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Original Research Paper

Planting a new cherry orchard system: evaluation of economic efficiency

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Abstract: Cherry growing is going through an intense phase of renewal. Innovation's economic and financial analysis is crucial for their success and diffusion. The study evaluates three types of planting at different densities considered, with no covers and three different kinds of shields: a traditional anti-rain net; a multitasking anti-rain and anti-insect net; a multitasking net with high automation of opening and closing operations. The best performing plant in economic terms seems the high-density plant (HDP), followed by the medium density plant (MDP) and then the very high-density plant (VHDP). Higher density plants reach a shorter payback period. Despite the high investment cost, the quicker breaking even makes high-density plants less risky. Plants with cover structures determine more secure and stable production yields, with benefits at the farm level and the whole production chain.
Nonetheless, the shielding structures display a significant quantity of waste during the plant's life and at the time of disassembling. It is crucial to progressively increase their environmentally friendly characteristics, which to date is still poor. The supports and canopies may have a significant salvage value in the shorter-cycle cherry orchards. Since it is inappropriate to replant the cherry tree in the same plot, it is essential to study structures that can move from plot to plot. Thus, considerably would improve the environmental performance and, accordingly, the economic performance of high-density, shorter-cycle plants.

Keywords: LCCA analysis; planting density; net covers; payback period; Regina cherry

1. Introduction

The Italian fruit sector has been in hardship for a long time, both for market and socio-economic reasons, due to climatic trends and the spread of new alien pathogens (Palmieri and Pirazzoli, 2018; Palmieri and Pirazzoli, 2019) and new consumption patterns. Among the market reasons, there are some historical concerns of the sector, such as the small farm size, the lack of producer concentration and the consequent weakness of commercial power, the growth of the global competition, and the fruit consumption decline. On the climatic side, we can see the increased frequency of hailstorms, the increase of extreme events, more concentrated rainfall in critical phases of fruit development, and the greater risk of late frosts following milder winters.

There is a strong need for sector innovation for all these reasons and the role of professional fruit growers. The introduction of innovations often allows a significant qualitative and quantitative harvest improvement. Still, in the end, the economic and financial performance can determine their success and consequent diffusion.

Cherry growing is going through an intense renewal phase in many aspects, such as variety, with new innovative cultivars able to improve qualitative and quantitative performances, new orchard systems and structures for protection from atmospheric and biotic agents (Sansavini and Catalano, 2019).

Orchard systems can have nowadays very different patterns: alongside the traditional medium-density plants, from 500 to 1,000 plants/ha (MDP, Medium Density Planting), there are also high-density plants, from 1,200-1,300 up to 2,000 plants/ha (HDP, High-Density Planting) and also very high-density plants, with over 5,000 plants/ha (VHDP, Very High-Density Planting). The traditional plants are still widespread in cherry's historical productive areas, such as Modena, Italy. Farmers' choice is increasingly moving to high or very high-density types in other emerging areas.

The management of the various types of plants and structures shows, for each one, strengths and weaknesses (Lang, 2001; Seavert and Long, 2004; Yin et al., 2007). The traditional orchard plants can live up to 25 years with the broadest planting patterns. Those with high and very high density, considering maintaining an adequate qualitative and quantitative production efficiency, are generally capped to around 12-15 years. On the other hand, the high-density plants can be cropped significantly in the first 2-to to three years because of their early production.

Other significant structural differences concern the smaller size of the trees in high and very high-density plantations: this facilitates and speeds up orchard management, particularly harvesting, which is a strategic operation for the cherry growing in economic terms. The smaller size of the plants and the narrower inter-row spacing also significantly impact the costs of canopies due to the lower height of the poles, the smaller width of the covering nets, and the need for lighter anchoring systems.

However, the above translates into higher initial costs for high-density plantings in financial terms, mainly due to the higher number of plants. Nevertheless, given the earlier production and the bigger fruits, high and very high-density plants can generate significant early income (Manolova and Kolev, 2011).

The planting issues are intertwined with those of protective structures: the cherry fruit is marked, albeit with significant differences between cultivars, by the sensitivity to rain, which can split in the event of cracking, causing a loss of production and a loss of picking efficiency, which considerably affects the production costs. This issue implies the need to shield the plants with adequate structures to reduce the investment risk. Moreover, in recent years, the spread of *Drosophila suzukii* has triggered a decisive trial due to the multiple treatments required affecting economic and environmental implications (Ioriatti et al., 2015).

