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COST-BENEFIT ANALYSIS OF FROST PROTECTION METHODS

ANALIZA STROŠKOV IN KORISTI METOD ZA ZAŠČITO PROTI POZEBI

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Abstract

Agricultural losses due to frost are high in various parts of the world, and in Slovenia, frost damage has frequently occurred in recent decades. Multiple methods for preventing frost damage exist and have been researched more or less extensively. Despite this, frost prevention measures are relatively sparsely used in Slovenia. This article aimed to review and compare active frost prevention technology for a case study of a typical fruit farm in Slovenia, based on a cost-benefit analysis. Most of the active methods require either large capital investment or have a high annual cost. According to our analysis, burning wood, used in Slovenia to battle frost damage in orchards and vineyards, proved to be the most cost-effective method, which is probably why it remains in wide use.

Povzetek

Izgube kmetijskih pridelkov zaradi pozebe so velike po vsem svetu, v Sloveniji pa se škoda zaradi pozebe v zadnjih desetletjih pojavlja vse pogosteje. Znanih je veliko metod za preprečevanje škode zaradi pozebe, ki so že bolj ali manj raziskane. Kljub temu pa se ukrepi za preprečevanje škode v Sloveniji zelo redko uporabljajo. Cilj tega članka je bil izdelati pregled in primerjavo različnih aktivnih ukrepov proti pozebi, ki so primerni za tipično sadjarsko kmetijo v Sloveniji na podlagi analize stroškov in koristi. Ugotovili smo, da so aktivni ukrepi dobra naložba, če so uporabljeni. Večina aktivnih ukrepov zahteva

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ali visok začetni kapital ali pa imajo velike letne stroške. Kurjenje, ki ga v Sloveniji uporabljajo za boj proti pozebi v sadovnjakih in vinogradih, se je po naši analizi izkazalo kot najbolj stroškovno učinkovita metoda, kar je verjetno razlog, da je še vedno v široki uporabi.

1 INTRODUCTION

Among other weather-related phenomena, frost damage is responsible for serious agriculture production losses. The Food and Agriculture Organization of the United Nations reports that more economic losses have been caused by the freezing of crops in the USA than by any other weather hazard, *[1].* In Slovenia, the frequency of spring frost was higher in recent decades than previously recorded, *[2]*.

Fields and orchards can be protected from the frost by passive and active methods. Passive techniques cannot completely prevent frost damage, but it is very important to implement them because they make it easier and more efficient to implement active methods, *[3].*

This study aimed to make a cost-benefit analysis and comparison of active frost prevention technology for a case study of a typical fruit farm in Slovenia. For this study, we assumed that all analysed active protection methods have the same effectiveness and have compared the investment value of specific methods, based on the defined criteria. We also analysed the cost-benefit of wood-burning, which is commonly used in Slovenia to prevent frost damage to vineyards and orchards.

2 DATA AND METHODS

2.1 Net present value

A thorough financial analysis should be conducted before investing in frost protection. A sound investment should satisfy three criteria: it must be profitable, the cash flow must be financially feasible, and the risk must be compatible with the preferences and financial position of the investor. Economic analysis of frost protection is complicated by the nature of weather and the net benefits derived from adopting a particular frost protection technology. One may not be able to evaluate the financial risk of the adoption decision unless adequate (e.g., 20- to 50-year time series) minimum and maximum temperature data are available, *[1]*.

As discussed in the introduction, there are different ways to protect crops against frost damage. We focused on solid fuel heaters, liquid fuel heaters, sprinklers, wind machines, helicopter rental, and wood burning in the analysis. We decided to create an analysis of the Net Present Value (NPV) for each protection method. With NPV, a project is measured according to its value rather than its costs. NPV assumes that money today is worth more than an equal amount of money tomorrow. Since the calculation is based on forecasted cash flows, a risk exists that the planned cash flows will not be reached, and thus must be considered, *[4].*

We took each specific protection measure, made an analysis of the major cost factors, and divided the costs into acquisition costs and variable costs, which can depend either on the frost frequency or on the total frost duration. The energy requirement for protecting the orchard E_R was set to be $140\ W\ m^{-2}$.

