Cite as: Parveaud, C.-E., Fleury, A., Combe, F., Oboussier, F., Gaslain, M., Dussert, L., Le Pans, M., Le Rossignol, L., Jacquot, M., Parel, M., Brun, L. (2024). Innovative organic apricot orchards to control pests and diseases: interest of rain cover, insect net and chicken breeding. *Proceedings of the 21st International Conference on Organic Fruit-Growing*, Filderstadt 2024.02.19-21. Ed. FOEKO e.V. 2024: 171-178

Innovative organic apricot orchards to control pests and diseases: interest of rain cover, insect net and chicken breeding

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Abstract

In order to assess the interest of the combination of practices to control pests and diseases in organic apricot production, two innovative orchards were designed based on (1) physical protection, *i.e.* single-rows rain protection combined with lateral insects' nets or (2) association of breeding laying hens in the orchard. Both systems were conducted under low phytosanitary inputs, in particular with no copper, and compared to an organic reference system. Each system was composed of a total of 120 trees, split into Tom Cot® and Vertige cultivars. Cultural practices, including phytosanitary practices, were adapted to each system. This study focuses on the effect of each system concerning the control of blossom and twig blight caused by *Monilinia* spp. and earwig damages, the effect on spiders' populations and agronomical performances. Results show that the physical protection has the same efficacy as the copper and lime sulfur treatments used in the Reference system to control twig blight. Chicken breeding reduced the number of earwigs by 50 to 57%, but earwig' damages on fruits were not decreased. The density of spiders observed on the tree crown and on the soil during two years was not clearly related to the effect of the system. The 4 years of experimentation highlighted, for example, (1) the need to adapt net opening and closing dates to enable biological regulation of aphids, and (2) the installation of additional protective netting to prevent predation of chickens by birds of prey. The cumulative marketable yield of each system over the 3 and 4 years-old orchard period ranged from 14 to 19 T/ha and 15 to 22 T/ha for Tom Cot® and Vertige respectively, suggesting the potential interest of these two different low-inputs systems.

Keywords: apricot, physical protection, chicken, agroforestry, *Monilinia* twig blight, earwig, spiders

Introduction

Pests and diseases control is one of the major challenges in organic apricot production. In the South-East of France, the occurrence of diseases such as canker, caused by *Pseudomonas syringae*, and European Stone Fruit Yellows phytoplasma, caused by *Candidatus phytoplasma*, can lead to the loss of many trees during the lifetime of the orchard (Lamicchane et al. 2014; Sauvion et al., 2020). Twig blight, caused by *Monilinia spp.*, is also threatening apricot production because the efficiency of direct (*e.g.* lime sulfur) and indirect (*e.g.* cultivar choice) methods can be limited when climatic conditions favor contaminations (Parveaud et al. 2021). Because earwig damages on apricot fruits can reach 40% in organic orchards, earwig control is also a major issue (Parveaud et al. 2023).

Physical protection offers promising efficient methods to control pests and diseases, while reducing the use of phytosanitary inputs. Rain shelters in apricot orchards have shown to be promising in the control of twig blight: damages were reduced by up to 95% by rain protection (Brun et al., 2023). Moreover, insect-proof nets are an opportunity to control the

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transmission of ESFY phytoplasma by *Cacopsylla pruni*. Although the effect of chicken predation on the control of earwig damages has not been demonstrated in apricot orchards, a possible effect can be supposed, as observed on larvae's predation in apple orchards (Lindhard Pederson et al. 2004).

In order to produce organic apricot using low phytosanitary inputs, in particular with no copper, two systems based on physical protections or chicken breeding were designed and compared to a reference system from 2020 to 2023.

Material and Methods

The experimental device is located at INRAE UERI Gotheron station (Saint-Marcel-lès-Valence, South-East France) under a sub-Mediterranean climate with 884 mm mean annual rainfall (1966-2008 mean value). The soil texture is 44.6% sand, 38.3% loam and 17.2% clay, pH = 7.0 without active calcium.

