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# Characterisation of apple orchard management systems in a French Mediterranean Vulnerable Zone

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**Abstract** – The objective of our study was to characterise cropping systems in apple arboriculture in the Carpentras basin. The study area has been listed as a “Vulnerable Zone” since 1993 under the European Nitrate Directive 91/676. It consists of 10 French districts located in the Mediterranean region north-east of Avignon. Interviews were conducted with 18 of the 22 identified farmers, the sample covering a variety of cropping patterns. We compared and analysed the farmers’ practices in terms of fertiliser application, pest and disease management, thinning and irrigation, spotlighting the role of crop indicators to decide and trigger the operations. As a result, we identified and characterised three main types of cropping systems. These were ranked according to risks of pollution by nitrate and pesticides. The systems were then confronted with soil types. The study showed that the potentially less polluting cropping systems are also situated in the less sensitive areas.

**apple orchard / on-farm survey / cultivation operation / management indicator / cropping system / environmental risk**

**Résumé** – Caractérisation des systèmes de culture du pommier dans une zone vulnérable en région méditerranéenne française. L’objectif de notre étude était de caractériser les systèmes de culture du pommier des dix communes du bassin de Carpentras, classées « Zone Vulnérable » en 1993 au titre de la Directive Nitrates 91/676. Pour réaliser cet objectif, des enquêtes ont été conduites auprès de 18 des 22 producteurs répertoriés, les exploitations soumises à l’enquête présentant des assolements variés. Nous avons comparé les pratiques relatives à la fertilisation, aux traitements phytosanitaires, à l’éclaircissage et à l’irrigation, en mettant en évidence les indicateurs utilisés pour choisir et déclencher les opérations. Sur ces bases, nous avons identifié et caractérisé trois types de système de culture. Ils ont été classés en fonction des risques de pollution par les nitrates et les produits phytosanitaires qu’ils sont susceptibles d’engendrer, puis confrontés aux types de sol. Les systèmes de culture potentiellement les moins polluants sont situés sur les zones les moins sensibles.

**verger de pommiers / enquête en exploitation / opération culturale / indicateur / système de culture / risque environnemental**

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## 1. INTRODUCTION

### 1.1. Challenges in developing new orchard management systems

Orchard management is facing new challenges, instigating new research and fruit production strategies in Europe [23]. The new market organisation enjoins farmers to form producer organisations (EU Regulations 2200/96 and 2201/96) which are required to improve the fruit quality and to reduce environmental impact.

Apple production, which is very important in France (3rd rank in the world), is directly affected by these recent changes, which call for changed technical management.

The improvement of apple crop management systems cannot be imagined without an analysis of existing systems. Concerning the latter, one question especially arose: are current practices in apple production likely to generate environmental risks? Following several authors who suggest using the concept of cropping system to devise better performing agricultural practices, in particular regarding environmental preservation [4, 16], our objective was to answer this question by identifying apple cropping systems at the farm level in a site of environmental concern and ranking their relative risks for the environment according to their location, following the principles of Lanquetuit and Sebillotte [13].

### 1.2. Using the cropping system concept in orchard production

The concept of cropping system has been designed for annual crops. It includes two components: (i) the type and sequence of crops (previously known as crop rotations) grown on fields treated identically; and (ii) the yearly sequences of technical operations applied to these different crops, including choice of cultivars (crop management itineraries) [25].

We did not deal with component (i) because crop rotations are not the main point of orchard systems, where they are very long-term. We focused on key points of component (ii), i.e. the consistency and association of technical choices corresponding to the different operations of the crop management itinerary (so we did not study the time dimension *per se*). We first described and analysed in a sample of orchard farms these technical choices. For this purpose, we investigated the indicators on which technical choices are based, and their observation and use scales. Such indicators relate either to the state of the crop or to its environment [26]. Then, we identified amongst the apple farms management pro-

files based on the combination of technical choices. We considered these profiles as mean pictures of cropping systems that were sufficient for our purpose, i.e. ranking their relative risks for the environment. We attempted to interpret the types of cropping systems by confronting them with descriptors of the orchard area, cropping pattern and farm location.

### 1.3. Environmental concerns as related to practices in apple production

The study area, the Carpentras Basin, was listed as a “nitrate vulnerable zone” in 1993 under the European Nitrates Directive (EU Regulation No. 91/676). Subsequently, an action programme was designed to reduce or prevent nitrate pollution from agricultural sources. Apple is the dominant tree crop in the study area and, therefore, a key production for research projects aimed at understanding the relationships between agricultural practices and water quality [3]. Orchards are usually irrigated or located in areas with a shallow water table; transfer of soluble compounds to the groundwater is therefore facilitated.