The multi-functional structures that can protect the orchard from insects require a higher initial investment for the cover structure. It significantly impacts management costs, deriving from opening and closing operations. On the other hand, the greater yield certainty should be considered, and the harvesting efficiency, in the case of full covers with anti-insect netting, saves unnecessary insecticide treatments.

Furthermore, the possible mechanization of the protective structure should reduce the annual management time against a foreseeable higher initial investment. Whether large or small, the type of farms plays a fundamental role in choosing the most appropriate cover system.

By these considerations, the study intends to evaluate three types of planting at different densities considered both without cover and with three different kinds of shields: a traditional anti-rain/anti-hail net (from now on referred to as anti-rain net); a multitasking anti-rain/hail and anti-insect net; a multitasking net with high automation of opening and closing operations (Monari et al., 2021).

A comprehensive sustainability analysis could also include an environmental assessment of benefits reaching from the reduced use of chemicals and costs due to the disposal of the covers at the end of their life. This study, however, focuses on the economic efficiency of the orchard systems.

2. Materials and Methods

The economic evaluation of the orchard systems deals with the well-known Life Cycle Cost Analysis (LCCA) methodology, which involves the annual analysis of the sales revenues and costs compared with the acquisition, operation, maintenance, and disposal of the investment (Fuller, 2016):

- Initial acquisition or resource acquisition costs
- Operating, maintenance, and repair costs
- Possible salvage values for resale or recovery, i.e., disposal costs

LCCA is a process of evaluating the economic performance of an investment over its entire life (cradle-to-grave). Sometimes known as “whole cost accounting” or “total cost of ownership,” LCCA balances initial monetary investment with the long-term expense of owning and operating the investment. LCCA is a well-defined procedure for estimating the overall costs of project alternatives. LCCA consists of adding all the initial and ongoing costs of the structure, product, or component over the time you expect to be using it, subtracting the value you can get out of the investment. Once the investment’s yearly cash inflow and outflow are defined, they are discounted to the present. In other words, all values count as base-year amounts in present currency; the LCCA method captures all sums for each current year and discounts them at present values as discounted cash flows.

The discount rate has been set at 2% due to the current market trend, the riskiness, and the type of investment that is not financial and is free from permanently updated inflationary dynamics. The capital needed for the investment is considered owned by the farmer so that the rate assumes the role of opportunity cost. The cash flow dynamic will be regarded as when the farmer needs to borrow the money.

The leading indicators for the economic-financial evaluation are usually the following: the Net Present Value (NPV), the Benefit/Cost ratio (BCR, expressed in monetary terms), the Internal Rate of Return (IRR), and the Payback Period (PBP).

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows throughout the investment. NPV is closely linked to the investment duration, being a sum of flows, so it’s not entirely fitting to compare projects with different durations. Due to the different lifespan of the plants, the study refers to the Equivalent Annual Annuity (EAA) Approach (Beedles and Joy, 1997). The EAA approach would compute the constant annual cash flow over its lifespan if it were an annuity.

$$EAA = (r \times NPV) / (1 - (1 + r)^{-n})$$

where:

$r = 2\%$

$n = 12$ in VHDP, 15 in HDP, 20 in MDP

The higher EAA is the better option when comparing investments with unequal lives.

The benefit-cost ratio (BCR) is a metric used to measure the total value of the costs of an investment against its expected benefits. If an investment performs a BCR higher than 1.0, the project is expected to deliver a positive NPV. The BCR translates the absolute amounts of benefits and costs into a ratio and facilitates the comparison of different investment or project alternatives, even with a different duration.

The internal rate of return (IRR) equals the present value of expected cash outflows to the present value of expected cash inflows. It is, therefore, that rate that makes the NPV equal to 0. The IRR is the return on the invested capital and the threshold rate at which the money can be borrowed.

Finally, the Payback Period (PBP) refers to the length of time it takes to recover the cost of an investment. PBP is an indicator that is not related to the duration of the investment and is the leading indicator of riskiness: the lower the PBP, the less risky an investment is.

The technical and economic features of the plants (Table 1 for technical elements and Table 2 for economic characteristics) refer to experimental plants managed by the University of Bologna Experimental Farm at various test fields. The plants are equipped with a multitasking net, and they have a density of 823 (MDP), 1,650 (HDP), and 6,000 plants/ha (VHDP). The related durations have been conservatively assumed to be 20, 15, and 12 years. The cultivar selected for all plant types is Regina, whose output flow is displayed in Figure 1. The flows represent the yields that can be reached under optimal agronomic conditions and in the presence of protective structures that offer, under ordinary conditions, good guarantees of achieving standard production.

Fast increasing production is clear as plant density increases, although the average yield per year, considering the whole full production phase, does not vary significantly in different plants (9 tons/ha for

Table 1. Technical features of the orchard systems.

