INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 7, Special Issue 1, 2016: 301-310 www.ijcs.uaic.ro

THERMAL WEED CONTROL ON HORIZONTAL AND VERTICAL SURFACES IN ARCHAEOLOGICAL SITES AS AN ALTERNATIVE TO HERBICIDES

Christian FRASCONI[1], Marco FONTANELLI[1], Luisa MARTELLONI[2], Michel PIRCHIO[2], Michele RAFFAELLI[1], Andrea PERUZZI[1*]

[1] *Dipartimento di Scienze Agrarie, Alimentari e Agro-ambientali (DiSAAAa), Università di Pisa, via del Borghetto 80, 56124 Pisa, Italy*
[2] *Centro di Ricerche Agro-Ambientali "E. Avanzi", Università di Pisa, via Vecchia di Marina 6, 56122 San Piero a Grado (PI), Italy*

Abstract

Flaming could be an alternative weed management at archaeological sites because it controls a wide range of weed species without inducting future resistance. The aim of this study was to test the weed control efficiency of flaming on various horizontal and vertical surfaces of archaeological buildings. Working times and costs were recorded. Flaming performances were compared to the normal herbicide treatments and mowing. Results showed that repeated flaming reduced weed cover by 100%. Working times and total costs decreased by increasing the number of applications over time. This is because the repeated flaming applications deplete the weed root stocks, thus keeping the mortar between the stones or bricks and the building materials free from weeds and their seeds for a long time. The method involved zero toxicity for humans and animals, thus providing safe accessibility to the archaeological buildings and visitor pathways. The application of flaming did not cause any damage or change of colour to the treated materials, although specific, multidisciplinary studies on this subject will have to be conducted in the next future, in order to exclude any negative effect on the remains. The results of these studies showed that flaming is a viable alternative for controlling weeds growing on archaeological surfaces.

Keywords: *Archaeological remains; Flaming; Historical buildings; Non-chemical; Monuments; Weed control.*

Introduction

Archaeological sites in Italy are of great artistic and historical value and play an important role in the service industry [1]. Many sites have become infested by weeds, which need to be managed because they can compromise the conservation of the walls of historical buildings, stone monuments, and statues. Weeds produce acid metabolites and the roots penetrate the archaeological materials or develop in spaces between the stones leading to chemical and physical damage. Leaves also tend to cover and hide the artefacts so that they cannot be fully appreciated. The damage to buildings is also not limited to that caused by weeds, but also includes the consequences of falling stones [2].

* Corresponding author: andreaperuzzi@unipi.it

Not all plants cause the same type or amount of damage. Herbaceous plants are certainly less destructive than trees and shrubs. Herbaceous perennials, such as *Cynodon dactilon* L., *Dittrichia viscosa* L. and *Cheiranthus cheiri* L., are more harmful than herbaceous annuals. *Sonchus tenerrimus* L. (herbaceous annual) and *Parietaria diffusa* Mert. et Koch (herbaceous perennials) are hardy pioneer plants that colonize the walls. The most destructive plants of all are those with vegetative reproduction. Stolon and rhizomes allow weeds to increase in size and favour their propagation over large areas, with the obvious detriment to archaeological remains. The damage caused by this type of vegetation is especially destructive to statues [2].

The effects of weed growth can be slowed down by restoration. For ruins, periodic cleaning of plants is required to prevent plant growth between the stones and subsequent crumbling. Weeds can be controlled with herbicides, however various environmental and toxicological aspects need to be verified before they can be used [2]. Ideally, herbicides used in archaeological sites should be of a low toxicity for humans and animals, have low environmental transferability and not impact the archaeological remains. For this kind of application, symplastic herbicides have been used, such us glyphosate and glufosinate [3]. Herbicides are not widely used at archaeological sites because they can chemically corrode monuments, and their oxidative degradation can lead to products with a higher acidity or long-term problems caused by the dispersion of soluble salts in the ground [4]. In most archaeological sites in Greece, mowing is used for weed control, which has been proved to be insufficient and expensive and can cause mechanical damage to the monuments [4].

