, *Broadcast* = fertiliser exactly or roughly applied under the tree row or broadcast; *Interact.vig* or *No.interact.vig* = interaction or not between fertilisation and other vigour management practices; *Counting* or *Not.counting* = fruit counting or not to estimate fruit load; *Need.grass*, *No.need.grass* = inter-row grass represents significant N requirement or not; *Amount.decid* or *Amount.not.decid* = the total amount of fertiliser is determined at the beginning of the year or not.

to farmers, N fertilisation did not interact with other vigour management practices.

Cluster 2 included farmers who first supplied fertiliser in spring, corresponding to blossoming and supposed to help tree blossoming and crop N uptake. This first supply was made of N only and was modulated either according to crop load or plot vigour or was not modulated. The second supply was carried out in May, the period corresponding to fruit growth or in some cases, to work availability. It was designed to help fruit growth and was modulated according to crop load, which was estimated by counting the number of fruit per tree. Fertilisers were precisely applied on the tree row and N fertilisation was considered as interacting with other tree vigour management practices.

First supply of Cluster 3 was close to that of Cluster 2; carried out in spring, it was designed to help blossoming and was made of N only. For some farmers, spring corresponded to cash flow availability making it possible to buy fertilisers. The second supply was carried out in June, after the physiological drop, and was designed to help fruit growth, red colouring or increase sugar content. It was made of fertilisers composed of two elements (potassium nitrate or ammonium phosphate) and was applied to bicoloured varieties such as Gala, and modulated according to plot vigour or crop load. No fruit was counted to estimate crop load.

Thirteen farmers applied a third supply, always in June, after the physiological drop and during fruit growth. N was often associated with P or K and this third supply was supposed to help fruit growth, red fruit colouring or to increase fruit sugar content. It was designed for bicoloured varieties and was modulated according to plot vigour and crop load. This third supply was very similar in time and amount to the second supply of Cluster 3. It was carried out by all farmers belonging to Clusters 1 and 2, except for three farmers (data not shown). Only four farmers carried out a fourth supply, generally in July and with an N-only fertiliser. It was applied for "green" varieties (Golden and Granny) and was supposed to "green" the fruit skin.

Table III. Profiles of farmers' N fertilisation timing from recorded data (correspondence analysis and classification of 18 farmers) over two years. For each profile and each period, the number in the table represents the ratio of farmers in the profile supplying N during the period.

		Winter	Spring	May	June	Summer
2002						
	Profile 1 (n = 7)	0	1	0.14	0.14	0.43
	Profile 2 (n = 7)	0	0.57	0.57	1	0
	Profile 3 (n = 4)	0	0.75	1	0	0
2003						
	Profile 1 (n = 8)	0.75	0.88	0	0.62	0.5
	Profile 2 (n = 5)	0.4	0. 4	1	0.8	0
	Profile 3 (n = 5)	0	1	0	0.6	0

3.2.3. Farmers' fertilisation conceptions and agronomic knowledge

N fertilisation practices were very little influenced by fertiliser cost. Different N fertilisation schedules could be identified according to the conception farmers had about the role of nitrogen. A conception may be defined as the way a farmer considers the objects he manages, including judgment values (Darré et al., 2004). A few farmers considered that supplying N in winter could help tree reserve constitution or blossoming whereas others considered that N supply in spring could improve fruit growth. All farmers thought that N in combined N-K fertiliser could increase fruit colouring or sugar content for the Gala variety. However, numerous experiments have shown that N fertilisation has no direct effect on fruit growth or fruit sugar content (Williams and Billingsley, 1974; Neilsen et al., 1984; Sanchez et al., 1995; Habib et al., 1996; Meheriuk et al., 1996; Drake et al., 2002; Neilsen et al., 2004). Fruits of bicoloured varieties tend towards green rather than red colour with N fertilisation (Reay et al., 1998). Moreover, although important N remobilisation occurs in autumn for tree species (Habib et al., 1989; Neilsen et al., 2001), fertiliser application may be inefficient for N reserve reconstitution (Tagliavini et al., 1998) and winter supply is not included in the efficient fertiliser use period (Weinbaum et al., 1978). Therefore, several farmers' conceptions about the role of N appeared to be wrong according to scientific knowledge and may cause negative environmental impacts. Other authors have already observed such contradictions between farmers' practices and technical recommendations (Fujisaka, 1993). In this case, farmers' conceptions may be based on their own experience in managing N fertilisation for other crops such as wheat, for which a relationship between N and crop growth and quality exists. They may also be based on a confusion about N and K roles in combined fertilisers, since K fertilisation enhances fruit growth and red colouring (Jadczuk et al., 2001; Hunsche et al., 2003). In fact, farmers rarely used simple K fertiliser, perhaps because of its local unavailability. Farmers cannot pinpoint these conceptions through trial and error since N fertilisation experiments need several consecutive years in perennial crops. However, a few conceptions were right such as the role of N fertiliser to increase tree vigour, particularly in the case of heavy fruit load (Elfving, 1988; Marsh et al., 1996; Lobit et al., 2001; Drake et al., 2002). Our results on the importance of farmers' conceptions are in accordance with the findings of different authors (Hubert et al., 1993; Keating and McCown, 2001; Darré et al., 2004). Extension workers should be more attentive to these conceptions in order to understand and, eventually, to correct farmers' practices. Local experiments, based both on farmers' conceptions and on recognised scientific knowledge of the role of nitrogen in apple crop growth, when demonstrated at the local level, may help to change false conceptions.