ORCHARD SYSTEM	MDP	HDP	VHDP
Cultivar	Regina	Regina	Regina
Rootstock	PHLA	Gisela 6	Gisela 5
Trees/ha	823	1,650	6,000
Training system	Fuso	Fusetto	Spindel
Total Duration (years)	20	15	12
Training period (years)	4	3	2
Full production (years)	16	12	10
Annual production (ton/ha) *	9	10.6	9.2
Picking efficiency (Kg/hour)**	12	15	17
Main fruit size (mm)	28-30	28-30	30-32
Labour required (Hours/ha) ***	115	135	170

* average yield during full production years
** in normal conditions of fruit damage
*** except picking and cover system management
Source: own elaboration

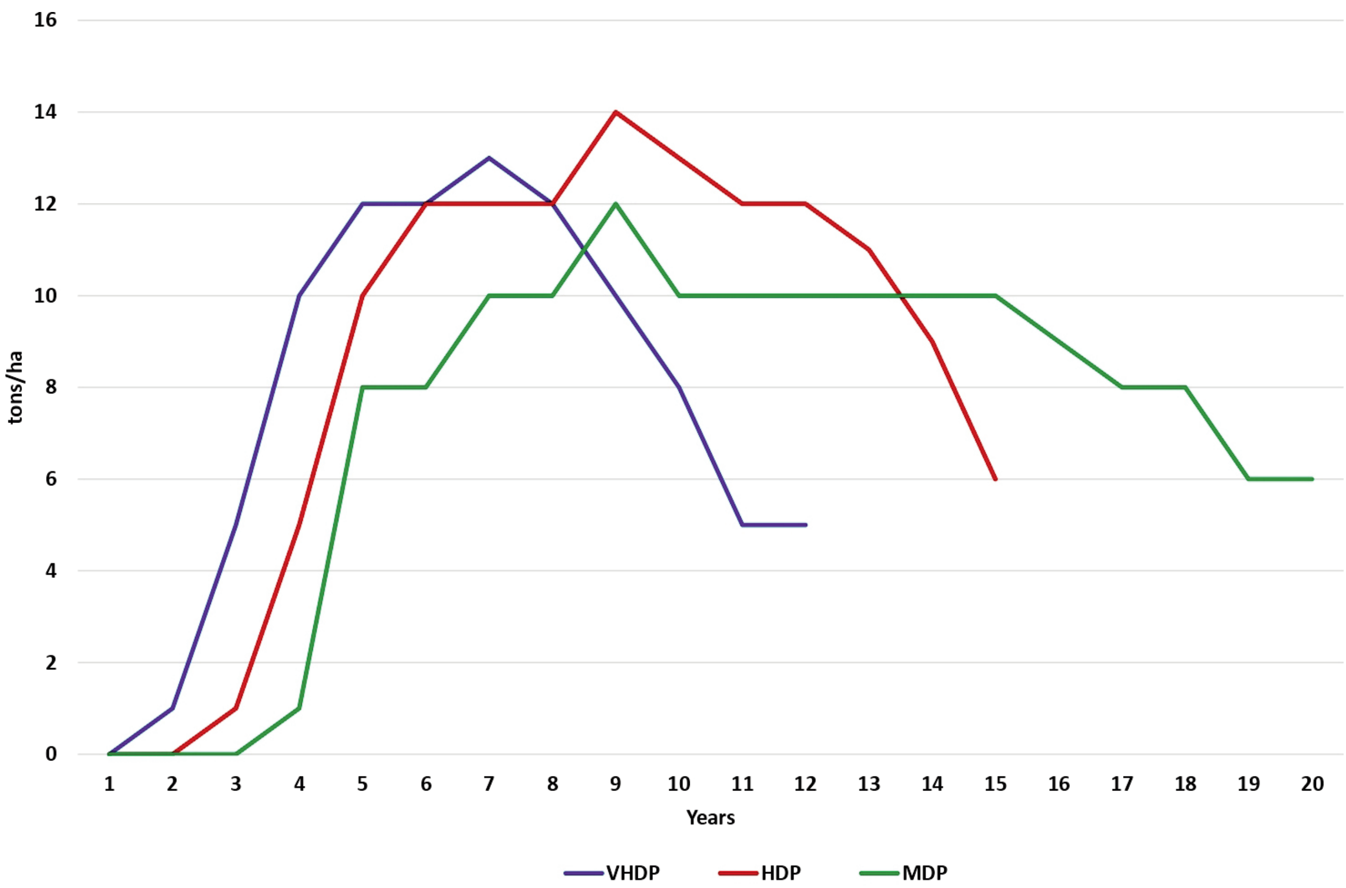

Figure 1. Production flows. Source: own elaboration

Table 2. Economic features of the orchard systems and the cover systems.

