Short-Term Effects of Pile Burn on N Dynamic and N Loss in Mediterranean Croatia

Domina Delač 1, Paulo Pereira 2, Igor Bogunović 1,* and Ivica Kisić 1

1 Faculty of Agriculture, University of Zagreb, 10000 Zagreb, Croatia; ddelac@agr.hr (D.D.); ikisic@agr.hr (I.K.)
2 Environmental Management Laboratory, Mykolas Romeris University, LT-08303 Vilnius, Lithuania; pereiraub@gmail.com
* Correspondence: ibogunovic@agr.hr; Tel.: +385-1-2393815

Received: 17 July 2020; Accepted: 4 September 2020; Published: 5 September 2020

Abstract: There is a lack of information in the rural Mediterranean area about agricultural pile burning impacts on soil nitrogen (N) dynamic and the N loss. Therefore, this research aims to study the impacts of moderate (MS), and high (HS) severity burn on N transformation and N losses, compared to an unburned (C) during the first year. The experimental plots (10 m²) were established in Croatia (43°58′ N 15°31′ E), in a slope ~18°, with a southwest exposition. Five days after the burn, C treatment had a significantly higher total N (TN) than MS and HS. Generally, the runoff was significantly different between burned and C treatments. Sediment yield, concentrations, and TN loss were significantly higher in MS than in C treatment. The concentrations of ammonium (NH₄-N) and nitrate (NO₃-N) in the runoff, and their losses were higher in burn treatments than in C treatment. These values were high in the first three months after burn, although the peaks in later periods correspond to extreme rainfall events. Principal component analysis showed that sediment yield was associated with sediment concentration, runoff, and TN loss (Factor 1). In addition, rainfall amount and intensity were inversely related to NH₄-N concentration and losses (Factor 2). The NO₃-N concentration was positively related to NO₃-N losses. Overall, MS treatment had severe effects on N loss and, sediment yield can be used as an indicator of soil degradation after pile burns.

Keywords: pile burn; nitrogen; burn severity; soil; runoff

1. Introduction

The risk of wildfires in Mediterranean areas increased with rural depopulation and the consequent accumulation of fuel in woodlands due to the lack of management [1,2], the prohibition of using fire for landscape management, and climate change [3]. However, burning agricultural residues in piles is a cost-effective alternative for reduction residues when the management of the landscape with fire is forbidden [4]. Pile burn is a widely adopted practice in the rural Mediterranean area for residues management [5,6] despite the environmental impacts (e.g., air and water pollution). Even though the environmental impacts can be relevant, the effects of this practice are poorly studied. Burning residues heat the soil (direct impacts), changing their properties depending on the severity of the burn [7]. In the period post-burning, the ash produced (indirect impacts) will affect the soil properties and the hydrological response [8]. Pile burns expose soils, increasing their vulnerability to erosion and overland flow. Nutrient losses occur mainly in the first months after burning [9,10]. The magnitude of post-burn nutrient loss is variable and depending on the interplay between burn severity, post-burn weather patterns, type of burned biomass, topography, soil properties, and land use [10–12] The varied Mediterranean landscape, such as abandoned terraces and intricate land-use patterns, lead to the different response of post-burn erosion at different sites and spatial scales [13].
Nitrogen (N) loss by volatilization is well documented [14], but less attention has been paid to the impacts of pile-burning on soil N chemical forms and losses in overland flow. N losses occur through the combustion of organic matter or water and sediment transport [15–17], contributing to water body pollution [16]. The N volatilization starts at ~200 °C, and the losses increase with temperature increasing [14,17]. The N that is not volatilized remains in the ash and can be converted to other available inorganic forms, such as ammonium (NH₄-N) and nitrate (NO₃-N). Conservation of ammonium (NH₄-N) to nitrate (NO₃-N) by nitrifying bacteria is one of the crucial steps leading to the transformation of inorganic N in the post-burn period [18–20]. Moreover, the process behind the increased inorganic N loss after a burn is still not well understood because of the cycle and complex nature of inorganic N transformations [21]. During burning, temperature controls the N release rate depending on the intensity [17]. Almost all N is volatilized at temperatures higher than 500 °C, and there is an increase in inorganic N [18,22]. High burn severity leads to a high N loss thought erosion or runoff [14,23,24]. After a moderate severity burn (~300 °C), substantial portions of soil organic N remain or changing its form [11].