M. Papafotiou et al [5] used soil solarization for herbaceous weed control in Roman room's remains that were completely covered with vegetation. They found that the weed population decreased by 80% the following winter and by 55% the next spring. Manual weeding is useful to control weeds but it is very costly and by extirpating herbaceous plants, large volumes of substrate are removed, thus compromising the stability and conservation of the archaeological remains [6].

Novel methods of managing weed growth at archaeological sites are needed. Flaming may be viable because it controls a wide range of weed species without inducing flame resistance [7]. Flaming is the most commonly applied non-chemical weed control method on hard surfaces in urban areas [8-9], thus its application is also possible for weed management on archaeological remains. The mode of action is based on the effect of high temperatures that denaturize plant proteins. This then results in the loss of cell function, causes intracellular water expansion, ruptures cell membranes, and finally desiccates the weeds, normally within two to three days [10]. The main advantages of flaming on hard surfaces include the lack of chemical residues in treated materials, soil and water, the lack of herbicide carryover, the very wide spectrum of weeds controlled, and the lack of resistance [9].

The aim of this study was to test the weed control efficiency of flaming on various horizontal and vertical surfaces of archaeological buildings. Working times and costs were recorded. Flaming performances were compared to the usual methods used in the zone, i.e. herbicides and mowing. The effects on the different treated materials were also taken into account.

Materials and methods

Experimental set up, design and treatments

The study was conducted on: (1) two selected parts (*sites 1* and *2*) of the external perimeter of the Basilica of San Piero (San Piero a Grado, Pisa, Italy, +43.679°N +10.346°E) characterized by a combination of limestone and quartzite stones, and marble of "Monte Pisano"; (2) the steps of the SS. Giovanni Battista and Rocco Church of Asciano (San Giuliano Terme, Pisa, Italy, +43.750°N +10.467°E) characterized by marble of "Monte Pisano"; and (3) the wall of the Camaldolese Abbey of Volterra (Volterra, Pisa, +43.415°N +10.850°E) characterized by a combination of travertine, limestone stones, and bricks. All the treated materials have a local origin and were commonly used in Tuscany to build churches and abbeys in the Middle Age.

The experimental design was a randomized complete block with four replications in all three monuments. Flaming was applied with an open flame backpack flamer or a trolley flaming machine, liquefied petroleum gas (LPG) fed equipment fully described by M. Raffaelli et al [9]. The flame acted directly on the weed leaves. A complete description of the mode of action of the burners can be found in M. Raffaelli et al [10]. The trolley flaming machine was used at the Basilica of San Piero (Fig. 1). The backpack flamer was used at the SS. Giovanni Battista and Rocco Church of Asciano and at the Camaldolese Abbey of Volterra (Figs. 2 and 3).

Fig. 1. Flaming on the external perimeter of the Basilica of San Piero.

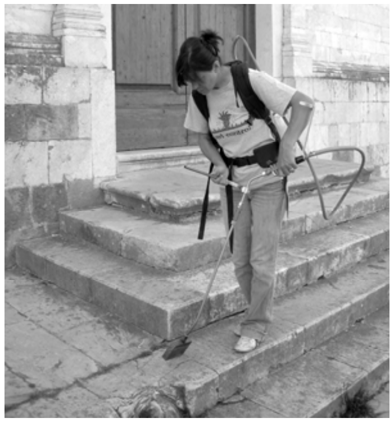

Fig. 2. Flaming on the steps of the SS. Giovanni Battista and Rocco Church of Asciano by using a backpack flamer.

Fig. 3. Flaming on the wall of the Camaldolese Abbey of Volterra by using a backpack flamer.

At the Basilica of San Piero, weeds were flamed six times×year^{-1} (F6 treatment) each at a distance of two months, or 12 times×year^{-1} (F12 treatment) each at a distance of one month for a total time of 18 months (from May 2006 to October 2007). Flaming effectiveness was compared with one application of 1.1g×a.i.×m^{-2} per year of glyphosate, and with the untreated control. One treatment per year was the maximum number of chemical herbicide applications permitted by the local authorities [11]. The herbicide was distributed with a backpack sprayer equipped with a manual lance and a hollow cone nozzle. The chemical management of weeds included the mowing of dried weeds, blowing and collecting the cut weeds, and the transport to the dump. These operations were included for the calculation of working times and total costs. At the SS. Giovanni Battista and Rocco Church of Asciano, flaming was applied 12 times×year^{-1} (F12 treatment) each at a distance of one month for a total time of 24 months (from May 2009 to April 2011). Flaming effectiveness was compared with mowing applied twice per year with a standard string trimmer, and with the untreated control. The calculation of the working times and the total costs included blowing, collecting the cut weeds, and transporting the material to the dump after mowing. At the Camaldolese Abbey of Volterra, flaming was applied five times in a period of 30 days. Flame weeding effectiveness was compared with the untreated control.