The main aim of the two innovative organic cultural systems designed is to decrease phytosanitary inputs. These two systems were compared to one reference system and drive as follow:

- **Reference system**: This system refers to the usual protection practices and regulations in organic, including copper. Annual cultural practices follow the regional agricultural advisory bulletin (*e.g.* "Zoom", "Objectives Info Arbo").
- **Protected system**: This system relies on physical protection composed of single-rows rain protection combined with lateral insects' nets to reduce pest and disease, and limit the use of active compounds spayed. It involves a significant investment in protection infrastructures, resulting in an objective of high yield and regular production to make these investments profitable, more oriented for long commercialization channel. The rain cover consisted of single-rows rain protection (3m wide transparent plastic rain shelters (Anisolar®, Filpack®, Vitrolles, France), comprising two 1.5 m wide strips connected on a ridge cable above the tree row,) combined with lateral insects' nets (Alt'Droso® mesh 6 x 8, Filpack®). The insect net was installed over the same periods as the rain covers each year. The rain roof was unfolded before blooming until the end of the harvest to protect the tree from blossom blight and fruit brown rot contaminations (table 2). The insects' net was unfolded from end February (Baggioloni stage: C) to prevent ESFY contamination by *Cacopsylla pruni*, and folded at the end of harvest in 2021. In 2022 and 2023, the insect net was raised to half height in mid-April, as soon as the risk of psyllid contamination was low, to foster natural regulation of aphids by hoverflies.
- **Chicken system**: the aim of this system is to take advantage of the complementary of laying chicken in mobile henhouse and apricot orchard. This system relies on the prophylactic action (by predation) that chicken can exert on pests by predation and inoculum diseases on the ground (dead leaves and fruit). It was designed to require a moderate level of technical expertise and reactivity when it comes to applying biocontrol products, resulting in a simplified use of sprayings. This multi-production system for premium products in its short direct sales circuit (apricots, eggs) and a positive image with its customers. A mobile henhouse is located inside the orchard, protected by two fences, to prevent predation. Each year, chickens are alternatively present in the two blocks of the orchard, except from mid-February to mid-April (because of phytosanitary sprayings) and from June (15 days before Tom Cot® harvest) to July (du to sanitary reason during harvest). No external organic fertilizer is brought onto the plot, so the only fertilizer comes from the droppings of the chicken.

The chicken droppings brought manually, when the henhouse is cleaned in March and May, represented a NPK contribution of 30-61-30 kg/ha/year. Natural inputs by chicken droppings in the orchards were not assessed.

The three systems are three orchards located in a 6000m^2 plot. The orchards of the Protected system and Chicken system are adjacent. The orchard of the Reference system is 70 meters from the other two. Trees were planted in January 2020 at a 4 x 2,5m density, all trees were grafted at 1.20 m high on Montclar rootstock to limit bacterial canker damages (table 1). Each system is composed of 120 trees split into two repetitions and two cultivars, Tom Cot® and Vertige. Trees were managed in a classical “gobelet” shape for Reference and Chicken systems., For the Protected system, trees were trellised in “palmette” shape so as to form a fruit wall about 1 meter wide. To avoid severe canker damages and tree mortality, trees were grafted at 1.3m in all systems.

Table 1: Characteristics of the three cultural systems assessed and soil management practices.

Name of the systems	**Reference system**	**Protected system**	**Chicken system**
Plantation, Density, Tree number	January 2020, 4 x 2.5m, 1000 trees/ha		
Cultivar, Rootstock, Grafting height	Tom Cot® and Vertige, Montclar, 1.3m		
Tree number, Plot surface	60 trees / cultivar / system, 1200m^2 / system		
Tree management	“gobelet”	“palmette”	“gobelet"
Row management *by superficial soil tillage (Braun)*	7 times/year (2023)	8 times/year (2023)	3 times/year (2023)
Inter-row management *by grass mowing*	5 times/year		
External fertilization NPK (Kg/ha)	107, 46, 101 (2022) 107, 37, 128 (2023)		0
Water supply	612mm (2022) 540mm (2023)	489mm (2023) 426mm (2023)	502mm (2022) 437mm (2023)

The decision rules were decided initially for each system, then adjusted if necessary (*e.g.* emergence of a new pest). The methods used to control pests and diseases depended of the system (table 2). Copper-based compounds were used in the Reference system only. Treatments are triggered according to sensitive phenological stages, forecast weather conditions, and trapping observations (psyllids, oriental fruit moth).

Table 2: Methods used to control pests and diseases according to the systems from 2021 to 2023. Active compounds mentioned were not systematically used each year.