Apple orchard management may generate pesticide pollution as a great number of agro-chemical treatments are applied, with an average of 20 treatments per year, each involving two or three different pesticides [14]. Pesticide pollution is very complex because of the diversity of targets: surface water, groundwater, soil and air (the latter being the major dispersion factor), and living organisms partly through concentration in food chains (as reviewed by van der Werf [28]). Nowadays, practices in terms of pesticide application are changing in France [21]. This trend is encouraged by the technical assistance provided to producer organisations and to individual farmers, in particular for Integrated Pest Management (IPM). Recommendations for pesticide management tend to shift from rather prescriptive to more flexible guidelines and rule-based strategies, adapted to the observations realised on orchards. Overall, the diversity of pest and disease problems occurring in apple orchards and the associated recommendations can lead to a variety of farmer strategies and practices.

Fertiliser application in apple orchards is a somewhat problematic and controversial topic, despite a general down trend in recommended amounts over the past decades. The range of recommended fertiliser applications is very wide. Further discussions relate to optimal periods for fertiliser application. Indeed, in the study area, spring and autumn are rainy periods where nitrate leaching can occur. N applications are sometimes advocated in early spring since tree requirements are higher at

the flowering stage. However, most of the nitrogen used during flowering derives from tree reserves [11]. Vaysse et al. [30] recommend splitting N fertilisation, with a major supply during shoot and fruit growth and a moderate supply when tree growth is almost nil. Catzeflis and Neyroud [5] suggest restricting or staggering autumn nitrogen fertilisation until late winter to improve its efficiency and reduce nitrate leaching. As a result, a wide diversity of fertiliser application patterns in orchards is to be expected.

In this work, the major cropping systems were ranked according to the pollution risks they generate. Their ranking was then collated with soil conditions in order to assess their relative effects on water resources.

## 2. STUDY AREA AND METHODS

### 2.1. Context: a nitrate-vulnerable zone in a Mediterranean region

This study focuses on 10 districts in the Carpentras basin considered to be a “Nitrate Vulnerable Zone”. It covers an area of approximately 250 km<sup>2</sup> of which 10500 ha are usable agricultural areas (UAA). The agricultural areas support a very large variety of productions (field and vegetable crops, vine, ...).

The apple orchards cover about 5% of the agricultural areas. They are located mainly on the plains to the west of the basin. The soils found there are poorly differentiated (on alluvial deposits) or hydromorphic (and gleyed soil conditions). They are relatively deep (3–4 m), with low infiltration capacity [24]. The soil depth is greater than the common range of depths to which apple roots penetrate, i.e. 1 to 2 m, the zone containing most roots being 0 to 50 cm depth [2].

The climate is Mediterranean. The combination of high temperatures and precipitation in autumn results in the significant mineralisation of the organic matter in the soil. Abundant rainfall during September and October may draw leachable mineral elements deep into the soil.

The hydrogeology of the Carpentras basin is characterised by the presence of superposed aquifers [15]. A significant increase in nitrate contents has been observed since 1980 in these two groundwaters. The contents in the alluvial waters often exceed the nitrate limit in drinking water (50 mg/l). The alluvial groundwater is the closest to the surface (1 to 15 m depth). It is mainly fed by infiltration water, i.e. rainfall and irrigation, and is mainly exposed to the consequences of land utilisation [3].

### 2.2. Diversity of cropping patterns and orchard size on the apple farms

Twenty-two apple farms were identified in the basin with orchards covering an area ranging from 2 to 75 ha. Fifty-nine percent of the areas planted with apple orchards in the sample belong to four farms (Farm No. 2, 3, 4 and 7 in Tab. I).

At first glance, we can distinguish three groups according to their cropping pattern. Twelve farms are predominantly apple-growing (Farms No. 1, 2, 3, 4, 5, 7, 11, 12 and 13 in Tab. I and 3 others which were not surveyed). In this group, the fully operational farms have an area of about 20 hectares of apple orchards per farm household, although collectively-managed structures exist. For five other farms, apple trees are associated with vine nurseries and, eventually, grapes for wine production or table use, or field crops (Farm No. 10, 14, 16, 17 and 18 of Tab. I). On these farms, where the UAA ranges from 4 to 30 ha, the area covered by apple trees is extremely variable (13 to 90% of the total area). Nevertheless, none of them have more than 12 ha of orchards. As for the five remaining farms, apple orchards co-exist with vegetable cropping and field crops (Farm No. 6, 8, 9 and 15 of Tab. I, and a farm that was not surveyed). Apple trees cover from 20 to 55% of the UAA which ranges from 16 to 25 ha.