Data collection

At the Basilica of San Piero, weed cover data were collected 19 times at a distance of one month each in all the experimental plots before treatment (irrespectively of whether or not the treatment recurred). At the SS. Giovanni Battista and Rocco Church of Asciano weed cover data were collected seven times at a distance of four months each in all the experimental plots before treatment (irrespectively of whether or not the treatment recurred). At the Camaldolese Abbey of Volterra weed cover data were collected three times at a distance of 15 days each in all the experimental plots before treatment. Weed cover samples were collected by taking digital images from a 750cm^2 (25cm × 30cm) area, in two randomly selected sampling points within each plot. Digital images were analysed using IMAGING Crop Response Analyser [12]. The digital image analysis procedure is described in J. Rasmussen et al [13]. The working times for each treatment were measured with a digital chronometer. The temperature of the stones surface was measured before and after each flaming application using a “k” thermocouple. The damage and the change of colour of the different flamed stones were evaluated by visual rating. The total costs were calculated by summing fixed and variable costs.

Statistical analysis

Weed cover data are non-binomial proportions and were logit transformed to normalize the distribution of data [14]. R statistical software [15] with the extension package *lmerTest* (Tests for random and fixed effects for linear mixed effect models) [16] was used to analyse the linear mixed model of weed cover logit transformed. Weed cover logit transformed was analysed with the treatment used and the time of weed cover observations (and their interaction) as fixed effects, and replications as random effects. Means, standard errors and statistical differences between means (confidence interval overlap test) were estimated with the functions *Lsmeans* and *difflsmeans* of the extension package *LmerTest* [16] of R [15]. Back-transformed values were estimated with the function *update* of the extension package *Lsmeans* (Least-squares means) [17] of R [15]. The extension package *Sciplot* (Scientific graphing functions for factorial designs) [18] of R [15] was used to plot the weed cover response in a two-way interaction plots.

Results and Discussions

In general the weeding effectiveness of flaming was observed in all sites and on all the weeds growing in all the treated stone materials, confirming that the thermal shock caused by open flame on the plants is completely independent from the substrate typology. For all the stones present in the sites the temperature of the surface measured 1.0s after flaming was only 1.0°C higher compared with the temperature measured before the application. No visual alteration in the colour or damage of the stone surfaces was observed during the experimental periods.

External perimeter of the Basilica of San Piero

Weed composition in both *sites 1* and *2* was constituted by *Urtica dioica* L. and *Parietaria diffusa* Mert. et Koch. When the weed cover observed during the treatment was the dependent variable, analysis of variance showed that the treatment used, the observation time expressed as months after the start of the treatment application and their interaction were significant ($p = 2.2\times10^{-16}$, 2.2×10^{-15} and 1.7×10^{-13}, respectively in *site 1*, and $p = 2.2\times10^{-16}$, 2.2×10^{-15} and 1.7×10^{-13}, respectively in *sites 1* and *2*).

Figures 4 and 5 show the two-way interaction plots with means and 95% confidence intervals for weed cover logit transformed between different treatments and 19 observation times expressed as months after the start of the application.