Pests and diseases	Reference	Rain cover and insects' net	Chicken breeding
Canker (*Pseudomonas sp.*)	Copper	-	
Blossom and twig blight (*Monilia sp.*)	Copper (preventive) Lime sulfur (curative)	Rain cover	Lime sulfur (curative)
Earwigs (*Forficula auricularia*, *Guanchia pubescens*)	Glue on the trunk since 2022		No glue Chicken predation*
ESFY (*Candidatus phytoplasma* transmitted by *Cacopsylla pruni*)	Clay	Insect net	Clay
Aphids (Hyalopterus spp., *Phorodon humulifoliae*)	Oil Local spraying of Potassium salts		
Scab (*Venturia carpophila*) Powdery mildew (*Podosphaera pannosa*) Coryneum blight (*Coryneum beijerinckii*)	Sulfur	Rain cover	-
Rust (*T. discolor* or *P. spinosa*)	Mn-Cu leaf fertilizer	Rain cover	Leaf degradation accelerated by chicken*
Oriental fruit moth (*Grapholita molesta*) Peach twig borer (*Anarsia lineatella*)	Mating disruption	Insect net	Chicken predation on larvae*

*: expected effects

Protocol: Twig blight damages

The proportion of necrotic shoot length on shoots bearing flower buds was visually estimated for each tree. The observations were realized the 15/04/2021, 14/04/2022 and 14/04/2023.

Protocol: Earwigs and spiders' density in the tree crown

To assess earwigs and spiders' density in the tree crown, one cardboard strip (25 x 10cm) per tree was wrapped around a branch of 3cm diameter near branch insertion point. 10 cardboard strips were set up per repetition and per cultivar, *i.e.* a total of 40 traps per treatment. The cardboard strips were installed the 13/04/2023 and opened the 16/05/2023 to count insects.

Protocol: Spiders density on the ground

Spiders' density was assessed by traps called '*barber pots'*. Pots are placed in the ground and its opening (8cm diameter) was at ground level, so that the spiders can fall into the pot as they move around. For each treatment, 8 pots were placed in the tree row and 8 in the alley in Vertige cultivar only. The soil traps were opened 24h in summer 2022 and autumn 2022, 9 days in spring 2023 and 7 days in 2023.

Protocol: yield and fruits damages

The yield was calculated by weighing the entire crop, *i.e.* 120 trees per treatment, distinguishing between fruit with no visual damages ('commercial yield') and the entire harvest ('total yield', not presented in this study).

Data analysis

Data were analyzed by analysis of variances (ANOVA) and post-hoc test (Newman-Keuls) at alpha=5% using R software (R Core Team, 2022).

Results

Twig blight and fruit brown rot (*Monilinia spp.*) damages

In 2021, 2022 and 2023, mean twig blight damages ranged from 2 to 53%. Twig blight damages in the chicken system are significantly higher than in the two others systems (Fig 1 left), which lead to a higher prophylactic pruning labor time (Fig 1 right). These results show that the Protected system has the same efficacy as the copper and lime sulfur treatments used in the Reference system to control brown rot (2021: 1,7kg/ha Cu metal;

2022: 1,7kg/ha Cu metal + 4,6kg/ha calcium polysulfides; 2023: 1,5kg/ha Cu metal + 7,0kg/ha calcium polysulfides). From 2021 to 2023, prophylactic pruning time was multiplied by 3 in the Reference and Protected system du to tree development, although brown rot damages remained below 4% in both systems.