ORCHARD SYSTEM	MDP	HDP	VHDP
Average producer price (Euro/Kg) *	3.20	3.39	3.55
Initial Investment (Euro/ha) **	19,115	24,250	47,500
COVER SYSTEM (WITH SUPPORT STRUCTURES)	Anti-rain/hail net	Multitasking net	Multitasking automatized net
Initial Investment (Euro/ha) ***	66,305	80,181	89,288
Annual management (hours/ha)	80	73	55

* weighted average price based on last five years
** excluding support structures and cover systems
*** including support structures and cover systems
**** opening and closing nets (with picking wagon)

Estimated cost flow per year (Euro/ha) with Anti-rain/hail net	1-4	5,000	1-2	5,000	1	5,000
	5-6	15,850	3	9,500	2	9,500
	7-8	17,700	4	12,500	3	12,500
	9	19,500	5	16,150	4	15,750
	10	28,200	6-8	17,600	5-8	17,050
	11-15	17,700	9	19,000	9	15,750
	16	16,800	10	23,600	10	14,450
	17-18	15,850	11-12	17,600	11-12	12,500
	19-20	14,050	13	16,850		
			14	15,400		
			15	13,200		
Estimated cost flow per year (Euro/ha) with Multitasking net	1-4	5,000	1-2	5,000	1	5,000
	5-6	14,750	3	8,350	2	8,400
	7-8	16,600	4	11,350	3	11,400
	9	18,450	5	15,050	4	14,650
	10	40,600	6-8	16,500	5-8	15,950
	11-15	16,600	9	18,000	9	14,650
	16	15,700	10	29,250	10	13,350
	17-18	14,750	11-12	16,500	11-12	11,400
	19-20	12,950	13	15,800		
			14	14,300		
			15	12,100		
Estimated cost flow per year (Euro/ha) with Multitasking automatized net	1-4	5,000	1-2	5,000	1	5,000
	5-6	14,500	3	8,150	2	8,150
	7-8	16,350	4	11,150	3	11,150
	9	18,200	5	14,800	4	14,400
	10	40,350	6-8	16,300	5-8	15,700
	11-15	16,350	9	17,800	9	14,400
	16	15,450	10	29,000	10	13,100
	17-18	14,550	11-12	16,300	11-12	11,150
	19-20	12,700	13	15,550		
			14	14,100		
			15	11,200		

MDP; 10.6 for HDP; 9.2 for VHDP). For every orchard system, the average yield doesn't change significantly, assuming that the result of a Multitasking system can be reached with an anti-hail/rain shell and the use of pesticides (insecticides). The picking efficiency is 12 kg/hour (MDP), 15 kg/hour (HDP), and 17 kg/hour (VHDP) in the three orchard systems: this is also highly relevant for economic estimates. Moreover, the effect of the average expected fruit size determines a production price, computed as the average producer prices over the last five years, ranging from 3.20 Euro/Kg for the MDP plant to 3.55 Euro/Kg for the VHDP plant: this difference is due to the average fruit size that typically increases from MDP to HDP and from HDP to VHDP. The investment cost and the annual management time derive from the average of the main types currently available on the market (Monari et al., 2021). For the anti-rain system without automatization, a cost of just over 66,000 Euro/Ha was evaluated, including installation costs. For the multitasking structures, the expected cost ranges from approximately 80 for non-automated types to 90,000 Euro/Ha for the semi-automated types.

One cover nets replacement was considered in the cost flow for MDP plant and HDP plant, at year 10th. In the VHDP plant, normally the net is not replaced due to the duration of 12 years.

3. Results

The plants with no cover structure were analyzed first, assuming a yield decline due to a progressive grade of fruit damage (cracking or *Drosophila*), 10%, 20%, and 30%, respectively.

As a benchmark, supposing any absence of fruit damage for the plant's entire life and taking the weighted average prices of the last five years, the economic performance is decidedly positive. The Benefit/Cost ratio (Table 3) counts over 1.40 for medium and high-density plants and 1.65 for high-density plants. The Equivalent Annual Annuity goes from a minimum amount of 7,300 euro/ha per year till a maximum of 12,000 euro/ha. The Internal Rate of Return ranges from 14% to 19%. These parameters represent a theoretical case for comparison since it is hard not to suffer any damaging event over the years. The BCR falls of some 10% with average yearly damage of fruits of 10%, 25%-30% with an injury of 20%, and 35% -40% with a damage of 30%.