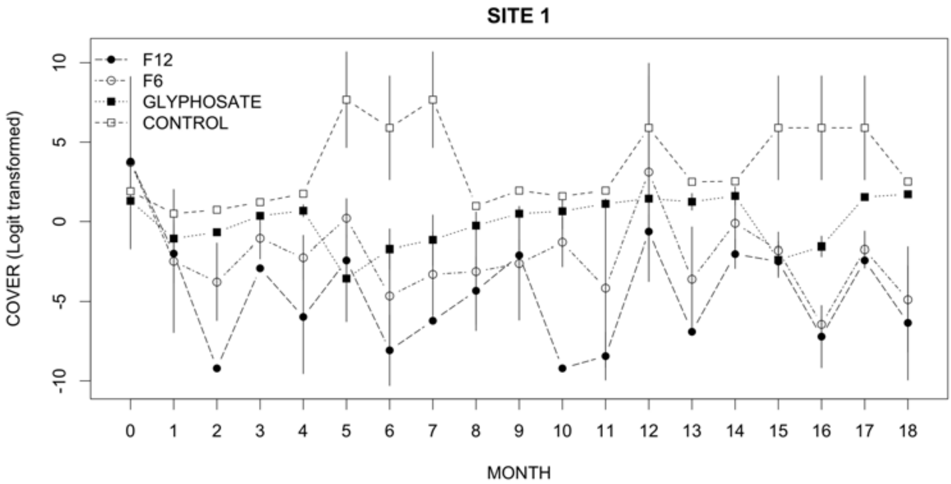

Fig. 4. Two-way interaction plot with means and 95% confidence intervals of weed cover, logit transformed, between different weed control treatments and 18 observation times expressed as months after the start of the treatments application. F12: flaming applied 12 times year^{-1}, in all months; F6: flaming applied six times year^{-1} in months 1, 3, 5, 7, 9, 11, 13, 15 and 17; Glyphosate was applied once year^{-1} in months 4 and 14. Weed cover data were collected before treatment applications in site 1.

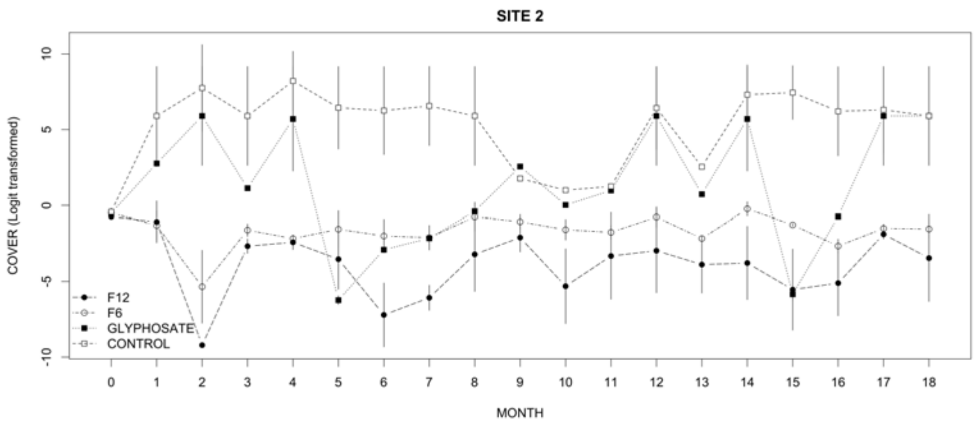

Fig. 5. Two-way interaction plot with means and 95% confidence intervals of weed cover, logit transformed, between different weed control treatments and 18 observation times expressed as months after the start of the treatments application. F12: flaming applied 12 times year^{-1}, in all months; F6: flaming applied six times year^{-1} in months 1, 3, 5, 7, 9, 11, 13, 15 and 17; Glyphosate was applied once year^{-1} in months 4 and 14. Weed cover data were collected before treatment applications in site 2.

The effect of the different weed control treatments varied according to the observation time, but generally flaming was more effective in controlling weeds than a single application per year of glyphosate. At the end of the study (month 18), both F6 and F12 treatments resulted in a significantly lower weed cover compared with the glyphosate application. The final weed cover when flame weeding was applied was 0-1% in *site 1*, and 3-18% in *site 2* (Tables 1 and 2).

Table 1. Estimated means logit transformed and back-transformed values for weed cover in site 1 as influenced by different weed control treatments at the end of the study (month 18), and confidence interval (CI) overlap test at the same date.

