inventions

Communication

Assessing the Performance of a Subsurface Water Retention System (SWRS) Prototype: First Evaluation of Work Productivity and Costs

Luigi Pari, Walter Stefanoni *, Nadia Palmieri and Francesco Latterini

Consiglio per la Ricerca in Agricoltura e L'analisi dell'Economia Agraria (CREA)—Centro di Ricerca Ingegneria e Trasformazioni Agroalimentari, Via della Pascolare 16, Monterotondo, 00015 Rome, Italy; luigi.pari@crea.gov.it (L.P.); nadia.palmieri@crea.gov.it (N.P.); francesco.latterini@crea.gov.it (F.L.)
* Correspondence: walter.stefanoni@crea.gov.it

Abstract: The potential to use Subsurface Water Retention Systems (SWRSs) to combat desertification and improve agriculture in arid and semiarid areas has already been investigated and proved promising. Nevertheless, a lack of specific machinery has prevented this technology from demonstrating its effectiveness on vast areas. In the present study, a specific prototype is presented along with the results obtained from a preliminary study conducted to assess effectiveness, performance and associated cost. During the test, the machinery permitted the construction of a SWRS 100 cm belowground using a 140 kW tractor. The effective field capacity (EFC) averaged at 0.19 ha h^{-1} whilst total cost was estimated to be as high as 4800.00 € ha^{-1}. However, 93% of the cost was associated with the purchase cost of the removable impermeable film. A removal operation was also investigated using a 42 kW excavator for evaluating the EFC and cost which averaged at 0.2 ha h^{-1} and 655.79 € ha^{-1}, respectively.

Keywords: climate change; desertification; rainwater harvesting; work performance

Citation: Pari, L.; Stefanoni, W.; Palmieri, N.; Latterini, F. Assessing the Performance of a Subsurface Water Retention System (SWRS) Prototype: First Evaluation of Work Productivity and Costs. *Inventions* **2022**, *7*, 25. https://doi.org/10.3390/inventions7010025

Academic Editor: Konstantinos G. Arvanitis

Received: 25 January 2022
Accepted: 8 February 2022
Published: 9 February 2022

1. Introduction

The expanding aridity in North African countries and in some South European countries such as Italy, Greece and Spain is a major issue limiting agriculture and thus adequate and reliable production of food [1]. Additionally, global warming, a worldwide phenomenon that could cut world economy by $23 trillion in 2050 [2], is creating concern among academics and politicians as the Mediterranean might be a region especially vulnerable global change [3–6]. In fact, in North African countries, precipitation events are expected to become rarer in the future, but characterized by larger rain events [7]. Floods and drought will alternate frequently and even if a large quantity of water is delivered yearly on the ground via rainfall, the contribution to agriculture will be very limited due to the high loss of fresh water through runoff. Indeed, such conditions worsen land degradation processes, loss of biodiversity, water availability and economic growth [8].

During recent decades, several attempts have been made to catch rainwater for agricultural purposes in arid and semi-arid regions and combat desertification via application of rain water harvesting (RWH) systems. The most common systems soak to intercept and collect the rainwater from roofs to tanks where the water remains available for irrigating local fields. Other efforts have been put into the construction of underground check dams and, according to the literature, these methods have helped to reduce stormwater runoff, improving water management and increasing crop yield [9,10]. However, these strategies did not help to prevent the loss of water via deep percolation nor the loss of nutrients due to leaching, yet the most recent attempts to mix soil with biochar or adsorbent polymers in the soil returned encouraging results [11,12]. Furthermore, the strategy to build more dams and irrigation canals for transporting retained water to distant dry fields is difficult to put into practice. Accordingly, some authors began to investigate the possibility of artificially retaining water near crop root zones via application of a Subsurface Water Retention System (SWRS) as early as the 1960s.

Initially, different materials were tested for their contribution to increasing yield in vegetable crops, for instance clay [13,14], gel conditioners [15,16], metal [17] and asphalt [18,19]. Regardless of the dramatic costs in terms of labor and environmental sustainability of using asphalt as SWRSs [20], this demonstrated higher yield in the bell pepper (*Capsicum annuum* L.), sweet corn (*Zea mays* L.), sweet potato (*Ipomoea batatas* L.) and rice (*Oryza sativa* L.). During the last two decades, other studies followed by applying plastic films instead. Elawady et al. (2003) reported 18% yield increase in spinach (*Spinacia oleracea* L.) [21] whilst Awady et al. (2008) found a 141% to 190% increase in tomato fruit yield (*Solanum lycopersicum* L.) [22] Other studies performed in Iraq highlighted positive effects of plastic SWRSs on both yield and water use efficiency in the chili pepper (*Capsicum annuum* L.) [23,24]. Kavdir et al. (2014) investigated the use of impermeable membranes in irrigated sandy soils and an increase in corn production was assessed to be as high as 238% more than under normal conditions [25]. Nevertheless, the effective contribution of such knowledge to address vast problems like desertification and food production in arid and semi-arid areas of the planet cannot be proved until SWRSs are tested in large field experiments. To achieve this goal, the Michigan State University and RFW Bron (Woodstock, Canada) developed a SWRS prototype capable of installing a U-shaped plastic membrane 15–45 cm deep in the soil [26]. Plants were cultivated immediately above the SWRS and Miller 2015 recorded a higher h-index and higher shoot to root ratio in corn [27].