Table 3. Economic performance of plants without cover structures*.

BCR	(0%)	(-10%)	(-20%)	(-30%)
MDP	1.41	1.29	1.04	0.86
HDP	1.65	1.54	1.26	1.06
VHDP	1.43	1.31	1.1	0.94
EAA (Euro/ha)	(0%)	(-10%)	(-20%)	(-30%)
MDP	7,279	5,080	724	-2,934
HDP	11,994	9,664	5,102	1,157
VHDP	8,697	6,098	2,188	-1,298
IRR (%)	(0%)	(-10%)	(-20%)	(-30%)
MDP	14.18	11.47	3.88	-
HDP	19.12	17.27	11.51	4.18
VHDP	15.53	12.3	6.41	-1.34
PBP (years)	(0%)	(-10%)	(-20%)	(-30%)
MDP	9	10	15	-
HDP	7	7	9	12
VHDP	6	7	8	-

* Based on the production flow shown in figure 1 and the average weighted producer prices over the last five years for each orchard system
Source: own elaboration

Nevertheless, considering an average yearly damage of 20%, the EAA decreases from less than 750 euro/ha till 5,100 euro/ha. In comparison, with fruits deterioration of 30%, there are situations of meager profitability or even no longer economically viable.

The more recurring conditions are intermediate, ranging from years without trouble and damage to years in which the level of deterioration can exceed 30%. Therefore, the values calculated should be assumed as a valuable benchmark for assessing the effects on the plant's profitability due to the lower production yield and the slowdown in the harvesting yard. The efficiency of the harvesting yard is essential, considering that cherry-picking is worth more than half of a cherry orchard's production cost.

The causes of the worsening in the economic performance are linked to the lower volume of harvested fruits and the lower picking efficiency, which means more time to harvest the fruits. Compared to a situation with no fruits damaged, the time for picking and sorting cherries increases by 6-7%, with average damage on 10% of fruits, 35%-40% with 20% damage, and 50% with 30% damage (Ghelfi et al., 2016). Picking 10 tons of no damaged cherries in an MDP orchard will take 833 hours, while the time grows to about 885 hours with 10% of damage and more than 1.100 hours with 20% of fruits damaged.

Table 4 crosses the dynamics of BCR, EAA, IRR, and PBP for the three types of plants with the three specified types of covers. In this table, the indicators are shown depending on the level of the average producer price. This allows a sensitivity analysis based on the producer price, the main variable factor of profitability, and the yield level. Identifying the threshold price capable of turning positive the Benefit/Cost ratio and, therefore, potentially sustainable investment is essential. The HDP plant shows a positive value of the BRC (higher than 1) starting from 2.5 Euro/Kg. In contrast, the minimum price must rise at least 2.7 Euro/Kg for the MDP plant and at least 3 Euro/Kg for the VHDP plant, which has the shortest duration.

The trend of the indicators is similar for the anti-rain net and the non-automated multitasking system, but the semi-automated multitasking system presents slightly lower values. The higher initial expenditure is not fully balanced with the annual management's savings in terms of labor costs. An appropriate choice between the different solutions must consider the farm structure, labor availability, and the extension of the plots.

The payback period analysis (Table 5) confirms what has already been observed in similar studies (Ghelfi and Palmieri, 2015). The shorter payback is reached in high and very high-density plants: in particular, with 3 Euro/Kg for the MDP plant, 13-15 years are needed, while for the HDP, only 10-11 years. At a 3.5 Euro/Kg price, VHDP can pay back the investment in just eight years, while MDP takes at least 11 years.

Based on the weighted average prices of the last five years in the production areas of Northern Italy (Table 6), it is possible to evaluate the results of the three plants considered. All the types of plants record positive values, thus showing full economic sustainability. The HDP plant was the best performing, with a BCR of approximately 1.40. The average IRR is about 7% for MDP and VHDP, while it rises to some 11% for HDP. It takes about 11-12 years to pay back (PBP) the investment cost for the MDP plant, around nine years for the HDP, and eight years for the VHDP. Finally, the EAA goes from 3,800 Euro/ha for the VHDP orchard system with multitasking automatized cover till 8,000 Euro/ha reached by HDP plants both with a simple anti-rain/hail cover and with a multitasking cover. In this table, the indicators are shown depending on the level of the average producer price.

The spreads between covered and uncovered plants range from 0.35-0.40 Euro/Kg for MDP and HDP plants to 0.50 and 0.60 Euro/Kg for the VHDP plant (Table 7).