2.2 Solid fuel heaters and burning wood analysis

Orchard heaters are commonly used to prevent frost damage to fruit and fruit trees. Multiple types exist: pipeline, lazy flame, return stack, cone, solid fuel and liquid fuel. Solid fuel heaters usually only consist of solid briquettes, which are placed on the ground and ignited. Proper location of the heaters is essential for the uniformity of the radiant heat distributed among the trees [5]. The number of heaters required per hectare N can be calculated using the following formulation from *[1]*:

$$N = \frac{E_R}{E_O F_C}(3.6 \cdot 10^7) = 503 \frac{heaters}{ha} \tag{2.1}$$

where N is the number of heaters required per unit of orchard area, E_R is the energy requirement $[W\ m^{-2}]$, E_O the energy output per heater $[MJ\ kg^{-1}]$, F_C is the fuel consumption per heater per hour $[kg\ h^{-1}]$. In our case, we used the following values: $E_O = 33.4\ MJ\ kg^{-1}$, $F_c = 0.3\ kg\ h^{-1}$. If we assume that $1\ kg$ of solid fuel costs $p\ =\ €4.45/kg$, and that every heater has a mass of $M_U = 2.5\ kg$, we can calculate the total price of solid fuel heaters per hectare per hour using:

$$P = \frac{p \cdot F_C \cdot N}{M_U} \cong 270 \frac{€}{h} \tag{2.2}$$

We also took into account the acquisition costs of equipment related to solid fuel heaters, namely an ignition torch, a frost alarm, a minimum thermometer, with a total cost of $€240$, and an approximate surveillance manhour cost, which was approximated at $€10/h/person$ with four people controlling the fires. The total variable cost per hour is $€310/ha/h$. Additional costs are the labour costs of placing, starting, and stopping the fires, removal of waste, lighting torch fuel, etc., which were approximated to be $€70/ha$ per every frost event.

For comparison, we calculated the same parameters for another solid fuel type, wood, which is commonly used to minimize frost effects in Slovenia. In this case, we assumed that $E_O = 16\ MJ\ kg^{-1}$, $F_C = 5\ kg\ h^{-1}$. Based on the energy requirement, we calculated that we would need 63 bonfires per hectare, each weighing $M_U = 10\ kg$. We assumed that the wood price is $€60/m^3$, which, calculated with an average mass density of $470\ kg/m^3$, gives us a price of $€0.1277/kg$. This gives us, together with surveillance costs, a total variable cost of approximately $€52/ha/h$. Variable costs, including manhour labour to set up the fires, fuel for trucks, etc., were estimated to be around $€200/ha$ per event.

2.3 Liquid fuel heater analysis

Liquid fuel heaters typically burn up to 4 litres of fuel per hour. The maximum heating effect for a well-adjusted stand-alone heating system in the right environment is about 300 to 330 $W\ m^{-2}$ [6]. In our case study, we took into consideration liquid fuel heaters with the following data: Energy output $E_O = 38\ MJ\ l^{-1}$, fuel consumption $F_C = 1.4\ l\ h^{-1}$. That gives us a total number of heaters per hectare of:

$$N = \frac{E_R}{E_O F_C}(3.6 \cdot 10^7) = 98\,\frac{heaters}{ha} \tag{2.3}$$

Liquid fuel is typically burnt in some type of a metal container with an opening at the top. Among the initial capital costs required to invest in a liquid fuel heating system are the cost of heaters themselves, a fuel can, a fuel pump, a reserve tank, ignition torches, a frost alarm and a minimum thermometer. Altogether, we estimated the initial capital costs of the equipment to be €$5{,}000$. Variable costs per hectare include labour costs for starting and stopping the fires, refilling the heaters, and fuel for torches. Variable costs per hectare per frosting event were estimated to be €$28/ha$. The total cost of fuel and labour of surveillance per hour was calculated to be €$58/ha/h$.

2.4 Sprinkler analysis

Sprinklers can be used to provide sufficient heat to plants in an environment with little wind and appropriate temperatures, as long as a film of free-liquid water surrounds the fruit leaf. The required application can be estimated if heat loss by convection, radiation and evaporation is known, *[7]*. Among the initial capital costs are the main and secondary flow lines, tubing accessories, sprinkler heads, regulators, and trenching costs, the cost of the pumping plant, installation of the system, alarms and thermometers. Altogether, the equipment cost estimation was €$7{,}450/ha$. Variable costs per hectare per frosting event, which included only the starting and stopping manhour labour, were valued at €$11/ha$, while the variable costs per hour of protection were presumed to be €$24/h$.

2.5 Wind machine analysis

Wind machines are tall, fixed-in-place, engine-driven fans that pull warm air down from high above ground during temperature inversions, and raise air temperatures in an orchard. They are not meant to be operated in windy conditions because high wind forces might cause too much stress on their blades, *[8]*. They are usually powered by internal combustion engines, although electrically powered fans can be used as well. Each wind machine, typically rated at $100\ kW$, is able to protect an area of around 4-5 hectares. In our analysis, a wind machine with an internal combustion engine was considered. The total acquisition costs of a single unit were estimated to be €$35{,}000$. Variable costs per single event per hectare, which include maintenance labour, vehicle use, and other miscellaneous replacement parts totalled €$320.40/ha$ per event. Variable costs per hour of protection, which include fan fuel cost and surveillance labour manhours were calculated at €$19/h$.