Considering the beneficial effects of SWRSs found in small scale experiments on vegetable production and the encouraging results reported by the Michigan State University in realizing a prototype to build small SWRSs, a bigger prototype was developed in the framework of the ERANETMED project (MediOpuntia) in order to upscale the use of SWRSs for improving agriculture in arid and semi-arid areas [28]. The machinery was developed and tested in Italy on sandy soil to evaluate both performance and cost and, possibly, to speculate on further improvements. In this short communication, the authors focused only on the performance and the suitability of the machinery for large field tests and preliminary scientific results are provided.

2. Results and Discussions

Once the machinery was positioned at the starting point, the excavating capacity of the rotary wheels was suddenly evident. In fact, the SWRS quickly adjusted to its maximum depth (approximately 100 cm) and the impermeable roll unfolded smoothly behind the prototype. Few manual adjustments of the film were needed at the beginning for positioning it correctly. Results of the work productivity are shown in Table 1.

Table 1. Total field capacity, effective field capacity and field efficiency are reported for every phase of SWRS realization.

Parameter	Details	Measure Unit	Avg.	St. Dev.
TFC	Started digging with excavator	ha h^{-1}	3.94	0.37
	SWRS installation with prototype	ha h^{-1}	0.38	0.06
	SWRS removal with excavator	ha h^{-1}	0.10	0.01
	Overall installation	ha h^{-1}	0.34	0.05
EFC	Started digging with excavator	ha h^{-1}	3.94	0.37
	SWRS installation with prototype	ha h^{-1}	0.20	0.07
	SWRS removal with excavator	ha h^{-1}	0.10	0.01
	Overall installation	ha h^{-1}	0.19	0.07
FE	Started digging with excavator	%	100.00	n.d.
	SWRS installation with prototype	%	52.34	17.52
	SWRS removal with excavator	%	100.00	n.d.
	Overall installation	%	54.40	17.48

According to the results, the preparation of the starting point for the SWRS prototype proceeded at the rate of 3.94 ha h^{-1} with FE as high as 100%. This is an interesting value as it highlights no wasted time throughout the operation. On the other hand, as partially expected, the EFC of the SWRS prototype was rather slow, and only 0.2 ha h^{-1} on average was recorded which corresponded to less than 0.1 km h^{-1} of working speed. The EFC averaged at 52.34% of the TFC for this phase only due to high presence of residual biomass on the ground that reduced the excavating capacity of the machinery. Some clogging occurred and, this, forced the contractor to stop the machinery for cleaning operations (Figure 1b). Considering both the preparation of the starting point and the realization of the SWRS, approximately 5 h of work were needed per hectare.