Treatment[a]	Mean (±SE)[b]	Back-transformed mean[c]	Comparisons	CI overlap test Estimate	Lower CI	Upper CI
F12	-6.3 (1.13)	0.00	F12 - F6	-1.5	-4.5	1.6
F6	-4.9 (1.13)	0.01	F12 - GLYPHOSATE	-8.1	-11.1	-5.0
GLYPHOSATE	1.7 (1.13)	0.82	F12 - CONTROL	-8.9	-11.9	-5.8
CONTROL	2.5 (1.13)	0.99	F6 - GLYPHOSATE	-6.6	-9.7	-3.5
			F12 - CONTROL	-7.4	-10.5	-4.3
			CONTROL - GLYPHOSATE	-0.8	-3.9	2.8

[a] F12: flaming applied 12 times×year^{-1}, in all months; F6: flaming applied six times year^{-1} in months 1, 3, 5, 7, 9, 11, 13, 15, 17 and 22; glyphosate was applied one time×year^{-1} in months 4 and 14.
[b] Means and standard errors (SEs) were estimated with the function *Lsmeans* of the extension package *LmerTest* (Tests for random and fixed effects for linear mixed effect models) [16, 17] of R [15].
[c]Back-transformed values were estimated with the update function of the extension package *Lsmeans* (Least-squares means) [17] of R [15].

Table 2. Estimated means logit transformed and back-transformed values for weed cover in site 2 as influenced by different weed control treatments at the end of the study (month 18), and Confidence Interval (CI) overlap test at the same date.

Treatment[a]	Mean (±SE)[b]	Back-transformed mean[c]	Comparisons	CI overlap test Estimate	Lower CI	Upper CI
F12	-3.5 (0.94)	0.03	F12 - F6	-1.9	-4.0	0.2
F6	-1.5 (0.94)	0.18	F12 - GLYPHOSATE	-9.4	-11.5	-7.2
GLYPHOSATE	5.9 (0.94)	1.00	F12 - CONTROL	-9.4	-11.5	-7.2
CONTROL	5.9 (0.94)	1.00	F6 - GLYPHOSATE	-7.4	-9.6	-5.3
			F12 - CONTROL	-7.4	-9.6	-5.3
			CONTROL - GLYPHOSATE	0.0	-2.1	2.1

[a]F12: flaming applied 12 times×year^{-1}, in all months; F6: flaming applied six times year^{-1} in months 1, 3, 5, 7, 9, 11, 13, 15, 17 and 22; glyphosate was applied one time×year^{-1} in months 4 and 14.
[b]Means and standard errors (SEs) were estimated with the function *Lsmeans* of the extension package *LmerTest* (Tests for random and fixed effects for linear mixed effect models) [16, 17] of R [15].
[c]Back-transformed values were estimated with the update function of the extension package *Lsmeans* (Least-squares means) [17] of R [15].

The glyphosate was effective only immediately after its application (Figs. 4 and 5). In site 1, the application of glyphosate at months 4 and 14 significantly reduced weed cover from 0.7 (±1.13) to -3.6 (±1.13) measured at month 5, and from 1.6 (±1.13) to -2.4 (±1.13) measured at month 15 (p-values of the differences: 0.007 and 0.011, respectively). In site 2 the reductions were from 5.7 (±0.94) to -6.2 (±0.94) measured at month 5 and from 5.7 (±0.94) to -5.8 (±0.94) measured at month 15 (p-values of the differences: 0.007 and 0.011, respectively, data were logit transformed). However, these reductions did not persist over time and at month 18, the weed cover was similar to the untreated control, suggesting that only one application of glyphosate per year was not sufficient to control weeds effectively (Tables 1 and 2). To obtain an effective weed control in non-agricultural areas for a long time 4-5-fold higher doses of herbicides than those used in agriculture are often used. In order to increase weed control efficacy, both residual and herbicides applied to leaves, which moves through the symplastic transport, are used. These practices increase the development of weed resistance and the possibility of leaching [6].

The working times (as a mean of both *site 1* and *2*) decreased by increasing the number of flaming applications over time, both for F6 and F12 treatments. When F12 was applied, the working time decreased by 26% (from 64h×1000m^{-2} to 47h×1000m^{-2} per year) from the first to the second year. The decrease was 10% (from 53h×1000m^{-2} to 48h×1000m^{-2} per year) when F6 was applied. This suggests that repeated flaming leads to a gradual depletion in weed root reserves, which consequently cannot regrow after a certain number of applications. It also suggests that weeds from new seeds are quickly controlled because they are at a very early growth stage. Consequently, the total cost of flaming management also decreases by passing from the first to the second year of application (from 870 to 642 Euros/1000m^{-2}, and from 732 to 666 Euros/1000 m^{-2} for F12 and F6, respectively).