2.6 Helicopter analysis

Helicopters have proven to be an effective method of crop protection. Bates, *[9]*, for example, found the helicopter action could raise the crop temperature above the plant's frost danger point. The affected area radius is approximately $r = 30\,m$, and 15- to 20-minute passes over the orchard are needed, *[9]*. We assumed in our case, that the investor will not buy a helicopter, but will rent one when needed. In this case, the only variable cost is helicopter and pilot rental per hour, which was estimated to be €1000 per hour. If we take into account an average helicopter speed of $15\,mph$ ($v = 6.7\,m/s$), and the required pass-by time $t = 15\,min$, we can approximately calculate the maximum area a single helicopter can cover within the given time span, given the width $w = 2r = 60\,m$, that denotes the affected span of each pass by:

$$A_{max} = vtw = 6.7\frac{m}{s} \cdot 15\,min \cdot 60 \cdot \frac{s}{min} \cdot 60\,m = 316{,}800\,m^2 = 31.68\,ha \quad (2.4)$$

2.7 Case study definition

Our case study orchard farm is located in Slovenia. Based on model calculations made by the Agricultural Institute of Slovenia, available in *[10]*, we estimated some typical values for a farm in Slovenia. Our chosen orchard area is 5 hectares. Annual fruit production mass is $40\ tonnes\ per\ hectare$. The selling price of apples is €$0.49\ /kg$, and the production costs add up to a total of €$17{,}423\ /ha$. Based on available and gathered data, we estimated that one major frost event happens every two years, and the length of the frost is approximately 8 hours. During the frost events, damage occurs to the plants, affecting 50% of the fruit. The complete input parameters for our analysis can be seen in Table 1 and Table 2.

Table 1: *Input parameters to the cost-benefit analysis*

Input parameters	
Orchard area	5 ha
Fruit mass	40 t/ha
Crop price	€0.49/kg
Production costs	€17,423 /ha
Frosty year occurrence (x years)	2 years
Number of frosts per frosty year	1 / year
Length of every frost event	8 h
Crop survival ratio	50 %
Discount rate	4.00 %
Project lifetime (years)	6 years
Annual results, without frost	
Income per hectare	€19,640/ha
Costs per hectare	€17,423/ha
Profit per hectare	€2,217/ha
Total profit	€11,087
Annual results, with frost	
Income per hectare	€9,820/ha
Costs per hectare	€17,423/ha
Profit per hectare	-€7,603/ha
Potential income per hectare	€9,820/ha

Table 2: *Annual cost and investment data for each protection method*

Protection method	Annual cost	Investment
Solid fuel heaters	€12,750	€1,200
Liquid fuel heaters	€2,460	€25,000
Sprinklers	€1,015	€37,250
Wind machines	€2,362	€35,000
Helicopters	€8,000	/
Wood burning	€4,680	€1,200

The net present value (NPV) method requires three parameters for each period for which we wish to calculate the current investment value; the annual cash flow, the discount rate and the expected lifetime of the project, in which we want to yield positive results, minus the initial investment cost. The NPV formula can be written as:

$$NPV = \sum_{i=1}^{n} \frac{R_i}{(1+r)^i} - Initial\ investment \qquad (2.5)$$

where R_i is the estimated net cash flow for i-th period, r is the discount rate, and n is the life of the project.

The initial investment in our case are all the costs of any equipment that have to be made before the first frost event occurs: the total equipment acquisition costs. We have chosen the net cash flow R_i to be the potential savings from protection, if a protection measure was to be installed or chosen to be used for protecting the crops. The effectiveness of all of the above measures was set to be 100 % to ensure the most optimal economic outcome in the case of investing. The results of the cost-benefit analysis can be seen in Table 3 and Figure 1. Our project lifetime is $n = 6\ years$.

3 RESULTS

Our economic analysis shows, as seen in Table 3, that all methods of protection yield effective results in the given project lifetime. Sprinklers, wind machines, and liquid fuel heaters require a large capital investment and have lower variable costs, while solid fuel heaters, helicopters and wood-burning require little to no capital investment, but have more significant variable costs. The most cost-effective method, according to our calculation, was burning wood, as it has the largest net present value of €105,003.64 after the designated project lifetime. The cost of all of the methods without frost events was considered to be zero, as little to no maintenance was considered to be required for the appropriate installed systems due to the short project lifetime.

***Table 3:** Net present value of different active protection methods*

Protection method	Annual cash flow (with frost)	Annual cash flow (no frost)	NPV (6 years)
Solid fuel heaters	€36,350	€0,00	€61,870.10
Liquid fuel heaters	€46,640	€0,00	€93,069.37
Sprinklers	€48,085	€0,00	€88,542.78
Wind machines	€46,738	€0,00	€83,593.17
Helicopters	€41,100	€0,00	€88,458.49
Wood burning	€44,420	€0,00	€105,003.64

Below, in Figure 1, the NPV of the protection methods is shown. It is clear that most of the protection methods give positive cost-benefit results (in this case, the NPV value is greater than zero for all analysed protection methods in just one year) after the initial capital investment, if calculating using the specified input data.