### 2.3. A survey based on interviews with fruit growers

In order to characterise apple cropping systems in the Carpentras basin, we based the survey on direct interviews with 18 of 22 apple farmers who produced apples in the basin (representing a total of 283 ha of apple trees).

The interviews, carried out from March to June, 1998, were “semi-open-ended”. The questions aimed at describing the technical choices, i.e. fertilisation (amounts and form of fertilisers, application periods), pest and disease control (treatment schedule, products, amounts), weed control (products, amounts), irrigation (equipment, frequency, periods, water amounts), and chemical thinning (type, number of operations). Pruning and harvesting operations were not taken into consideration because they were not directly linked to environmental problems. We asked questions to understand on which bases operations are planned and triggered, i.e. whether they concern the entire orchard or variants are encountered according to cultivars for example, and which indicators are observed and used, at what scale. So, the information on indicators came from the farmer’s statements, and was illustrated when possible by orchard

**Table I.** Farms' characteristics: usable arable area (UAA), apple orchard area and management techniques. The amount of mineral elements employed for fertilisation (N, P, K) is more or less than a given threshold. The fertiliser schedule is autumn and spring (A+S), spring only (S), spring with possible complement in late spring (S+s), autumn only (A). Pest and disease control is either systematic (syst) or reasoned (reas). Irrigation is by gravity (g), gravity + drip or sprinkler irrigation (g+e) or absent except sprinkler irrigation for some plots (ni). Chemical thinning is either systematic (C), possible (L) or never occurs (N). NA=not available.

Farm No.	UAA (ha)	Apple area (ha)	Dose N (kg/ha)	Dose P <sub>2</sub> O <sub>5</sub> (kg/ha)	Dose K <sub>2</sub> O (kg/ha)	Fertiliser schedule	Pest control	Irrigation	Thinning
1	9	7	N>80	P>60	K>140	A+S	syst	g	C
2	50	50	N<80	P<60	K<140	A+S	reas	ni	C
3	95	75	N<80	P<60	K<140	S+s	reas	ni	C
4	23	21	N<80	P<60	K<140	S	reas	ni	C
5	11	5	N>80	P>60	K>140	A+S	reas	ni	C
6	24	15	N>80	P>60	K>140	S	reas	ni	C
7	23	21	N<80	P<60	K<140	S+s	reas	g	C
8	16	8	N<80	P>60	K<140	S	reas	g	C
9	15	13	N<80	P>60	K<140	S+s	syst	g	L
10	8	4	N<80	P>60	K<140	S+s	syst	g+e	L
11	8	7	N>80	P>60	K>140	S+s	syst	g	N
12	16	8	N>80	P>60	K>140	S	syst	g	C
13	32	17	NA	NA	NA	NA	syst	g	C
14	25	8	N>80	P>60	K>140	A+S	reas	g	C
15	23	6	N<80	P>60	K<140	S+s	reas	g+e	C
16	5	4	N<80	P>60	K<140	S+s	reas	g+e	C
17	11	2	N>80	P<60	K<140	A	syst	g+e	L
18	30	12	N>80	P<60	K>140	S	reas	g+e	C

visits. The interview also included a survey of cultivar distribution and the pinpointing of fields on a map in order to compare cropping systems with environmental data.

## 2.4. Data analysis

The analysis of technical management resulted in the coding of descriptors reflecting the diversity of technical choices among the studied farms. As the technical choices did not refer only to quantitative data but also to ways of doing things, a qualitative coding was chosen (presented in Sect. 3.1). Relationships between the different cropping practices were studied on the basis of a correspondence analysis (CA), the table cross-referencing farms and groups of the different qualitative descriptors (complete disjunctive table). We particularly relied on the ratios of correlations between qualitative variables and factors [8] to interpret the results of the CA. The farms described by their coordinates in relation to the first factors (extracting a significant part of the data variance) were then submitted to an ascending hierarchical classification (AHC) using Ward's algorithm of aggregation by variance [31] in order to make groups corre-

sponding to technical management profiles considered as mean pictures of cropping systems.