Research about the impacts of pile burn severity on soil N and transported in sediment is lacking. This work aims to study the impacts of a pile burn in (a) soil and (b) sediments N forms according to different severities.

2. Materials and Methods

2.1. Study Site and Location

The experimental site is located in Croatia (43°58′ N 15°31′ E; 20 m a. s. l.), with a slope of ~18°, and southwest aspect. The soil type is classified as Leptosols (IUSS Working Group WRB, Vienna, Austria 2015), with 5%, 58.9%, and 29.6% of sand, silt, and clay. According to Köppen’s climate classification, the climate is Mediterranean Cfb (warm temperature with fully humid and warm summer) [25]. The mean annual temperature (1961–2019) is 15.2 °C, and the mean annual precipitation is 851 mm (Ravni Kotari meteorological station, 6 km from the experimental site, Polaca, Croatia). The location is surrounded by a mosaic of arable and permanent crops, vegetables, and vineyards. In this area, the residues’ management using fire is common, especially in late winter or early spring.

2.2. Experimental Designs and Laboratory Analyses

The experiment included moderate severity (MS), high severity (HS), and unburned treatment–control (C). MS treatment represented the burning of 10 kg m⁻² barley straw, and HS treatment 10 kg m⁻² barley straw, and 15 kg m⁻² vine stem. One treatment covered an area of ~10 m². The meadow plants (*Foeniculum vulgare* Mill., *Elymus repens* (L.) Gould, *Digitaria sanguinalis* (L.) Scop.) and the Maquis shrubland are the dominant vegetation in the study area and C treatment. The experiment was set up on the agriculture sloped terrain, abandoned 40 years ago. Fifteen metal rings (5 per treatment) with 0.2 m² area were set before biomass deposition. Biomass was staggered equally on burn treatments to obtain similar burn effects on each ring. Piles were burned on 18 March 2019 in 26- and 40-min duration on MS and HS plots, respectively. Burn severities were assessed by observing ash color, using the Munsell color chart [26]. After the burn, on the side of the rings facing downstream, a plastic tube was mounted to 5 L collectors to monitor runoff and soil loss. The first runoff was collected 5 days after the burn (DAB), and then approximately every 25 days in a period of 247 days, after rainfall events.

Additionally, soil samples (0–3 cm) were collected in the vicinity of each plot 5, 122, and 247 DAB, and ash samples immediately after burn (IAB) for total N (TN) determination. Soil and ash samples (ash only in the burned plots) were collected in 5 repetitions along each ring, stored in plastic bags, and taken to the laboratory for analysis. Sediment yield was determined by filtering (2 μm filter paper) after air-drying at room temperature and weighting of the filter paper. TN loss was determined after the calculation of TN concentrations with the mass of sediment yield. Additionally, the runoff was filtrated through active carbon and 0.45 μm filter paper to determine runoff NH₄-N and NO₃-N
concentrations with a Dionex ICS-1000 system. TN content was obtained by a dry-combustion method with a vario MACRO CHNS analyzer.

2.3. Statistical Analyses

Before statistical analysis, data were checked for normality with the Kolmogorov–Smirnov test. Data were considered normal at \( p > 0.05 \) level. Only of ash and soil TN followed the Gaussian distribution. One-way ANOVA was applied to test whether ash TN varied significantly between MS and HS treatments, and two-way ANOVA was applied to observe differences between sampling dates and treatments for soil data. The data of runoff, sediment yield, sediment concentration, N concentrations, and N loss were tested with several data transformation methods, such as logarithm, square root, and Box-Cox to see which one normalized most data distribution. The transformed data did not correspond to raw scale data (i.e., means), so a two-way ANOVA was applied to raw data to identify differences among treatments and dates. All comparisons were carried out with the Fisher post-hoc test to identify significant differences at \( p < 0.05 \) level. Original data were presented in graphics and tables. A principal component analysis (PCA) was carried out (using the original data), based on the correlation matrix to identify the relations among all variables. All analyses were performed using Statistica 12.0 for windows.

3. Results

3.1. Post-Burn Rainfall

Figure 1 shows total rainfall between sampling dates and the maximum 30-min rainfall intensities \( (I_{30}) \). In the period between experiment setup and 5 DAB, there was a total of 20 mm rainfall. Approximately every 25 days, between 5 and 85, a similar amount of rainfall was observed (50 mm), and then decreased between 85 and 122 DAB (35 mm). A higher amount of rainfall occurred in the period from 122 to 155 (72 mm), and then a decrease in rainfall amount (20 mm) was noted until 180 DAB. The major rainfall occurred between 208 and 247 DAB (188 mm). The maximum 30-min rainfall intensity \( (I_{30}) \) was noted at 247 DAB, followed by 85 and 155 DAB.