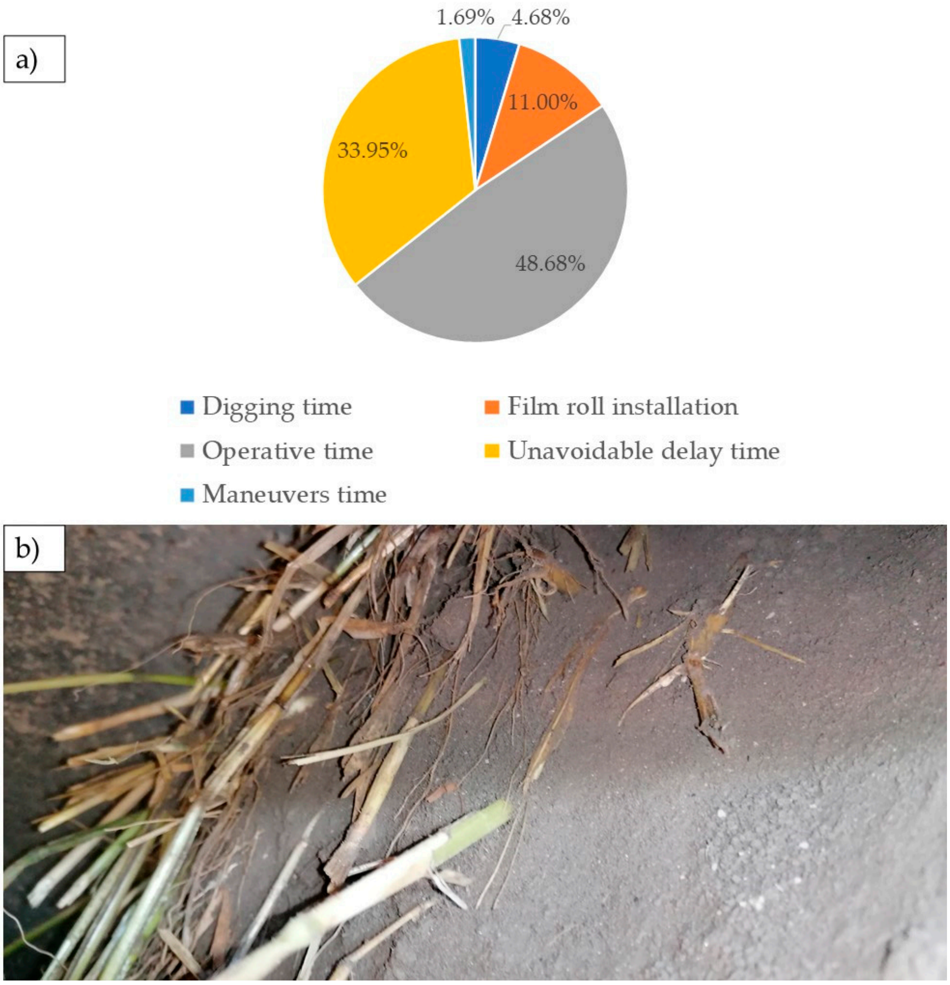

Figure 1. (**a**) Pie chart of the working times, and (**b**) image of the clogging experienced due to presence of residual biomass on the field.

Although it might appear to be a substantial amount of time to invest for the realization of SWRSs, it should be noted that its lifetime is expected to be very long, potentially longer than 50 years [9,29]. This depends on the matter of the impermeable film, and is an aspect that could be worthy of further investigation in order to assess the possibility of employing different materials. Furthermore, the above-ground usage of biopolymer based plastic films does not demand high mechanical resistance to load and elongation [30–32] which are important for SWRS operations considering the high amount of soils that are returned by the prototype on the film. Ideally, specific biopolymer based plastic film could be developed for the creation of SWRSs in order to improve its environmental sustainability. However, the biodegradation time has to be calibrated according to the purpose of SWRSs and, generally, longer lasting is better, particularly considering the high cost of the operation.

A similar attempt to create local water harvesting systems directly on field was financed by the FAO via the Acacia Operation Project (AOP) to adopt a machinery named "Delfino", developed by Vallerani enterprise (Umbria, Italy) [33]. The machinery, similar to a plough equipped with of a ripper and a reversible mouldboard could create micro basins to collect water, seeds, top soil and organic matter borne by wind and water. Unfortunately, the micro basins created with solely soil disappeared after heavy rains, making the efforts worthless. Hence, it continues to be important to create reliable SWRSs capable of supporting plants with moisture as long as possible, at least until spontaneous vegetation takes over, in the case of fighting desertification.

The economic cost of SWRSs with the presented prototype was also investigated, and results are given in Table 2.

Table 2. Final cost for installation and removal of the SWRS performed two weeks later.

	SWRS Installation				SWRS Removal
	128 kW Tractor	SWRS Prototype	42 kW Excavator	Total	
€ h^{-1}	47.98	913.35	44.38	1005.71	67.38
€ ha^{-1}	240.42	4576.54	11.26	4828.22	655.79

Since we made the decision to use thick and strong plastic film for testing the performance of the SWRS, the total cost per hectare reached 4828.22 € where 93% of it was due to the sole purchase cost. On the other hand, the mere cost for realizing the SWRS, excluding the price of the plastic film used, was lower than 1000 € ha^{-1}, which is acceptable if considering the fact that this operation is not needed frequently. In order to evaluate the possibility of removal of the impermeable film after its use (30–50 years), a full row of 150 linear meter was removed. Due to the fact that the film had an excellent traction force, as a polypropylene 630 gr m^{-2} film was chosen, no film was broken or detected during the removal. This is extremely important as no plastic debris was left after the removal in the field, which usually happens when removing thinner plastic layers like those employed for mulching. In fact, the film used in the SRWT should be considered as the impermeable films normally utilized in the artificial basins. They are deposited on the ground during the construction of basins and completely removed and disposed of after the basin life. The removal cost was also assessed and reported in Table 2. This cost is valid in the conditions described above. In fact, different soils with different degrees of compaction can significantly affect the performance of the excavator and thus affect the removal cost as well. Disposal cost was retrieved via direct interviews of the local farmers. They stated that the disposal cost for plastic is 1 € kg^{-1}. Consequently, each SWRS in our experimental field costed approximately 150 € with regard to disposal cost. Lifetime of removable impermeable underground foils is difficult to predict, and a specific study should be performed in order to estimate the turnover of SWRSs and adjust the removal cost according to the performance of the excavator in removing the foil in highly compacted soils. However, further investigation on the possibility to use cheaper materials to reduce operational cost is also strongly recommended.