## 3. RESULTS

### 3.1. Management of cultivation operations in the Carpentras basin

#### 3.1.1. Standard and adaptative management of an orchard

We have identified a type of management considered to be standard since it is predictable from one year to the next. It consists of defining the main crop management policies, as a function of available equipment, input purchase programming and the organisation of operations. As for pest and disease control, this basic programme could consist of adopting a treatment schedule provided by extension services. For this type of management, the main criteria are the structuring of the orchard by cultivar and age, which define large clusters of plots to be treated similarly. Concerning age, the total area covered by juvenile trees (about 12.5%) constitutes a management unit in itself, whose management itinerary is



different from those of productive trees. In the following we focus on the management of adult trees.

Standard management is supplemented by adaptive management which is based on a yearly evaluation of indicators of the state of the apple orchards and of expectations in relation to the harvest. These adaptations are respectively aimed at (i) improving fields which do not meet desired production standards, through thinning or localised pest and disease control for example, (ii) readjusting the objectives themselves, which implies modifications to the management itinerary, such as the application of a second fertilisation in the case of a heavy fruit load which is impossible to reduce chemically.

We have identified four major indicators used by the farmers to various degrees:

- harvest from the previous year,
- flower-bearing,
- fruit load in May,
- pressure from pests and diseases.

The first three indicators are indicative of the fact that the fruit farmer tries to stabilise the fruit load and reduce the incidence of alternate bearing. The indicators (except the first one) are evaluated by means of counts on several trees that are averaged. A rating of “weak” or “strong” is attached, influencing the implementation of one or several operations. These evaluations are subjective and rely on the fruit farmer's experience to compare the present situation with those already known. The indicators are most often observed at the plot level, when between-tree homogeneity can be assumed, and in this case the corresponding technical options may be applied on the scale of one or several plots. However, in some cases indicators may be observed and the corresponding options applied on a sub-plot scale.

In the following, we illustrate the standard and adaptive management and the role of indicators while describing the cropping practices. As all of the orchards surveyed were grassed down and weeding practices seemed to be homogeneous according to the available data, weed control was not considered. The descriptors chosen were coded into a small number of groups (from 2 to 4) as well-balanced as possible, to prepare the data analysis aiming at defining cropping systems.

### 3.1.2. Fertiliser application practices

We observed a high degree of variability between the different farms in relation to orchard fertilisation. The main differences are related to the quantities applied for each of the mineral elements, the distribution in time of applications, and the formulation of fertilisers applied by farmers.

The quantity of nitrogen applied by each farmer is here defined as the total quantity regularly applied to the orchard, since additional nitrogen fertilisation may be conditional on areas with higher expected yields. It ranged from 50 to 150 units per hectare, resulting in a ratio of 3. As for phosphorus and potassium, the ratio between the biggest and smallest total fertiliser applications was still higher: 10 and 4 respectively. For each mineral element, the population of apple farmers can be separated into two groups: those who apply more than the maximum quantity recommended by different sources and those who apply less. The thresholds that we chose according to Gautier [9], Westwood [32], Pouey and Gregorini [20] and Soing [27], are 80 kg/ha for nitrogen, 60 kg/ha for phosphorus and 140 kg/ha for potassium.

Fertiliser application periods are spread out over 8 months. Three main schedules can be identified:

- “spring and possible complement in late spring” (S+s). Two variants can be encountered. In the first one, the first application takes place in February or March, using organo-mineral fertilisers such as 6-8-12 or 6-12-10 (40 to 60 kg/ha of nitrogen). In the second one, the first application occurs in March or April, after budbreak, with slow-release fertiliser (12-8-17, including 50 to 70 kg/ha of nitrogen). In both variants, the second application is optional, in May or June, applying mineral fertilisers on the plots with the biggest fruit loads. In the second variant, in case this second optional fertiliser application occurs, the global N amount applied remains relatively low (75 to 100 kg/ha). S+s is applied by seven farmers on 130 ha. The total quantity of nitrogen regularly applied to the orchard is < 80 kg/ha except for one farm (Farm No. 11 applies 100 kg/ha). The additional fertilisation concerns mainly nitrogen, although three farmers use compound fertilisers;
- “spring” (S). Applications always include organo-mineral fertilisers, even exclusively for the farmer who applied the biggest quantities of nitrogen in the sample (Farm No. 6: 150 kg/ha). They can also combine organo-mineral and compound fertilisers. This type of fertiliser application is used by five farmers over 64 ha, with variable fertiliser doses;
- “autumn and spring” (A+S). An application of organo-mineral fertilisers in November-December is systematically followed by an application in March-April, using either chemical or organo-mineral fertilisers. It entails a total amount of nitrogen/ha over 80 kg, except in one case (Farm No. 2). This type of fertiliser application is used by four producers, over 70 ha of apple orchards;

In addition one farmer (Farm No. 17) applies all fertilisers during autumn (A), using both urea and organo-mineral fertilisers. The total amount involved is 90 kg/ha of nitrogen, on a limited area of 2 ha.