The working time for the chemical management of weeds was of 17h×1000m^{-2} per year, for a total cost of 404 Euros/1000 m^{-2}. Repeated flaming prevents the development of large weeds. This thus leaves the very small (often at the cotyledonary stage) desiccated weeds on the monument, without the need for mowing, blowing, collecting, and transporting them to the dump. This thus substantially reduces the total cost of a single flaming application compared with the chemical management, which, moreover, does not guarantee a stable weed control level over time.

Steps of the SS. Giovanni Battista and Rocco Church of Asciano

Weed composition was constituted by *Conyza canadensis* (L.) Cronq., *Trifolium* spp. and *Parietaria diffusa* Mert. et Koch. When the weed cover observed during the treatment application was the dependent variable, analysis of variance showed that the treatment used, the observation time expressed as months after the start of the treatment application and their interaction were significant ($p = 5.5\times10^{-7}$, 2.8×10^{-4}, and p-value = 0.04, respectively).

Figure 6 shows the two-way interaction plots with means and 95% confidence intervals for weed cover logit transformed between different treatments and seven observation times expressed as months after the start of the application.

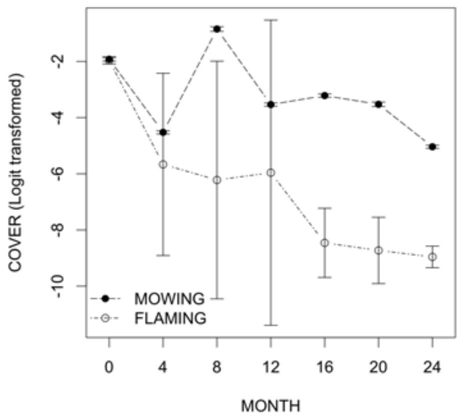

Fig. 6. Two-way interaction plot with means and 95% confidence intervals of weed cover, logit transformed, between different weed control treatments and 6 observation times expressed as months after the start of the treatments application. F12: flaming applied 12 times year^{-1}; mowing was applied twice year^{-1}. Weed cover data were collected before treatment applications.

The effects of both the weed control treatments and mowing varied according to the observation time. In the first year, the weed cover after flaming was similar to that observed after mowing. The second year flaming was more effective in controlling weeds than mowing. However, at the end of the study (month 24), both mowing and flaming treatments resulted in an effective weed control, with levels of weed cover of 1% and 0%, respectively (Table 3). One disadvantage of mowing is still the impossibility of devitalize roots growing in building materials, which can cause new weed regrowth a few months after the mowing. On the other hand, repeated flaming depletes the weed root stocks, thus preserving the mortar between the stones or bricks and keeping the building materials free from weeds and their seeds for a long time.

Table 3. Estimated means logit transformed and back-transformed values for weed cover as influenced by different weed control treatments at the end of the study (month 24), and confidence interval (CI) overlap test at the same date.

Treatment[a]	Mean (±SE) [b]	Back-transformed mean[c]	Comparisons	CI overlap test Estimate	Lower CI	Upper CI
F12	-9.0 (1.07)	0.00				
MOWING	-5.0 (1.07)	0.01	MOWING - F12	3.9	1.17	6.68

[a]F12: flaming applied 12 times×year^{-1}, in all months; mowing was applied twice year^{-1}.
[b]Means and standard errors (SEs) were estimated with the function *Lsmeans* of the extension package *LmerTest* (Tests for random and fixed effects for linear mixed effect models) [16, 17] of R [15].
[c]Back-transformed values were estimated with the update function of the extension package *Lsmeans* (Least-squares means) [17] of R [15].

The working times decreased by increasing the number of flaming applications over time. When flaming was applied, the working times decreased by 36% (from 66h×1000m^{-2} to 42h×1000m^{-2} per year) from the first to the second year. Consequently, the total costs of flame weeding management decreased from the first to the second year of application (from 1140 to 712 Euros/1000m^{-2}). The working time for mowing was of 16h×1000m^{-2} per year, for a total cost of 720 Euros/1000m^{-2}. The repeated applications of flame weeding led to a reduction on the cost of flaming in the second year that was similar compared with mowing.