In the current study, the long-term effects on soil compaction were not investigated as we mainly focused on the design, building and tuning of the prototype. Soil disturbance is indeed important to evaluate due to the radical modification of soil structure caused by the machinery [34–38]. During the excavation of the ditch, the machinery continuously mixed the soil from top to bottom layer, thus creating a very different substrate for roots. Chemical and physical changes are expected and lower fertility in the short period is also likely.

3. Materials and Methods

3.1. Description of the Prototype

Considering the ambitious goals of building 100 cm deep SWRSs (almost three-fold as deep as the Michigan State University's prototype could reach), the concept design started from a double-wheel central excavation ditcher which was equipped with ad hoc designed conveyors to deliver the soil behind the machinery and above the removable impermeable film. The rotary wheels spun at 23° counter drive direction of the tractor. The prototype was attached to the tractor via a three-point hitch system and it measured approximately 2000 kg in weight. The machinery required 100 kW of power that was delivered via 1000 rpm PTO. The removable impermeable film was mounted below the conveyers and held by lateral bearings to permit the continuous unrolling of the film during the onwards moving of the machinery. An iron triangle shaped structure was installed close to the roll in order to permit the smooth adherence of the film to the walls of the ditch excavated (Figure 2A).

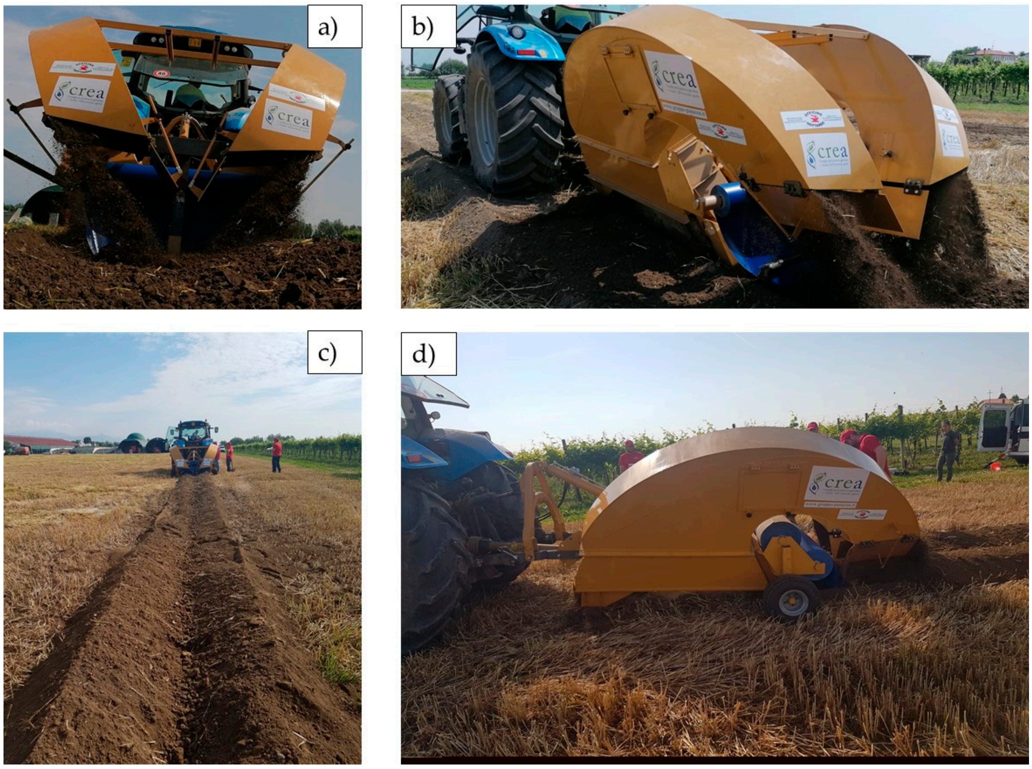

Figure 2. Views of (**a**) the rear of the prototype, where the iron triangle shaped structure is partially visible behind the removable impermeable film, (**b**) the soil being discharged on the film, (**c**) the appearance the SWRS at the end, and (**d**) a lateral view of the prototype.

For the preliminary test of the SWRS prototype, 630 gm m^{-2} polyethylene film was used. The roll measured 1.5 m in width and 150 m in length. A transversal section of the SWRS is given in Figure 3. Once the 1 m depth was reached, the removable impermeable film adhered smoothly on the walls of the ditch giving 30 cm of impermeable film free soil to permit tillage operations.

3.2. Experimental Field and SWRS Realization

The performance of the prototype was tested in Fontanelle Municipality (Veneto, Italy, 45.806565 N; 12.435727 E). Before testing, 10 randomly chosen 1 m^2 plots were selected on the field to sample soil and residual biomass. Samples were put in sealed bags and brought to the lab for the analysis. Physical properties of the soil are given in Table 3.