Only four farmers of the sample apply less than the defined thresholds for the three macro elements. They all belong to the S+s schedule, and use slow-release fertilisers. Conversely, other formulations lead to excess in at least one macro element.

Within the farms which use the S and A+S fertiliser schedules, the plots are all fertilised in the same way, since all of the applications take place before the farmer can anticipate the future harvest. It is an illustration of what we called the standard management, which concerns the entire orchard. The second application in the S+s schedule exemplifies the adaptative management. The indicator used is here the fruit load. The fruit farmer waits until the risk of frost is over. At this stage, which is over by May or June depending on the year and the cultivar, he can easily evaluate the quantity of fruit which can be potentially harvested, with the exception of unforeseen climatic (hail) or pest (codling moth) conditions. He can then adjust nitrogen supply to the plant requirement by means of an additional nitrogen application.

This heterogeneity in relation to the application periods can certainly be attributed to modifications which are presently taking place in fertilisation practices. In the last few years, agricultural extension services have tried to make producers aware of the risks of nitrate leaching and of the reduction of production costs. Farmers are advised to stop autumn fertilisation which can generate leaching risks since it occurs approximately 4 months before the beginning of the growing season, and to put off fertilisation until the beginning of spring.

Finally, we used four descriptors to characterise the fertilisation practices encountered (Tab. I). The first three involve the amount of three macro-elements, each one further broken down into one of two groups defined by the above-mentioned threshold. The fourth descriptor is the fertiliser schedule, with four modalities corresponding to the three main schedules described above, plus the autumn pattern used in Farm No. 17.

### 3.1.3. Types of pest and disease control

Pest and disease control obeys both standard and adaptative management. Standard management is exemplified by treatments against aphids and apple scab between budbreak and flowering, which either concern the entire orchard or are clustered per cultivar when they precisely depend on phenology. Another example is that all the Golden apple trees undergo special treatments to prevent them from russetting to which they are sensitive.

Adaptative management uses the indicator called “pressure from pests and diseases” in year (n) for the majority of treatments and in year (n–1) for certain ones. For example, large populations of aphids or scale insects observed one year will lead the producer to take preventive measures against pests early in the season of the following year in order to destroy the eggs or larvae which may have escaped.

Given the complexity of treatments applied to the apple tree which is the fruit species which requires the greatest number of applications, it seemed necessary to limit ourselves to a synthetic variable consisting of two types of treatment: either “reasoned” (reas. in Tab. I) control or “systematic” (syst.) control. During the interviews some farmers clearly referred to spraying conditions, specific targets (mite, scab, codling moth...), operational rules and observations. Conversely, other farmers referred to agendas, chemicals, warnings or pre-harvest delays. This classification is mainly based on the behaviour of the farmer in relation to mite control as attacks are often very localised. It is therefore possible to know if the farmer treats all of his fields before they are attacked by mites or even as soon as he detects a focus of mite, or if, on the contrary, he is satisfied to treat only the focus or the field in question within the framework of a “reasoned” control. The latter case illustrates the use of a sub-plot scale for observing and using management indicators (see Sect. 3.1.1), mostly derived from IPM principles.

Eleven farms in the survey practised reasoned control and six farms practised preventive control. They represent 225 ha (79% of the total area of surveyed farms) and 58 ha, respectively (Tab. I).

### 3.1.4. Irrigation practices

Concerning irrigation, we did not obtain precise answers to questions on periods, frequency and water amounts. The farmer decides when to begin irrigation on the basis of the state of the vegetation, weed growth and meteorological observations. Tensiometers or water balances are not used. The abundance of irrigation canals also leads to the persistence of irrigation techniques which are costly in water consumption such as irrigation by gravity.