Concerning the non-monetary elements, we consider it essential to focus on comparing pest savings and plastic pollution. The study included the economic consequences, which aims to do a business analysis. At the same time, the environmental and social aspects need to be also evaluated with relevant non-economic skills. The impact of chemicals on biodiversity and human health is well known (EFSA, 2021). Still, reducing treatments with pesticides reduces CO2 emissions from spraying machinery. The multitasking systems reduce treatments with pesticides in a range from 5 to 8.

Table 4. Sensitivity analysis: BCR, IRR, PBP and EAA as a function of the output price (from 2.5 till 4.0 Euro/Kg) for the considered orchard and cover systems.

MDP PLANT

Price (€/Kg)	Anti-rain/hail				Multitasking				Automatized Multitasking			
	BCR	IRR (%)	PBP (years)	EAA (€/ha)	BCR	IRR (%)	PBP (years)	EAA (€/ha)	BCR	IRR (%)	PBP (years)	EAA (€/ha)
2.5	0.96	0.5	21	-863	0.96	0.7	21	-878	0.94	0.3	21	-1,292
2.6	1.00	1.9	21	-87	0.99	1.9	21	-102	0.98	1.3	21	-516
2.7	1.03	3.1	17	689	1.03	2.9	17	674	1.01	2.3	19	260
2.8	1.07	4.1	15	1,465	1.07	3.8	16	1,450	1.05	3.2	17	1,036
2.9	1.11	5.1	14	2,241	1.11	4.7	15	2,226	1.09	4.1	15	1,812
3.0	1.15	6.0	13	3,017	1.15	5.5	14	3,002	1.13	4.8	15	2,588
3.1	1.19	6.9	13	3,793	1.19	6.3	13	3,778	1.16	5.6	14	3,364
3.2	1.23	7.7	12	4,569	1.22	7.0	13	4,554	1.20	6.3	13	4,140
3.3	1.26	8.5	11	5,345	1.26	7.7	12	5,330	1.24	6.9	13	4,916
3.4	1.30	9.2	11	6,121	1.30	8.3	12	6,107	1.28	7.5	12	5,692
3.5	1.34	9.9	11	6,897	1.34	8.9	11	6,883	1.31	8.1	12	6,468
3.6	1.38	10.5	10	7,673	1.38	9.5	11	7,659	1.35	8.7	11	7,244
3.7	1.42	11.1	10	8,449	1.42	10.1	10	8,435	1.39	9.3	11	8,020
3.8	1.46	11.7	10	9,225	1.45	10.7	10	9,211	1.43	9.8	11	8,796
3.9	1.49	12.3	9	10,001	1.49	11.2	10	9,987	1.46	10.3	10	9,572
4.0	1.53	12.9	9	10,777	1.53	11.7	10	10,763	1.50	10.8	10	10,348

HDP PLANT

Price (€/Kg)	Anti-rain/hail				Multitasking				Automatized Multitasking			
	BCR	IRR (%)	PBP (years)	EAA (€/ha)	BCR	IRR (%)	PBP (years)	EAA (€/ha)	BCR	IRR (%)	PBP (years)	EAA (€/ha)
2.5	1.04	3.1	13	766	1.04	3.1	13	870	1.01	2.4	14	304
2.6	1.08	4.3	12	1,664	1.08	4.2	12	1,769	1.05	3.4	13	1,202
2.7	1.12	5.4	11	2,562	1.12	5.2	12	2,667	1.09	4.4	12	2,100
2.8	1.16	6.5	11	3,461	1.17	6.1	11	3,565	1.14	5.3	12	2,998
2.9	1.20	7.4	10	4,359	1.21	7.0	11	4,464	1.18	6.1	11	3,897
3.0	1.24	8.4	10	5,257	1.25	7.8	10	5,362	1.22	6.9	11	4,795
3.1	1.28	9.2	10	6,156	1.29	8.6	10	6,260	1.26	7.7	10	5,693
3.2	1.33	10.1	9	7,054	1.33	9.4	10	7,159	1.30	8.4	10	6,592
3.3	1.37	10.9	9	7,952	1.37	10.1	9	8,057	1.34	9.2	10	7,490
3.4	1.41	11.6	9	8,850	1.41	10.8	9	8,955	1.38	9.8	9	8,388
3.5	1.45	12.4	9	9,749	1.46	11.5	9	9,853	1.42	10.5	9	9,286
3.6	1.49	13.1	8	10,647	1.50	12.2	9	10,752	1.46	11.1	9	10,185
3.7	1.53	13.7	8	11,545	1.54	12.8	9	11,650	1.50	11.7	9	11,083
3.8	1.57	14.4	8	12,444	1.58	13.4	8	12,548	1.54	12.3	9	11,981
3.9	1.62	15.0	8	13,342	1.62	14.0	8	13,447	1.58	12.9	8	12,880
4.0	1.66	15.7	8	14,240	1.66	14.6	8	14,345	1.62	13.4	8	13,778