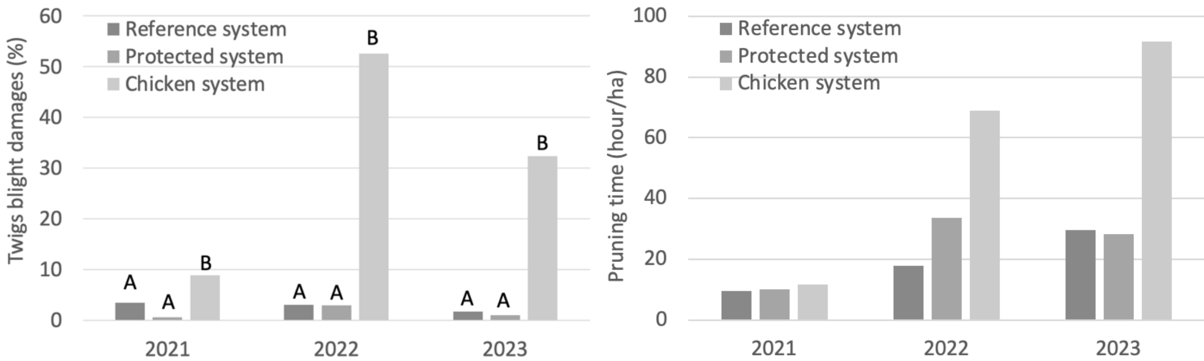

Figure 1: Twig blight damages and labor time to prune contaminated twigs in 2021, 2022 and 2023 in the tree systems.

Earwigs' population and damages on fruits

Two species of earwigs were observed in the tree crown: *Forficula auricularia* and *Guanchia pubescens*. In May 2022 sampling, *F. auricularia* and *G. pubescens* represented respectively 62% and 38% of the 395 earwigs observed.

In May 2023, a significant effect of the systems and the cultivars was observed on earwig density (Fig. 2 left; ANOVA, $p<0.05$). Chicken reduced the number of earwigs by 50% and 57% in Tom Cot® and Vertige cultivars respectively, in comparison with the Reference system. Earwig damages on fruits at harvest ranged from 2 to 9%. The decrease of earwig density observed in May in the Chicken system didn't has an effect on the intensity of earwig damages observed on fruits the 16 June for Tom Cot® and the 4 July for Vertige, *i.e.* 70 and 88 days after earwig density observation.

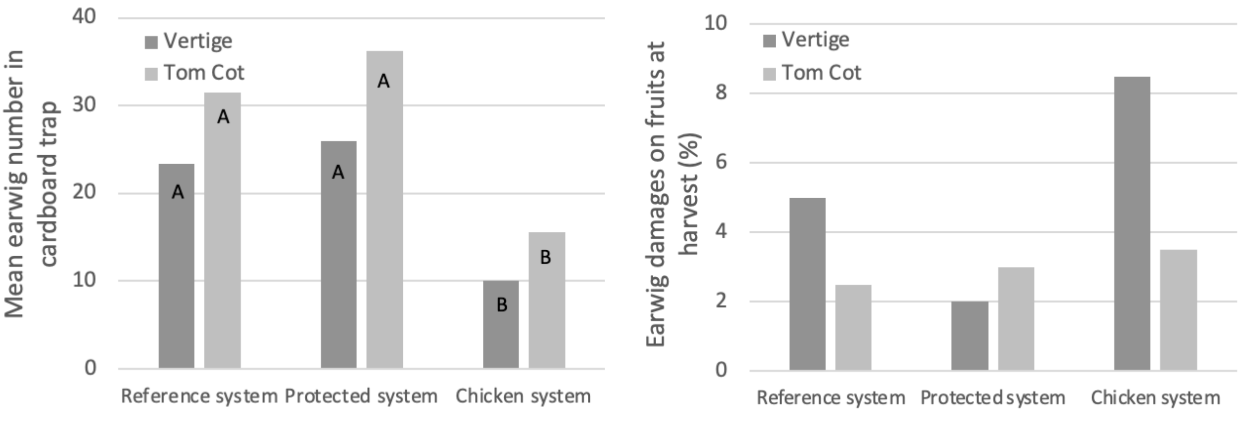

Figure 2: Earwig population observed in the trees (left) and their damages observed on fruits (right) in 2023 in the three systems.

Effect of the cultural practices on natural regulation: assessment of spiders' population

In the tree crown, the mean number of spiders catch ranged from 0 to 2.9 individuals per cardboard trap. The spiders observed were Salticidae (82%), Thomisidae and Philodromidae (7%) and others groups (11%). In spring 2022, no spiders were caught. Hot and dry weather conditions may be one explanation: spiders preferred areas less exposed to high temperatures to seek shelter and prey. Significantly more spiders were observed in the Chicken system in Autumn 2023. If the reason for this increase is tricky to explain, it at least shows that the presence of the chicken has not affected these spiders' group, known to be active in the tree crown.