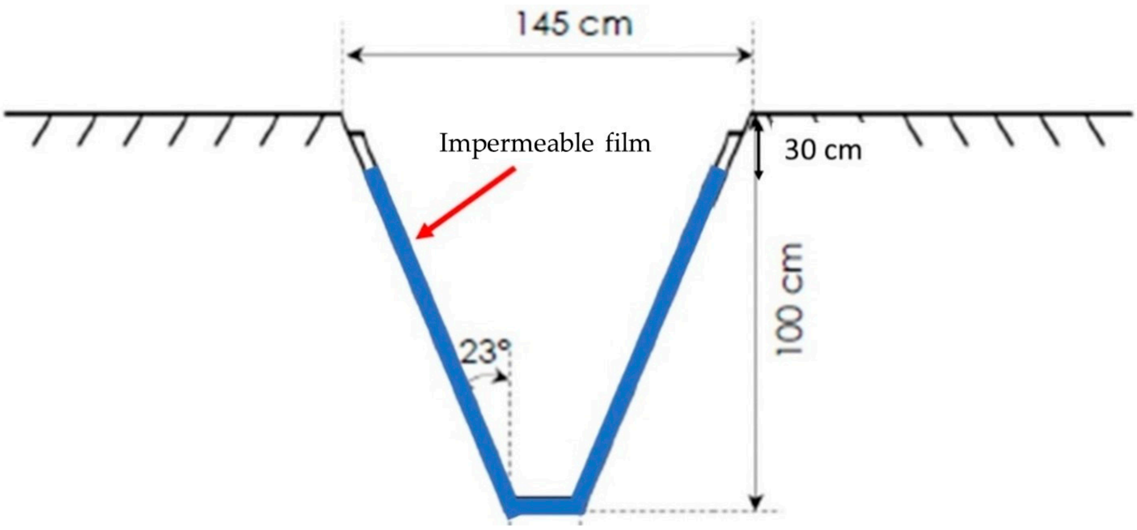

Figure 3. Schematic transversal view of the SWRS and impermeable film positioning.

Table 3. Physical parameters of the soil.

Parameter	Value	Methodology
Skeleton	Trace	DM 13/09/99 G.U. n° 248 del 21/10/99 Method II.1
Sand (%)	64	DM 13/09/99 G.U. n° 248 del 21/10/99 Method II.6
Loam (%)	22	DM 13/09/99 G.U. n° 248 del 21/10/99 Method II.6
Clay (%)	14	DM 13/09/99 G.U. n° 248 del 21/10/99 Method II.6
Texture	sandy loam soil	DM 13/09/99 G.U. n° 248 del 21/10/99 Method II.6
Porosity * (%)	11.6	MUAFS99 Met IV.1
Moisture (%)	17.29	Gravimetric
Bulk density (g cm^{-3})	1.282	ISO 11272:2017

* Porosity includes micro- and macro-porosity. The methodology applied is in compliance with the regulations issued by "Società Italiana della Scienza del Suolo" and validated with the Italian law n. 79 of 11 May 1992. Amended by D.M. 13/09/99 n. 185 with further modifications.

The residual biomass was estimated in 3.8 Mg FM ha^{-1} of annual ryegrass (*Lolium multi-florum* L.) at 61.30% of residual moisture. In the field, two SWRSs 120 m long and 10 m spaced were formed. The ditch was initiated using a 42 kW excavator consisting of digging a 1 m^3 hole in the ground to permit the prototype properly loaded the soils from the beginning of the operation. Then, approximately 1 m in length of the removable impermeable film was manually unrolled and laid across the hole. Afterwards, the machinery was started. Technical feasibility, time and cost of impermeable foil removal was also assessed and the same 42 kW excavator was used as shown in Figure 4.

3.3. Work Productivity and Cost Evaluation

Working times were evaluated according to the methodology proposed by Reith et al. (2017) [39] on 13 sample plots preventively selected measuring between 150 m^2 and 500 m^2. In detail, the working times were divided into: effective working time, maneuver time, avoidable delay time, unavoidable delay time and accessory time (for instance, the time needed to replace the roll). The elaboration of working time allowed for the identification of the theoretical field capacity (TFC, ha h^{-1}) of the effective field capacity (EFC, ha h^{-1}), and of the field efficiency (FE, %, consisting of the ratio between EFC and TFC), as reported in previous similar studies of working time evaluation [40–42]. These parameters were calculated for single operations and throughout the working system. Results were also provided for cost estimation. The contractor was interviewed for purchase cost and operating cost of both the tractor and excavator. Purchase cost of SWRS machinery was considered similar to a brand-new ditch excavator. Standard values for cost calculation were retrieved from the methodology proposed by CRPA (Research Centre on Animal Production) [43]. The price of the machinery was discounted to 2019 by applying a 3% lending rate [44]. Fuel consumption was measured using a graduated cylinder; before starting the plot, the tank of the tractor was refilled, and volume of the fuel recorded for fuel consumption estimation. Lubricant consumption was estimated according to the ASAE standard D497.4 [45]. The details of the economic assessment are given in Table 4.

Figure 4. Views of (**a**) the field before building the SWRS, (**b**) removal of the SWRS using the excavator, and (**c**) SWRS machinery at work.