![Temporal precipitation (mm) and maximum rainfall intensity \( (I_{30}, \text{mm h}^{-1}) \) in the period between 5 and 247 days after pile burning.](image)

**Figure 1.** Temporal precipitation (mm) and maximum rainfall intensity \( (I_{30}, \text{mm h}^{-1}) \) in the period between 5 and 247 days after pile burning.

3.2. Ash and Surface TN Content

Pile burn severity did not affect \( (p > 0.05) \) the ash TN content. The content of soil TN was not significantly different between treatments and sampling dates (Table 1). Treatment \( \times \) sampling date interaction \( (p < 0.05) \) indicate a significant effect on soil TN. At 5 DAB, the soil TN content was significantly higher in C treatment than at MS and HS treatments. Seasonal dynamic at C treatment shows significantly higher TN at 5 than at 122 and 247 DAB.
3.3. Runoff and Sediment Characteristic

Runoff was significantly different among treatments (F = 22.3, p < 0.0001), sampling dates (F = 11.2, p < 0.0001), and in the treatments × sampling dates interaction (F = 1.9, p < 0.05). At 25, 52, 65, 85, 155, and 247 DAB, runoff was significantly higher in MS and HS than in C treatments. In the C treatment runoff, no significant differences were observed among dates. In MS treatment, the runoff was significantly higher at 52, 65, 155, and 247 than at 5, 85, 122, 180, and 208 DAB. In HS treatment, runoff was significantly higher at 247 than at 5, 65, 85, 122, 155, 180, and 208 DAB. Likewise, at 25, 52, 65, and 155, runoff was significantly higher than at 5, 85, 122, 180, and 208 DAB (Figure 2).

Sediment yield was significantly different among treatments (F = 11.2, p < 0.001), sampling dates (F = 2.92, p < 0.05), and the treatments × sampling dates interaction (F = 1.88, p < 0.05). At 25, 52, and 155 DAB, significantly higher sediment yield was observed in MS compared C treatments. No differences were identified between C and HS treatments among sampling dates for sediment yield. At MS treatment, a significantly higher sediment yield was observed at 155 and 52 than at 5, 65, 85, 122, 180, 208, and 247 DAB. Likewise, at 25 DAB, sediment yield was significantly higher than at 5, 122, 180, and 208 DAB (Figure 3).
Nitrogen Concentrations in Runoff

NH₄-N concentration was significantly different among treatments (F = 3.6, p > 0.05). Significant difference was not observed among sampling dates (F = 1.38, p > 0.05), and in the treatments × sampling dates interaction (F = 1.4, p > 0.05). At 180 and 247 DAB, NH₄-N concentrations were significantly higher in C treatment than MS and HS treatments. In C treatment, NH₄-N concentration was significantly higher in C treatment than MS and HS treatments. In C treatment, NH₄—N concentration was significantly higher than at 5, 65, 122, 180, and 247 DAB. In HS treatment, significantly higher sediment concentration was identified at 25 and 52 DAB compared to all other sampling dates. Likewise, at 85, and 155 sediment concentration was significantly higher than at 5, 65, 122, 180, and 247 DAB. In MS treatment, significantly higher sediment concentration was observed in MS compared to C and HS treatments. In C treatment, no significant differences in sediment concentration were observed among sampling dates. In MS treatment, significantly higher sediment concentration was observed at 52 than at 5, 85, 122, 180, and 247 DAB. In HS treatment, significantly higher sediment concentration was observed at 52 than at 5, 85, 122, 180, and 247 DAB (Figure 4).

Figure 3. Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on sediment yield (g m⁻²) between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show significant differences within the same date. Mean values followed by the different uppercase letters show significantly different within the same treatment. Significant differences were observed at p < 0.05. Hanging bars represent the standard error (n = 5).