Four irrigation systems can be distinguished (Tab. I). Eight farms use gravity irrigation for all of their fields (Group g, total of 89 ha). Five farms use gravity irrigation in addition to more sophisticated sprinkler or drip irrigation systems on equipped fields (Group g+e). They represent a total of 28 ha, of which 13 ha are equipped with sprinklers and 1 ha is equipped with a drip system. Moreover, many fields are never irrigated because of

their proximity to the water table which is easily reached by the tree roots. The fields on five farms are not currently irrigated (Group ni, total of 166 ha). Most of the fields on four of these farms are never irrigated and the others are equipped with sprinkler systems (50 ha), mainly for frost control but also for irrigation in the summer during dry years.

### 3.1.5. Thinning practices

Together with pruning, thinning operations aim at managing the fruit load and thus are a determining factor in obtaining market grade apples. Thinning is principally based on the intensity of flowering (combined with meteorological conditions) and thus linked to pruning. Because of the alternate bearing pattern which most of the cultivars are subject to, pruning changes according to the harvest from the previous year, i.e. a big harvest in year (n-1) will correspond to a "long" pruning in year (n) in order to conserve the maximum number of flower buds. The fruit farmer will choose a light thinning in the case of light flowering, or even in the case of heavy flowering which is then followed by damage from frost or rain, or heavy thinning in the case of heavy flowering associated with meteorological conditions which favour pollination (hot and dry weather). The fruit load indicator may be used too. In this case, the plots will be subjected to a total of 0 to 3 applications of thinning products after first evaluating flower-bearing and then the quality of the first stage of fruit formation. Farmers use products mostly derived from hormones (NAD and NAA) and Carbaryl. Their experience of chemical thinning varies from 2 to 15 years but some farmers still maintain manual thinning on older orchards.

Because of the high degree of variability in yield from one year to the next, the way thinning operations are carried out is also highly variable. Rather than describing the operation in relation to the number of applications which depend on the year and the cultivar, two main categories were defined on the basis of whether chemical thinning is almost always used on most of the cultivars (Category C, 14 farmers), or only used some years on the rows with the heaviest fruit loads or even individual trees (Category L, 3 farmers). Indeed the orchard area is smaller in this situation (average 6.3 ha). Category L exemplifies the sub-plot scale for observing and using indicators (see Sect. 3.1.1). In this group, farmers do not take the risk of thinning trees which do not seem overloaded. One farmer never thinned his trees (category N, Tab. I).

## 3.2. Main cropping systems

### 3.2.1. Characterisation

Farm No. 13, whose fertilisation characteristics were not known in detail (Tab. I) did not participate in the data analysis. The first four factors of the CA, which include 73% of the data variance, were used. Below is the interpretation of the first two which were the most significant ones. The variables contributing the most to the first factor (25% of the data variance) are fertiliser doses and schedule, and thinning (Tab. II). F1 opposes small doses of fertiliser applied in (S+s) application or in autumn only (A), and situations where chemical thinning is used very little (L), to the right, to big doses of fertiliser, applied in autumn plus spring (A+S) or in spring only (S), to the left (Fig. 1). For F2 (24% of the data variance), the variables which contributed the most are pest and disease control, thinning and irrigation (Tab. II). F2 opposes systematical control and the absence (N) or little use (L) of chemical thinning, at the bottom, to reasoned control combined with chemical thinning (C) and the absence of irrigation (ni), at the top (Fig. 1).

The hierarchical classification designed with the first four factors made it possible to define three types of cropping systems whose characterisations are based on the interpretation of these factors (Fig. 1):

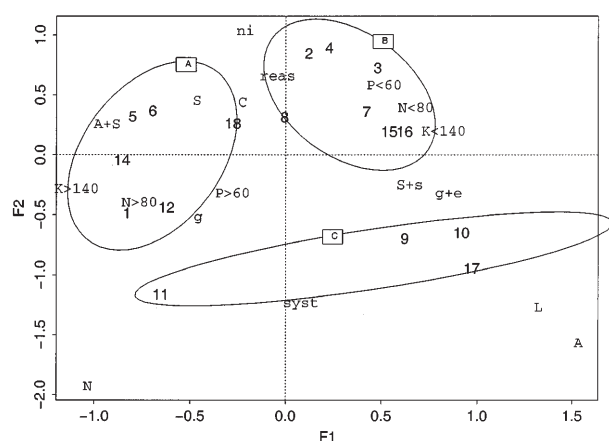
- type A (Farms No. 1, 5, 6, 12, 14 and 18) is characterised by the use of large doses of fertilisers applied in autumn plus spring or spring only. No conditional application occurs. The pest control is most frequently reasoned. The practice of chemical thinning is general and the irrigation system is variable. Type A represents 55 ha (21% of the apple orchard area of the farms surveyed, with the exception of Farm No. 13 which did not participate in the analysis);

- in type B (Farm No. 2, 3, 4, 7, 8, 15 and 16) all farmers use reasoned control, associated with small

**Table II.** Correlation ratios between the descriptors of the management techniques and the first two factors of the correspondence analysis.