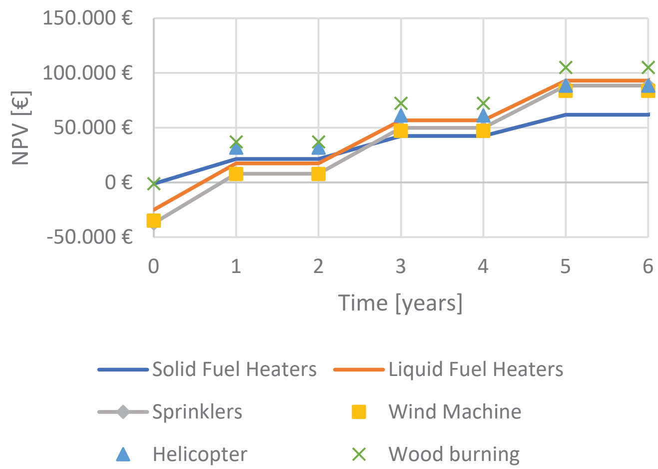

Figure 1: *Net Present Value of various active frost protection methods*

In Figure 2, we directly compare the total annual costs per hectare for our case study farm to illustrate the comparative cost of each protection method. Based on our calculation, a minimum of $€203/ha$ of variable costs are needed to ensure sprinkler frost damage protection. Most methods have an annual variable cost range of approximately $€200/ha$ to $€1600/ha$.

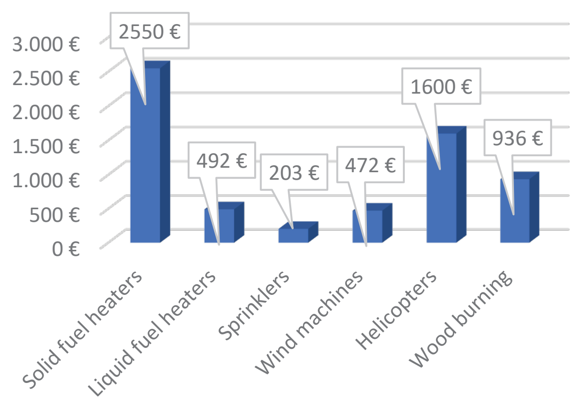

Figure 2: *Annual variable costs of various protection methods per protected hectare per frosty year*

The total investment costs per hectare are shown in Figure 3. Initial capital costs for renting a helicopter, wood-burning and solid fuel heaters are low while liquid fuel heaters, sprinklers and wind machines investment cost are high.

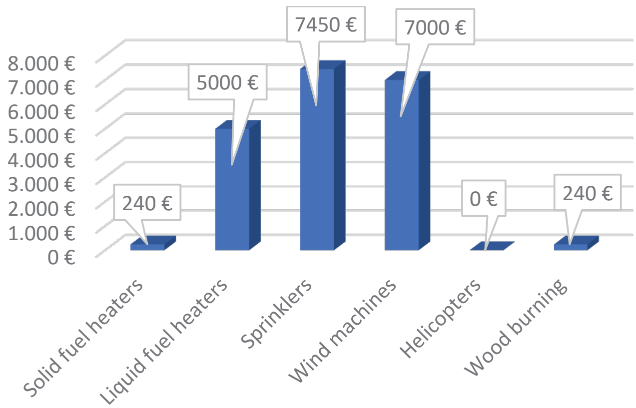

Figure 3: *Investment costs of various protection methods per hectare*

4 CONCLUSION

Based on the conducted cost-benefit analysis, it is evident that frost protection systems, when effective, are beneficial in increasing the total profit of fruit producers, in an environment where frost is a relatively frequent occurrence. In our case study, all of the methods yielded positive economic results as soon as the first frosty year.

The most effective measure was burning wood, which increased the potential profit (over the project lifetime of six years) by more than €100,000 in total. Sprinklers and liquid fuel heaters were approximately equally economically successful. Wind machines, helicopters, and solid fuel heaters have the smallest benefit-to-cost ratio, but these investments also gave positive investment value and are to be considered for potentially decreasing damage due to frost.

Figure 4: *Example of burning wood in Slovenia*

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Nomenclature

(Symbols)	(Symbol meaning)
t	time
N	heater count per hectare
E_R	frost protection energy requirement
E_O	frost protection energy output
F_C	fuel consumption
p	fuel price
P	heater price
M_U	heater mass
w	helicopter affected protection width
v	speed
A	area
NPV	Net Present Value
R_i	net cash flow
i	annual period
r	required rate of return