3.3. Significance of the interview and methodological questions

Table III describes three timing profiles emerging from the analysis of recorded fertilisation schedules for each of two subsequent years (2002 and 2003). In 2002, no fertilisation occurred in winter. From discussions with the farmers, a possible explanation was weather conditions leading to insufficient soil-bearing capacity for tractor practicability. That year, all the farmers in the first timing profile supplied N in spring and half of them in summer. All the farmers in the second timing profile supplied N in June and none in summer. No farmer in the third profile supplied N in June or summer, and all the farmers fertilised in May. In 2003, no farmer in the first profile supplied N in May. All the farmers in the second profile supplied N in May, and none in summer. No farmer in the third profile supplied N in winter, May or summer. The timing profiles were obviously different from 2002 to 2003 ($P = 0.95$), which rendered meaningless a comparison of such timing profiles with timing profiles from interviews. However, concerning the presence/absence of fertilisation per period, there was a global coherence between the recorded data and the interviews in 2003 (i.e., the year some farmers supplied N in winter, according to the interview), with more than half of the 18 farmers supplying

Table IV. Number of farmers (from a total of 18) supplying N or not, for each of the five periods of the year, on the basis of both mandatory recorded data for the year 2003 and interviews.

	Winter	Spring	May	June	Summer
N Supply	6	13	4	8	2
No N supply	9	1	8	2	12
Total	15	14	12	10	14

or not supplying N at each period from both sources of information (Tab. IV).

It can be hypothesized that interviews and recordings concerned different time scales and topics. During the interview, the farmer may refer to either past practices over a short or medium-term period, ideal practices he can only carry out during some years, or general planning features. Recorded data concern precise years. This stresses the difference between planning and adapting practices to particular annual (climatic) events (Girard et al., 2001). It may also explain why time-phasing is more relevant for farmers when referring to phenological events during interviews, since benchmarks used by farmers do not always refer to a calendar.

Questions still remain about the way to conduct interviews, which has not been addressed in most studies (Fujisaka, 1990; Fujisaka et al., 1993; Eilu et al., 2003; Lansink et al., 2003; Orr and Ritchie, 2004), though it is the basis of research on the determinants or consequences of farmers' practices (Bellon et al., 2001; Eilu et al., 2003; Ondersteijn et al., 2003; Biarnès et al., 2004). The interview method has not been very formalised by agronomists. Shaffer and Brodahl (1998) propose to organise the interview by identifying (i) each general farming operation and assigned resources and conventions, (ii) the constraints and how the farmer deals with them, (iii) when the operation takes place and, finally (iv) the bail-out rule set the farmer uses. Such a methodology may be helpful to understand the farmer's general crop management approach and to represent it through an action model (Sebillotte and Soler, 1988). However, it may be insufficient to conduct in-depth interviews about particular practices. Using farm crop-related information such as model outputs may help to structure the interview and to question farmers' action rules (Nesme et al., 2006). In this work devoted to irrigation and fertilisation, we codified a posteriori a description of practices emerging from semi-structured interviews, with particular emphasis on what was done, when, why and how. Further methodological efforts are needed, with a possible contribution from ethnography or the social sciences (Orr et al., 2002).

Questions still remain about the statistical treatment of interviews. Most studies analyse and present results in a literal way, focusing on the farmers' main ideas and the links between these ideas (Fujisaka, 1990; Biarnès et al., 2004; Mathieu, 2004; Orr and Ritchie, 2004). At first sight, one may consider that describing farmers' practices through modalities is far from being representative of decision-making. However, we decided to analyse the description of practices with a correspondance analysis that objectively identifies links between modalities. These types of associations may be counterintuitive (e.g., amount of water per round and irrigation system) or may help to identify complex situations (e.g., Cluster 2 in Fig. 1). Correspondence analyses also facilitate the clustering of statistical units. However, the interpretation of correspondance analysis must rely on interview results to avoid artefactitious interpretation.

Our results were based on interviews conducted in a small agricultural region where the impact of local pedo-climatic conditions, extension workers or past history could be strong. However, our results can also be considered from a general point of view since the four apple varieties considered are found throughout France. Moreover, the guidelines to which producers adhere are very common in France. Interviewed farmers were representative of the local farmer diversity since particular attention was paid to the size of the farms, and we were able to interview almost all of the members of one of the three cooperatives.

4. CONCLUSION

Our results showed the strong dependence of irrigation practices on irrigation devices and pest control practices. We identified different fertilisation schedules according to farmers' conceptions. These elements could be a first step towards the design of cropping systems that take interactions between practices into account, as well as farmers' crop management decisions. Such an approach could be an alternative to the design of drastic new cropping systems that explore new cropping technique combinations without considering constraints related to farmers' practices. Our results also underscored the need to treat information collected through interviews with caution because of the inaccuracy inherent in farmers' testimonies: practices of the last year or of past years, ideal practices, etc. This emphasizes the need for a more precise definition of agronomic survey conditions and methods.

Acknowledgments: The authors thank Pierre Rouet for his help in data collection, the farmers who answered the survey and Gail Wagman for improving the English. This work was funded by the nationwide INRA programme on Integrated Fruit Production, "*Action Transversale : Production Fruitière Intégrée*".

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