	F1	F2
Dose of N	0.52	0.18
Dose of P <sub>2</sub> O <sub>5</sub>	0.14	0.19
Dose of K <sub>2</sub> O	0.84	0.06
Fertiliser schedule	0.58	0.25
Pest control	0	0.80
Irrigation	0.31	0.45
Thinning	0.41	0.65





**Figure 1.** Plot of farms (numbers) and of management techniques (classes indicated by labels, see Tab. I) described by their coordinates on the first two factors of the correspondence analysis. The types of cropping systems are indicated by variance ellipses (95%).

doses of fertilisers, and, except in one case, the two-fold spring application (S+s). They all use chemical thinning. As for A, the irrigation system is variable. The cumulative area of farms in the B category represents 201 ha, or 75% of the area of the farms surveyed;

- in type C (Farm No. 9, 10, 11 and 17) the fertilisation practices include an additional application on the plots with the heaviest fruit loads (S+s), except in one case. Pest control is exclusively systematic and irrigation is always by gravity, in addition to sprinklers for two of the farms. Chemical thinning is little or not used. The type C represents 26 ha or 10% of the area of the farms surveyed.

### 3.2.2. Confrontation with farm characteristics

The area of the orchard is much greater in type B (average = 26 ha) than in the others (between 6 and 10 ha). Practices or a combination of them seem to be a function of the orchard area, which is also an indication of the economic magnitude of the farm (c.f. Sect. 2.2) and of the means of production used. For example, the maximum area which a man working alone on his farm can treat in the same day is approximately 12 ha according to the results of our interviews. This may generate organisational constraints for disease and pest control in some farms, but not in the biggest farms in the survey

(30 to 80 ha) that have sufficient means in equipment and personnel.

Contrary to what we expected, the combination of crops had little impact on management itineraries applied to apple trees. No relationship could be observed between the three types of cropping systems and cropping patterns.

Finally, we observed an important “location” effect in relation to irrigation practices: gravity irrigation is practised by all of the farms located on soil with the greatest filtering capacity. The absence of irrigation can be observed on all of the farms on the plain, on hydromorphic soil corresponding to the site of former marshlands. Thus, the soil conditions determine the different systems of irrigation.

### 3.3. Preliminary assessment of environmental impacts of cropping systems

#### 3.3.1. Ranking cropping systems according to the pollution risks they generate

It is not possible to evaluate the environmental impact of each cropping system identified on the basis of our study but it is possible to classify them in relation to cropping practices considered to be essential for this impact. The latter consist mainly of fertilisation, irrigation and the use of chemicals to control diseases and pests.

The cropping system B is characterised by the use of small doses of fertilisers and one plus a conditional spring application. These two elements make it possible to minimise the leaching risks of mineral elements. Moreover, farms in this category belong to a system which practices reasoned control, associated with a decrease in the number of treatments.

Cropping systems C and A present an increased risk in relation to the two preceding ones. System C is characterised by systematic pest and disease control which implies greater reliance on chemicals. It also uses more fertilisers than B. Contrary to the other types, the gravity irrigation is general. Cropping system A uses more reasoned than systematic pest and disease control but applies considerable fertiliser doses on all of the plots. Three farms in this group make their first application in autumn (Farm 1, 5 and 14), creating a major risk of leaching, given the pluviometric conditions of the region.

The classification in terms of risks generated by cropping systems is as follows:

$$C = A > B.$$

### 3.3.2. Location of the identified cropping systems and combination with area sensitiveness

Most of the apple orchards are located in the western plain where the nitrate content of the aquifers is lower than in other areas of the Carpentras basin. The denitrification process is particularly important in the unsaturated area and in the groundwater of the plain [17]. Despite this lower sensitivity, the hydrodynamic properties of the soil and the nitrate content of the plain aquifers are heterogeneous. From the hydrodynamic point of view, the depth and the texture of the soil make it possible to differentiate two major types of soil, “hydromorphic” and “alluvial”. Alluvial soil is deeper with less hydromorphic properties, and the denitrification phenomenon is more pronounced in the hydromorphic soil. The distribution of the two soil types in the three cropping systems shows that the hydromorphic soil corresponds to 65.5% of the total area of B whereas the alluvial soil predominates in C (65.4% of the area) and in A (65.0%). Thus, the system B, which both exhibits the lowest environmental risks as a result of cropping practices used and gathers the largest apple area amongst the identified cropping systems (201 ha vs. 81 ha for the two other ones) is also essentially located in a less sensitive environment, at least as far as nitrogen is concerned. On the other hand, a more sensitive soil occupies more than 60% of the area of the two other systems.