continues

Table 4. continues from previous page

VHDP PLANT

Price (€/Kg)	Anti-rain/hail				Multitasking				Automatized Multitasking			
	BCR	IRR (%)	PBP (years)	EAA (€/ha)	BCR	IRR (%)	PBP (years)	EAA (€/ha)	BCR	IRR (%)	PBP (years)	EAA (€/ha)
2.5	0.85	-4.2	13	-3,562	0.84	-4.0	13	-4,013	0.1	-4.7	13	-4,724
2.6	0.88	-2.6	13	-2,750	0.87	-2.6	13	-3,200	0.84	-3.3	13	-3,911
2.7	0.92	-1.1	13	-1,937	0.90	-1.3	13	-2,387	0.88	-2.1	13	-3,099
2.8	0.95	0.3	13	-1,125	0.94	-0.1	13	-1,575	0.91	-0.9	13	-2,286
2.9	0.99	1.5	13	-312	0.97	1.0	13	-762	0.94	0.2	13	-1,473
3.0	1.02	2.7	10	501	1.00	2.1	12	51	0.97	1.2	13	-661
3.1	1.05	3.8	10	1,313	1.04	3.1	10	863	1.01	2.2	12	152
3.2	1.09	4.9	9	2,126	1.07	4.0	10	1,676	1.04	3.1	10	965
3.3	1.12	5.9	9	2,939	1.10	4.9	9	2,488	1.07	4.0	10	1,777
3.4	1.16	6.8	8	3,751	1.14	5.8	9	3,301	1.10	4.8	9	2,590
3.5	1.19	7.7	8	4,564	1.17	6.7	8	4,114	1.14	5.7	9	3,402
3.6	1.23	8.6	8	5,376	1.20	7.5	8	4,926	1.17	6.4	8	4,215
3.7	1.26	9.5	8	6,189	1.24	8.2	8	5,739	1.20	7.2	8	5,028
3.8	1.29	10.3	7	7,002	1.27	9.0	8	6,552	1.23	7.9	8	5,840
3.9	1.33	11.1	7	7,814	1.30	9.7	8	7,364	1.27	8.6	8	6,653
4.0	1.36	11.8	7	8,627	1.34	10.4	7	8,177	1.30	9.3	8	7,466

Table 5. Payback period as a function of the producer price.

Price (Euro/Kg)	MDP			HDP			VHDP		
	Anti-rain net	Multi tasking	Automated Multi tasking	Anti-rain net	Multi tasking	Automated Multi tasking	Anti-rain net	Multi tasking	Automated Multi tasking
2.5	-	-	-	13	13	14	-	-	-
2.6	-	-	-	12	12	13	-	-	-
2.7	17	17	19	11	12	12	-	-	-
2.8	15	16	17	11	11	12	-	-	-
2.9	14	15	15	10	11	11	-	-	-
3.0	13	14	15	10	10	11	10	12	-
3.1	13	13	14	10	10	10	10	10	12
3.2	12	13	13	9	10	10	9	10	10
3.3	11	12	13	9	9	10	9	9	10
3.4	11	12	12	9	9	9	8	9	9
3.5	11	11	12	9	9	9	8	8	9
3.6	10	11	11	8	9	9	8	8	8
3.7	10	10	11	8	9	9	8	8	8
3.8	10	10	11	8	8	9	7	8	8
3.9	9	10	10	8	8	8	7	8	8
4.0	9	10	10	8	8	8	7	7	8

Table 6. Economic performance based on weighted average prices over the last five years.

EAA (Euro/ha)	Anti-rain net	Multitasking	Automated Multitasking
MDP	4,569	4,554	4,140
HDP	8,761	8,865	8,298
VHDP	4,970	4,520	3,809
BCR	**Anti-rain net**	**Multitasking**	**Automated Multitasking**
MDP	1.23	1.22	1.2
HDP	1.4	1.41	1.37
VHDP	1.21	1.19	1.15
IRR (%)	**Anti-rain net**	**Multitasking**	**Automated Multitasking**
MDP	7.7	6.98	6.26
HDP	11.55	10.77	9.76
VHDP	8.19	7.07	6.06
PBP (years)	**Anti-rain net**	**Multitasking**	**Automated Multitasking**
MDP	12	13	13
HDP	9	9	9
VHDP	8	8	9

Source: own elaboration

Table 7. Summary of the economic, financial, and environmental indicators.