On the ground, the mean number of spiders catch ranged from 0 to 3.1 individuals per soil trap. *Pardosa* sp. (Lycosidae) represented 100% of the spiders catch in summer 2022. Since the number of spiders catch was very low, capture duration was increased in 2023 samplings. In Spring and Autumn 2023, Lycosidae represented 54% and 75% of the spiders catch in the soil trap, respectively. A significant effect of the systems was observed in Spring 2023 (ANOVA, $p<0.05$): spider density is 2.5 time lower in the rain cover system than in the Reference system. No significant effect was observed in autumn 2023.

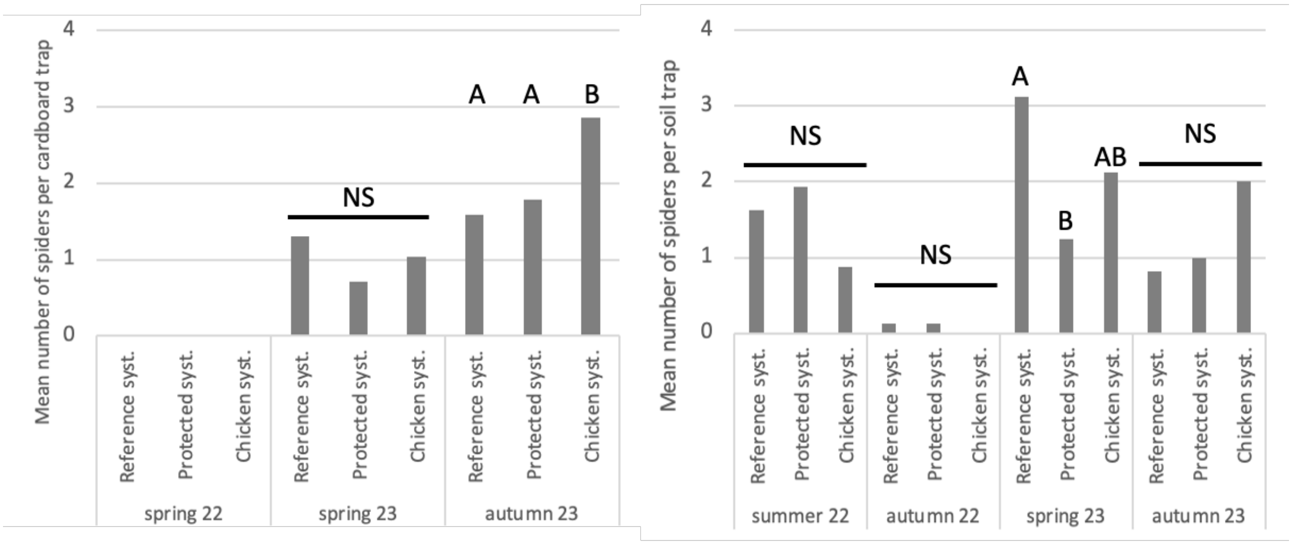

Figure 3: Spiders density observed in the tree crown for three sampling periods (left) and on the ground for four sampling periods (right) for the three systems.

Yield

No fruit was harvested in 2021 because frost damages the 8 April 2021. For Tom Cot® cultivar, annual yield ranged from to 5.6 to 7.4 T/ha in 2022 (3 years-old orchard) and from 6.2 to 13.5 T/ha in 2023 (4 years-old orchard) according to the systems. The 2022-2023 cumulative yield of the Reference system is significantly lower than the two other ones. It can be explained by a lower production in 2023 which was attributed to a low fruit setting, due to (1) an important fruit load in 2022 and/or (2) a too early soil tillage in Spring 2022, leading to a reduced availability of soil nutrients because of possible superficial root damages.

For Vertige cultivar, annual yield ranged from to 3.7 to 8.4 T/ha in 2022 and from 11.7 to 15.0 T/ha in 2023 according to the systems. No significant effect of the systems was observed on the cumulative yield of 2022 and 2023. In 2022, the yield of the Chicken system is two times lower in comparison to the Reference and Protected system. This can be explained by the intensity of twig blight in this system: 68% of the twigs were dried out by moniliosis, leading to an important yield reduction. Although 50% of twigs were dried out by moniliosis in the Chicken system in 2023, the impact on yield was much less marked.