Table 4. Financial, fixed and variable costs evaluated.

			128 kW Tractor	SWRS Prototype	42 kW Excavator
Financial costs	Investment	€	128,830	40,000	119,000
	Service life	year	10	10	10
	Service life	h	14,000	4000	14,000
	Resale	%	59.82	29.50	32.59
	Resale	€	77,071.90	11,800.45	38,786.40
	Depreciation	€	51,758.10	28,199.55	80,213.60
	Annual usage	h year^{-1}	400	400	400
	Interest rate	%	3	3	3
Fixed costs	Ownership costs	€ year^{-1}	5175.81	2819.95	8021.36
	Interests	€ year^{-1}	3088.52847	777.01	2366.80
	Machine shelter	m^2	12.78	6.48	14.384
	Value of the shelter	€ m^{-2}	100	100	100
	Value of the shelter	€ year^{-1}	25.56	13.0	28.8
	Insurance costs	€ year^{-1}	322.08	100	297.5
Variable costs	Repair factor	%	80	60	80
	Repairs and maintenance	€ h^{-1}	2.10	6.00	1.94
	Fuel cost	€ lt^{-1}	0.57		0.57
	Fuel consumption	lt h^{-1}	20.99		6.00
	Fuel consumption	€ h^{-1}	11.96		3.42
	Lubricant cost	€ lt^{-1}	3.03		3.03
	Lubricant consumption	lt h^{-1}	0.29		0.24
	Lubricant consumption	€ h^{-1}	0.88		0.73
	Manpower costs	€ h^{-1}	11.5		11.5
	Cost of SWRS film	€ m^{-2}		3.00	

4. Conclusions

In order to combat desertification and improve agriculture in arid and semiarid areas in North Africa and South Europe, SWRSs have been reported as effective tool for decades. However, the lack of mechanization has prevented the possibility of further investigation of this technology in large experimental fields and the effectiveness of extensive application has not been proven.

Therefore, in the present study, a prototype for creating SWRSs has been presented along with the performance and cost estimated during ad hoc tests. The machinery accomplished the task brilliantly, though attention should be given to potential residual biomass on the ground which can prevent the machinery from driving the soil backwards, thus creating clogs in the conveyers. Furthermore, due to the lack of a specific plastic film to create SWRSs, the purchase cost of the plastic film remarkably increased the total cost of the operation, suggesting further studies are needed to develop cheaper and more environmentally friendly impermeable film.

Author Contributions: Conceptualization, W.S., F.L. and L.P.; methodology, W.S. and F.L.; writing—original draft preparation, W.S., F.L. and N.P.; writing—review and editing, W.S., F.L. and L.P.; supervision, L.P.; funding acquisition, L.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by ERANETMED 2017 "EURO-MEDITERRANEAN-Cooperation through ERANET joint activities and beyond"—Joint Transnational Call 2017—Fostering sustainable water management for the economic growth and sustainability of the Mediterranean region". MediOpuntia Project. D. D. n. 230—12 February 2019 and published in GU. 12 April 2019 n. 87 and the APC was funded by MediOpuntia Project. Grant agreement No. 1911.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Sandu Lazar, Francesco Cescon and Zaira Cescon for the support in field surveys; Roberto Vendrame for having made available the experimental field, and Claudio Gottardo and Nicola Gottardo for the technical design and development of the prototype.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Miraglia, M.; Marvin, H.J.P.; Kleter, G.A.; Battilani, P.; Brera, C.; Coni, E.; Cubadda, F.; Croci, L.; De Santis, B.; Dekkers, S.; et al. Climate change and food safety: An emerging issue with special focus on Europe. *Food Chem. Toxicol.* **2009**, *47*, 1009–1021. [CrossRef] [PubMed]
2. Flavelle, C. Climate Change Could Cut World Economy by $23 Trillion in 2050, Insurance Giant Warns. *New York Times*, 22 April 2021.
3. Giorgi, F.; Lionello, P. Climate change projections for the Mediterranean region. *Glob. Planet. Change* **2008**, *63*, 90–104. [CrossRef]
4. Diffenbaugh, N.S.; Giorgi, F. Climate change hotspots in the CMIP5 global climate model ensemble. *Clim. Change* **2012**, *114*, 813–822. [CrossRef] [PubMed]
5. Ouatiki, H.; Boudhar, A.; Ouhinou, A.; Arioua, A.; Hssaisoune, M.; Bouamri, H.; Benabdelouahab, T. Trend analysis of rainfall and drought over the Oum Er-Rbia River Basin in Morocco during 1970–2010. *Arab. J. Geosci.* **2019**, *12*, 128. [CrossRef]
6. Zarei, A.R.; Shabani, A.; Mahmoudi, M.R. Comparison of the climate indices based on the relationship between yield loss of rain-fed winter wheat and changes of climate indices using GEE model. *Sci. Total Environ.* **2019**, *661*, 711–722. [CrossRef] [PubMed]
7. Goubanova, K.; Li, L. Extremes in temperature and precipitation around the Mediterranean basin in an ensemble of future climate scenario simulations. *Glob. Planet. Change* **2007**, *57*, 27–42. [CrossRef]
8. Yao, Y.; Liu, J.; Wang, Z.; Wei, X.; Zhu, H.; Fu, W.; Shao, M. Responses of soil aggregate stability, erodibility and nutrient enrichment to simulated extreme heavy rainfall. *Sci. Total Environ.* **2019**, *709*, 136150. [CrossRef]
9. Pari, L.; Suardi, A.; Stefanoni, W.; Latterini, F.; Palmieri, N. Economic and environmental assessment of two different rain water harvesting systems for agriculture. *Sustainability* **2021**, *13*, 3871. [CrossRef]