Wall of the Camaldolese Abbey of Volterra

Weed composition was constituted by *Conyza canadensis* (L.) Cronq., *Trifolium* spp. and *Parietaria diffusa* Mert. et Koch., *Atriplex latifolia* Wahlenb., *Galium aparine* L., and *Artemisia* spp.. When the weed cover observed during the treatment application was the dependent variable, analysis of variance showed that flaming, the observation time expressed as days after the start of the treatment application and their interaction were significant ($p = 1.6\times10^{-7}$, 5.2×10^{-5}, and p-value = 1.8×10^{-5}, respectively).

Figure 7 shows the two-way interaction plots with means and 95% confidence intervals for weed cover logit transformed between different treatments and three observation times expressed as days after the start of the application.

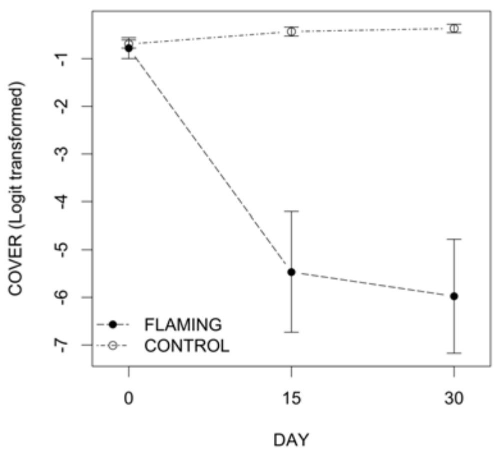

Fig. 7. Two-way interaction plot with means and 95% confidence intervals of weed cover, logit transformed, between different weed control treatments and 3 observation times expressed as days after the start of the treatments application. Flaming was applied 5 times in a period of 30 days. Weed cover data were collected before treatment applications

The effects of flaming increased by increasing the number of applications. At the end of the study (day 30), flaming treatments resulted in an effective weed control, with a level of weed cover of 0%. In the untreated control, the weed cover was 60% higher than the flamed plots (Table 4). This suggests that flaming is also effective when applied on vertical surfaces. The measured working time was 5.5h×$1000m^{-2}$ for a total cost of 70 Euros/$1000m^{-2}$ per single operation.

Table 4. Estimated means logit transformed and back-transformed values for weed cover in site 1 as influenced by flame weeding at the end of the study (day 30), and confidence interval (CI) overlap test at the same date

Treatment[a]	Mean (±SE)[b]	Back-transformed mean[c]	CI overlap test Comparisons	Estimate	Lower CI	Upper CI
FLAMING	-6.0 (0.37)	0.00				
CONTROL	-0.4 (0.37)	0.41	FLAMING - CONTROL	-5.6	-6.69	-4.53

[a]Flaming applied 5 times in a period of 30 days.
[b]Means and standard errors (SEs) were estimated with the function *Lsmeans* of the extension package *LmerTest* (Tests for random and fixed effects for linear mixed effect models) [16, 17] of R [15].
[c]Back-transformed values were estimated with the update function of the extension package *Lsmeans* (Least-squares means) [17] of R [15].

Conclusions

Flaming led to 100% weed control in all three studies, both on horizontal and vertical surfaces. Its repeated application depleted weed root stocks, preserving the mortar between the stones or bricks and keeping the building materials free from weeds and their seeds for a long time. This thus reduces the working times and total costs over time. One application of glyphosate per year is not enough to maintain effective weed control for a long time. Mowing twice per year provides an effective weed control however it fails to devitalize the roots growing in building materials, which leads to new weed regrowth a few months after cutting. Unlike hand weeding, flaming prevents the removal of large volumes of substrate, which compromise the stability, and conservation of the archaeological remains. Flaming involves zero toxicity for humans and animals, providing safe accessibility to the archaeological buildings and visitor pathways. The results of these studies showed that flaming is a potentially viable method to control weeds growing in archaeological sites. However, further studies are needed in order to evaluate if flaming can cause changes of colour or any other damage to different remain materials and at what LPG dose such problems could eventually occur. Some specific multidisciplinary experiments on this subject are planned and will be conducted in the next future.