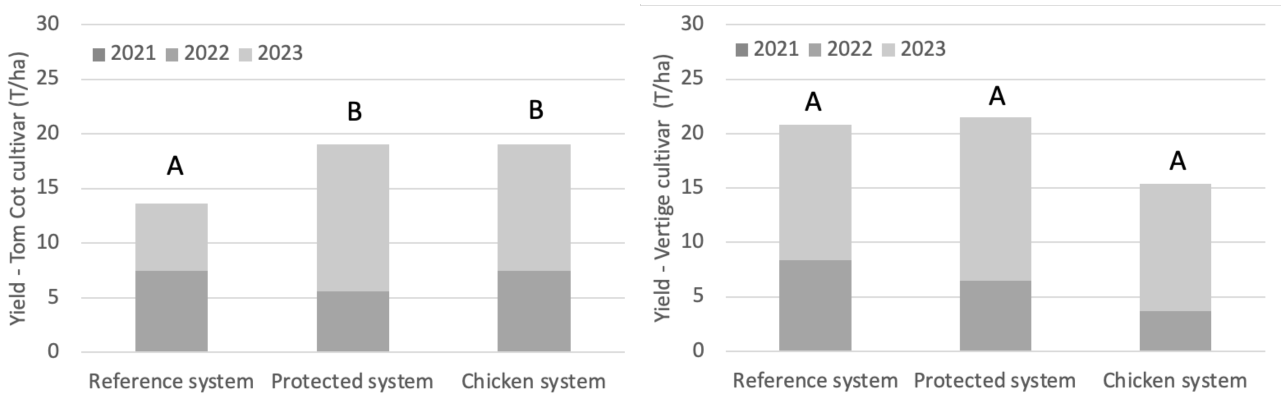

Figure 4: Cumulative commercial yield for Tom Cot® (left) and Vertige (right) in 2021, 2022 and 2023 in the tree systems.

Discussion

This study show that physical protection can be an efficient method to control twig blight damages. Indeed, as Brun et al. (2023) observed, the efficacy of the protection by rain shelters is equivalent to an organic farming fungicide protection based on copper sulfate and calcium polysulfides. In addition, a better fruits' conservation was observed in 2022 and 2023: only 2 to 8% of the fruits were damaged by brown rot in the Protected system after 7 days of conservation at room temperature, *versus* 3 to 46% on the other two treatments (results not shown).

In the Chicken system, the significant decrease of earwigs' density observed in May can be attributed to chicken predation since it has been observed in the orchard. However, no sufficient effect was observed on the control of fruits' damages. Two hypotheses can be proposed: (1) the decrease of earwig population observed was not enough to have a sufficient effect on fruits' damages and/or (2) earwig' population increased during the period between chicken removal (mandatory quarantine due to risk of *Salmonella*) and harvest, i.e. 15 days and 34 days for Tom Cot® and Vertige, respectively.

Although there are significant differences of spider' density between treatments at some dates, results do not allow to conclude at an overall effect of the systems on spider populations. The number of spiders caught is low regardless of the trapping system. The increase in capture time did not increase the number of individuals captured. It should also be noted that some spiders are not caught by these devices: a significant number of Araneidae were observed in the orchard of the Protected system treatment on the poles supporting the nets, but they were not observed in the trapping devices used.

The yield of the two innovative systems is equivalent to or higher than the Reference system, which is promising since these two systems are based on a very limited use of phytosanitary inputs (total treatment frequency index ranged from 0 to 5 in 2021, 2022 and 2023). However, in both innovative systems, uncertainties were encountered. In the Chicken system, predation by birds of prey led to the mortality of 1 chicken per day due to goshawk (*Accipiter gentilis*) attack. The bird net installed between the tree rows protected efficiently the chicken from predation. In the Protected system, significant aphid damage was observed in 2021 and 2022, even leading trees mortality: 5% of the trees for Vertige and 17% of the trees for Tom Cot®. *Phorodon humulifoliae*, an invasive aphid, was discovered in this system (Buchard et al. 2023). In order to enhance natural regulation of aphids by hoverflies, the nets were lifted halfway up in mid-April, at a time when the risk of contamination by psyllids was not yet over. Thus, managing aphid damage therefore challenges the Protected system strategy. These observations highlight the potentials and drawbacks of these innovative systems.

Acknowledgements
This research was funded by the French Ecophyto Programs (Ministry of Agriculture: 2019-X4IN40AR).

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