10. Mango, N.; Makate, C.; Tamene, L.; Mponela, P.; Ndengu, G. Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa. *Land* **2018**, *7*, 49. [CrossRef]
11. Yang, L.; Yang, Y.; Chen, Z.; Guo, C.; Li, S. Influence of super absorbent polymer on soil water retention, seed germination and plant survivals for rocky slopes eco-engineering. *Ecol. Eng.* **2014**, *62*, 27–32. [CrossRef]
12. Bruun, E.W.; Petersen, C.T.; Hansen, E.; Holm, J.K.; Hauggaard-Nielsen, H. Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. *Soil Use Manag.* **2014**, *30*, 109–118. [CrossRef]
13. Obst, C. Non-wetting soils: Management problems and solutions at "Pineview", Mundulla. In Proceedings of the 2nd National Water Repellency Workshop, Perth, Australia, 1–5 August 1994; Carter, D.J., Howes, K.M.W., Eds.; pp. 137–139.
14. Ismail, S.M.; Ozawa, K. Improvement of crop yield, soil moisture distribution and water use efficiency in sandy soils by clay application. *Appl. Clay Sci.* **2007**, *37*, 81–89. [CrossRef]
15. Taylor, K.C.; Halfacre, R.G. The effect of hydrophilic polymer on media water retention and nutrient availability to Ligustrum lucidum. *HortScience* **1986**, *21*, 1159–1161.
16. Silberbush, M.; Adar, E.; De Malach, Y. Use of an hydrophilic polymer to improve water storage and availability to crops grown in sand dunes I. Corn irrigated by trickling. *Agric. Water Manag.* **1993**, *23*, 303–313. [CrossRef]
17. Welsh, D.A.F.; Kreuter, U.P.; Byles, J.D. Enhancing subsurface drip irrigation through vector low. In Proceedings of the 5th International Microirrigation Congress, Orlando, FL, USA, 2–6 April 1995; pp. 688–693.
18. Brunstrum, L.C.; Ott, L.E.; Speer, T.L. Increasing crop yields with underground asphalt moisture barriers. In Proceedings of the 7th World Petroleum Congress, Mexico City, MX, USA, 2 April 1967.
19. Hansen, C.M.; Erickson, A.E. Use of asphalt to increase water-holding capacity of droughty sand soils. *Ind. Eng. Chem. Prod. Res. Dev.* **1969**, *8*, 256–259. [CrossRef]
20. Rao, K.V.P.; Varade, S.B.; Pande, H.K. Influence of subsurface barrier on growth, yield, nutrient uptake, and water requirement of rice (*Oryza sativa*) 1. *Agron. J.* **1972**, *64*, 578–580. [CrossRef]
21. Elawady, M.N.; Abd El-Salam, M.F.; Elnawawy, M.M.; El-Farrah, M.A. Surface and subsurface irrigation effects on Spinach and sorghum. In Proceedings of the 11th Annual Conference of Misr Society of Agricultural Engineers, Kafr El-Sheikh, Egypt, 15–16 October 2003; Volume 15, p. 16.
22. Awady, M.N.; Wassif, M.A.; Abd El-Salam, M.F.; El-Farrah, M.A. Moisture distribution from subsurface dripping using saline water in sandy soil. In Proceedings of the 15th Annual Conference of the Misr Society of Agricultural Engineering, Shubra El-Kheima, Egypt, 12–13 March 2008; Volume 12, p. 13.
23. Aoda, M.I.A.; Ati, A.S.A.; AL-Rawi, S.S.A.-R. Subsurface Water Retention Technology (SWRT) for Water Saving and Growing Tomato in Iraqi Sandy Soils. *J. Zankoy Sulaimani Part A* **2018**, *7*, 127–134. [CrossRef]
24. Hommadi, A.H. Subsurface water retention technology improves water use efficiency and water productivity for hot pepper. *J. Kerbala Univ.* **2018**, *14*, 125–135.
25. Kavdir, Y.; Zhang, W.; Basso, B.; Smucker, A.J.M. Development of a new long-term drought resilient soil water retention technology. *J. Soil Water Conserv.* **2014**, *69*, 154A–160A. [CrossRef]
26. Smucker, A.J.M. Subsurface Barrier Retention System and Methods Related Thereto. U.S. Patent 9,615,518 B2, 11 April 2017.
27. Miller, S.A.; Smucker, A.J.M. A new soil water retention technology for irrigated highly permeable soils. In Proceedings of the Joint ASABE/IA Irrigation Symposium 2015: Emerging Technologies for Sustainable Irrigation, Long Beach, CA, USA, 10–12 November 2015; pp. 726–730.
28. Presentation of MediOpuntia Project. Available online: http://www.panacea-h2020.eu/wp-content/uploads/2021/01/MediOpuntia-project_cactus-plantation.pdf (accessed on 20 May 2021).
29. Rigamonti, L.; Borghi, G.; Martignon, G.; Grosso, M. Life cycle costing of energy recovery from solid recovered fuel produced in MBT plants in Italy. *Waste Manag.* **2019**, *99*, 154–162. [CrossRef] [PubMed]
30. Kapanen, A.; Schettini, E.; Vox, G.; Itävaara, M. Performance and environmental impact of biodegradable films in agriculture: A field study on protected cultivation. *J. Polym. Environ.* **2008**, *16*, 109–122. [CrossRef]
31. Briassoulis, D. Analysis of the mechanical and degradation performances of optimised agricultural biodegradable films. *Polym. Degrad. Stab.* **2007**, *92*, 1115–1132. [CrossRef]
32. Briassoulis, D. An overview on the mechanical behaviour of biodegradable agricultural films. *J. Polym. Environ.* **2004**, *12*, 65–81. [CrossRef]
33. Vallerani Delfino System. Available online: http://www.vallerani.com/wp/?page_id=1675 (accessed on 20 May 2021).
34. Venanzi, R.; Picchio, R.; Grigolato, S.; Latterini, F. Soil and forest regeneration after different extraction methods in coppice forests. *For. Ecol. Manag.* **2019**, *454*, 117666. [CrossRef]
35. Venanzi, R.; Picchio, R.; Spinelli, R.; Grigolato, S. Soil disturbance and recovery after coppicing a Mediterranean Oak stand: The effects of silviculture and technology. *Sustainability* **2020**, *12*, 4074. [CrossRef]
36. Venanzi, R.; Picchio, R.; Grigolato, S.; Spinelli, R. Soil disturbance induced by silvicultural treatment in chestnut (Castanea sativa Mill.) coppice and post-disturbance recovery. *Forests* **2020**, *11*, 1053. [CrossRef]
37. Picchio, R.; Latterini, F.; Mederski, P.S.; Tocci, D.; Venanzi, R.; Stefanoni, W.; Pari, L. Applications of GIS-based software to improve the sustainability of a forwarding operation in central Italy. *Sustainability* **2020**, *12*, 5716. [CrossRef]
38. Picchio, R.; Venanzi, R.; Tavankar, F.; Luchenti, I.; Iranparast Bodaghi, A.; Latterini, F.; Nikooy, M.; Di Marzio, N.; Naghdi, R. Changes in soil parameters of forests after windstorms and timber extraction. *Eur. J. For. Res.* **2019**, *138*, 875–888. [CrossRef]