Acknowledgements

These studies were funded by the Fondazione Cassa di Risparmio di Pisa, Italy, the Fondazione Cassa di Risparmio di Volterra, Pisa, Italy, and the Municipality of San Giuliano Terme, Pisa, Italy. The authors would also like to acknowledge Calogero Plaia from the Department of Agriculture, Food and Environment (DAFE) of the University of Pisa and Roberta Del Sarto from the CiRAA "E. Avanzi" (University of Pisa) for their technical support.

References

[1] L. Celesti-Grapow, C. Blasi, *The role of alien and native weeds in the deterioration of archaeological remains in Italy*, **Weed Technology, 18**, 2004, pp. 1508-1513.
[2] M. Lisci, M. Monte, E. Pacini, *Lichens and higher plants on stone: a review*, **International Biodeterioration and Biodegradation, 51**, 2003, pp. 1-17.

[3] P. Rossi Pisa, G. Bitelli, M. Bitelli, M. Speranza, L. Ferroni, P. Catizone, M. Vignudelli, *Environmental assessment of an archaeological site for the development of an archaeological park*, **Case Studies on Research Planning, Characterisation, Conservation and Management of Archaeological Sites**, Archaeopress, Oxford, 2008, pp. 273-285.

[4] K. Zahos, *Spontaneous flora in archaeological sites. The case of Greece*, **Proceedings of the seminar "Native flora in Archaeological sites"**, 22th-23th May 1998, Athens, Greece.

[5] M. Papafotiou, E. Kanellou, G. Economou, *Alternative practices for vegetation management in archaeological sites – the case of Eleusis*, **Acta Horticulturae, 881**, 2010, pp. 879-883.

[6] R. Miravalle, S. Otto, G. Zanin, *Il diserbo delle aree non agricole*, **Malerbologia**, Pàtron Editore, Bologna, 2001, pp. 855-877. [In Italian]

[7] J. Ascard, *Effects of flame weeding on weed species at different developmental stages*, **Weed Research, 35**, 1995, pp. 397-411.

[8] A.M. Rask, P. Kristoffersen, *A review of non-chemical weed control on hard surfaces*, **Weed Research, 47**, 2007, pp. 370-380.

[9] M. Raffaelli, L. Martelloni, C. Frasconi, M. Fontanelli, A. Peruzzi, *Development of machines for flaming weed control on hard surfaces*, **Applied Engineering in Agriculture, 29**, 2013, pp. 663-673.

[10] M. Raffaelli, C. Frasconi, M. Fontanelli, L. Martelloni, A. Peruzzi, *LPG burners for weed control*, **Applied Engineering in Agriculture, 31**, 2015, pp. 717-731.

[11] M. Mojžiš, *Energetic requirements of flame weed control*, **Research in Agricultural Engineering, 48**, 2002, pp. 94-97.

[12] * * *, **IMAGING Crop Response Analyser**, Ellen, Christian and Anders Petersens Foundation, http://imaging-crops.dk. [accessed on 12 January 2016].

[13] J. Rasmussen, M. Nørremark, B.M. Bibby, *Assessment of leaf cover and crop soil cover in weed harrowing research using digital images*, **Weed Research, 47**, 2007, pp. 299-310.

[14] D.I. Warton, F.K.C. Hui, *The arcsine is asinine: the analysis of proportions in ecology*, **Ecology, 92**, 2011, pp. 3-10.

[15] R Core Team, *R: A language and environment for statistical computing*, **R Foundation for Statistical Computing**, Vienna, Austria, 2013.

[16] A. Kuznetsova, P.B. Brockhoff, R.H.B. Christensen, **CRAN - Package LmerTest**, http://CRAN.R-project.org/package=lmerTest [accessed on 12 January 2016].

[17] L. Russell, **CRAN - Package Lsmeans**, http://CRAN.R-project.org/package=lsmeans. [accessed on 12 January 2016].

[18] M. Morales, **CRAN - Package Sciplot**, http://CRAN.R-project.org/package=sciplot. [accessed on 12 January 2016].

Received: January, 15, 2016
Accepted: February, 25, 2016