## 4. DISCUSSION AND CONCLUSIONS

### 4.1. The management indicators used by the growers refer to pest / disease pressure and to fruit load

We identified the indicators used in choosing the timing and type of cultivation operations to be applied. The cropping systems we identified were clearly related to their use/non-use by the growers. Of course they differ from those used for annual crops (those mainly investigated so far), which include in particular soil conditions [1, 6, 22]. The main ones refer to the pest and disease pressure and to what may be termed the “fruit load” (relating to the previous year, i.e. number of fruits produced, or the current year, i.e. number of flowers or of young fruits). Research on the former set of indicators especially, but more generally on various indicators, is of interest for ‘Integrated Fruit Production’, which is a possible future course for the European fruit industry [23]. In this perspective, new indicators and operation rules for a management able to guarantee both environmental preservation and fruit quality are urgently needed.

### 4.2. Typology of cropping systems: questions beyond a static and mean pattern

We outlined three main cropping systems in our sample, labelled A to C. We classified them as regards environmental risks as follows:  $C = A > B$ . This pattern may not be a static one. For example, members of C and B show similarities as far as fertilisation is concerned. IPM development could contribute to render them closer to each other, since all the farms in B already apply IPM principles. This illustrates the question of possible transitions between groups, which can be studied by the method of Perrot [19] and is important because growers nowadays have to adapt to the current European market reorganisation and its environmental requisites (see Sect. 1).

The identified pattern did not take into account varietal differences. According to the interviews, these differences did not seem to be reflected in fertilisation, irrigation or weeding. Little data is available concerning the differences in pesticides used as a function of the cultivar. However, active fungicide products most likely to find their way into surface waters (captane, mancozebe and thirame) have a secondary role in reducing rugosity. These products may therefore be used preferentially on Goldens. This hypothesis remains to be proven as well as the eventual presence of these active products in the water.

### 4.3. Further information is needed to overcome the study limitations

Being an exploratory study, this preliminary work suffers some limitations. First, it was limited to the apple farms of a vulnerable zone, with the result that only a small sample was analysed. Although clear trends emerged, these should be confirmed by extending the survey to include other apple farms in a wider region. Other limitations were due to lack of information. Some technical operations did not appear to discriminate between farms because not precisely described, and thus could not be used to identify types of cropping systems. Such was the case for weed control, which does however need to be considered since it is very likely to pollute groundwater [12]. In fact, weedkillers considered to be dangerous for groundwater were identified during the interviews (aminotriazole, gluphosinate, simazine, diuron) and molecules of the chemicals have been found in the Carpentras Basin groundwater [18]. Another point concerns the precise data required to assess the environmental impact of the cropping systems. They could not be collected because a pre-requisite was the knowledge of cultivation operations management in orchards, which

constituted a main objective of this preliminary study. Existing methods and their adaptation to orchard systems should be examined. Diagnostic tools for nitrate leaching risks have been used in vineyards [7]. As regards pesticides, environmental exposure is difficult to assess or model because the fate of active ingredients is complex [28]. As an alternative, several authors propose using agro-environmental indicators [10, 29]. This methodology seems to offer valuable openings.

Data relating to farmer objectives and labour constraints was also lacking for interpreting the different types of cropping systems and thus their potential environmental impact. For example, type C that exhibits higher environmental risks associates gravity irrigation, fairly large fertilisation doses and 'systematic' pest control based on an a priori spraying time schedule. One may suggest that as gravity irrigation constrains access to the plot, using a spraying time schedule makes it easier to reconcile the two operations. Similarly, one may wonder whether a heavy fertilisation aims to compensate for fertiliser dilution by gravity irrigation on soils with higher infiltration capacity or is merely a safeguard regarding yield. Complementary studies are needed to test these assumptions.

The problem of lacking data is often linked to the unavailability of written data on the farms. However, this problem should be partly solved in the future since traceability procedures are being set up to meet the European recommendations (see Sect. 1).

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