39. Reith, S.; Frisch, J.; Winkler, B. Revision of the working time classification to optimize work processes in modern agriculture. *Chem. Eng. Trans.* **2017**, *58*, 121–126. [CrossRef]
40. Latterini, F.; Stefanoni, W.; Sebastiano, S.; Baldi, G.M.; Pari, L. Evaluating the suitability of a combine harvester equipped with the sunflower header to harvest cardoon seeds: A case study in central Italy. *Agronomy* **2020**, *10*, 1981. [CrossRef]
41. Stefanoni, W.; Latterini, F.; Ruiz, J.P.; Bergonzoli, S.; Palmieri, N.; Pari, L. Assessing the camelina (Camelina sativa (L.) Crantz) seed harvesting using a combine harvester: A case-study on the assessment of work performance and seed loss. *Sustainability* **2020**, *13*, 195. [CrossRef]
42. Suardi, A.; Stefanoni, W.; Bergonzoli, S.; Latterini, F.; Jonsson, N.; Pari, L. Comparison between two strategies for the collection of wheat residue after mechanical harvesting: Performance and cost analysis. *Sustainability* **2020**, *12*, 4936. [CrossRef]
43. Assirelli, A.; Pignedoli, S. Costo di esercizio delle macchine agricole. *Cent. Ric. Prod. Anim.* **2005**, *5*, 1–10.
44. Banca d'Italia Banca d'Italia Lending Rate. American Society of Agricultural Engineers. Available online: https://www.bancaditalia.it/ (accessed on 11 July 2020).
45. American Society of Agricultural Engineers ASAE standard D497.4. In *Agriculture Machinery Management Data*; ASAE: St. Joseph, MI, USA, 2003; pp. 373–380.