Price-trigger for BCR > 1 (€/Kg)	No cover	Anti-rain net	Multitasking	Automated Multitasking
MDP	2.26	2.6	2.61	2.66
HDP	2.05	2.42	2.41	2.46
VHDP	2.45	2.95	2.98	3.07
Pesticide treatments reduction * (nr.)	-	1-2	5-8	5-8
Nets weight (tons/ha)	-	1.5	3-6.5	3-6.5

* compared with no cover plants
Source: own elaboration

On the other hand, orchard cover structures have a significant environmental impact (while, on the contrary, the economic impact is low) due to dismissing nets, plastic, and canopies at the end of the plant's life. Disposal or reuse of cover structures and nets will undoubtedly be a burning topic for research in the future. A simple anti-hail net counts some 1.5 tons/ha of plastic, while, for a multitasking cover, the weight of the net can rise to over 6 tons/ha. In the case of plants lasting twenty years, these figures must be double due to the need to provide for replacement (Monari et al., 2021) after more or less than ten years.

4. Discussion

When comparing covered and uncovered plants, it is essential to consider the impact of farming activities downstream of the value chain.

The certainty and continuity of production achievable with protection systems reflect more constant and efficient use of processing warehouses and machinery. It also produces market advantages from stable relationships with wholesale and retail companies.

The protective structures display a significant quantity of waste during the plant's life and, above all, at the time of disassembling. Cover nets show a different rate of wear and tear, which generally does not exceed ten years. To improve the environmental performance of nets, it is crucial to progressively increase their environmentally friendly characteristics, which to date is still poor (Maraveas, 2020).

The annual consumption of plastics for orchard nets (polyethylene) in Italy counts some 5,300 tonnes per year out of 30,000 tonnes for farming, 17% of the European consumption (Scarascia-Mugnozza et al., 2011).

The dismissing of the plant also raises the issue of disposal of the support structures, such as poles, anchors, wires, etc., which may have a longer life than the plant's useful life. For shorter-cycle cherry orchards, the supports may have a significant salvage value. Still, since it is inappropriate to replant the cherry tree on the same site, it is essential to study structures that can move from plot to plot. Thus, considerably would improve the environmental performance and, accordingly, the economic performance of high-density, shorter-cycle plants.

5. Final remarks

Based on average prices in recent years, all the three plants assessed (MHP, HDP, and VHDP) generated a positive result in all the coverage combinations investigated. The best performing plant in economic terms seems the high-density plant (HDP), followed by the medium density plant (MDP) and then the very high-density plant (VHDP).

Regina is the selected variety for comparisons in this study and was chosen because it is widely used in many countries and because it is a variety adaptable to different types of orchard systems. This assumption is not guaranteed in all cherry varieties. However, it appeared sustainable from previous analyses on Ferrovia (Ghelfi and Palmieri, 2015). Furthermore, as also highlighted in other studies (Sansavini and Palmieri, 2020), the assumption that higher density reaches a shorter payback period is confirmed. The quicker breaking even makes high-density investment less risky, despite the high cost of orchard establishment. In addition, high-density plantings can have higher quality fruit for a more extended period by maintaining light interception in the smaller trees. Finally, the better picking efficiency in high-density plants saves time in harvesting.

Of course, the main trouble in the high-density plants is the higher initial cost of the installation, which may discourage especially farmers with smaller budgets. The quicker payback period makes high-density orchards more suitable for large investors.

Similar considerations can be applied to the cover systems. In the lack of coverage, the same types of planting clearly show lower investment costs that determine significant financial impacts. Still, the economic advantage remains within an average annual damage boundary of around 10%, while above 20%, the economic results can quickly fall. Considering the climate changes, with more frequent hailstorms and more concentrated rainfall, covering a new orchard seems worthwhile for every farm. Larger farms can find more suitable automated systems that save time in annual managing. In contrast, small farms will find the optimal way out in a less expensive manual system. Concerns about the choice between a simple anti-hail shell or a multitasking one can vary along the time because of the cost and availability of pesticides and nets in evolution. However, in the case of organic farms, as for fruits with low chemical residuals standards, choosing a multitasking cover appears mandatory.

In the long run, plants equipped with cover structures determine more secure and stable production yields, with benefits at the farm level and the whole production chain.

From an environmental point of view, while waiting for in-depth studies on the covers' different impacts, it must be considered that this stable production mitigates the environmental indexes per product unit.

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