Sediment concentration was significantly different among treatments (F = 17.6, p < 0.0001), and sampling dates (F = 3.6, p < 0.001). Significant differences were not observed in the treatments × sampling dates interaction (F = 1.43, p > 0.05). At 25, 85, 155, 180, and 208 DAB, a significantly higher sediment concentration was observed in MS compared to C and HS treatments. In C treatment, no significant differences in sediment concentration were observed among sampling dates. In MS treatment, significantly higher sediment concentration was identified at 25 and 52 DAB compared to all other sampling dates. Likewise, at 85, and 155 sediment concentration was significantly higher than at 5, 65, 122, 180, and 247 DAB. In HS treatment, significantly higher sediment concentration was observed at 52 than at 5, 85, 122, 180, and 247 DAB (Figure 4).

Figure 4. Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on sediment concentration (g L⁻¹) between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show significant differences within the same date. Mean values followed by the different uppercase letters show significantly different within the same treatment. Significant differences were observed at p < 0.05. Hanging bars represent the standard error (n = 5).

3.4. Nitrogen Concentrations in Runoff

NH₄-N concentration was significantly different among treatments (F = 3.6, p > 0.05). Significant difference was not observed among sampling dates (F = 1.38, p > 0.05), and in the treatments × sampling dates interaction (F = 1.4, p > 0.05). At 180 and 247 DAB, NH₄-N concentrations were significantly higher in C treatment than MS and HS treatments. In C treatment, NH₄-N concentration...
was significantly higher at 180 and 247 DAB than at all other dates. In MS and HS treatments, NH₄-N concentration was not significantly different (Figure 5).

Figure 5. Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on ammonium (NH₄-N) (mg L⁻¹) concentration between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show significant differences within the same date. Mean values followed by the different uppercase letters show statistically significant differences within the same treatment. Significant differences were observed at p < 0.05. Hanging bars represent the standard error (n = 5).

NO₃-N concentration was significantly different among treatments (F = 16.9, p < 0.0001), sampling dates (F = 4.31, p < 0.0001), and the treatments × sampling dates interaction (F = 3.19, p < 0.0001). At 85, 122, and 155, DAB NO₃-N concentration was significantly higher in MS than in C treatments. In C and MS treatments, NO₃-N concentration was significantly different among sampling dates. In HS treatment, NO₃-N concentration was significantly higher at 122 DAB than at all other sampling dates. Likewise, at 155, NO₃-N concentration was significantly higher than at 5, 25, 52, 65, 180, 208, and 247 DAB (Figure 6).

Figure 6. Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on nitrate (NO₃-N) (mg L⁻¹) concentration between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show significant differences within the same date. Mean values followed by the different uppercase letters show statistically significant differences within the same treatment. Significant differences were observed at p < 0.05. Hanging bars represent the standard error (n = 5).

3.5. Nitrogen Loss in Sediment

NH₄-N loss was not significantly different among treatments (F = 1.74, p > 0.05), and in the treatments × sampling dates interaction (F = 1.66, p < 0.05), but was among sampling dates (F = 1.98,
NO3–N loss was significantly different among treatments \((F = 21.1, p < 0.0001)\), sampling dates \((F = 7.23, p < 0.0001)\), and the treatments \(\times\) sampling dates interaction \((F = 3.34, p < 0.0001)\). At 25, 52, 65, 85, 122, 155, and 247 DAB, significantly higher NO3–N loss was observed at MS and HS than at C treatments. At 122 DAB, significantly higher NO3–N loss was identified at HS than at MS and C treatments. In C treatment, no significant differences were observed for NO3–N loss. In MS treatment, significantly higher NO3–N loss was identified at 52 and 65 DAB than at all other sampling dates. In C treatment, significantly higher NO3–N loss was observed at 52, 65, 122, 155, and 247 than at 5, 25, 85, 180, and 208 DAB (Figure 8).

Figure 7. Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on NH4–N loss between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show statistically significant differences within the same date. Mean values followed by the different uppercase letters show statistically significant differences within the same treatment. Significant differences were observed at \(p < 0.05\). Hanging bars represent the standard error \((n = 5)\). NO3–N loss was not significantly different among treatments \((F = 1.66, p > 0.05)\), and sampling dates \((F = 2.92, p < 0.05)\). At 247 DAB, significantly higher NH4–N loss was observed in C treatment compared to MS and HS treatments. In C treatment, significantly higher NH4–N loss was observed at 247 DAB than in all other sampling dates. No significant differences in MS and HS treatments were observed in NH4–N loss among sampling dates (Figure 7).

Figure 8. Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on NO3–N loss between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show statistically significant differences within the same date. Mean values followed by the different uppercase letters show statistically significant differences within the same treatment. Significant differences were observed at \(p < 0.05\). Hanging bars represent the standard error \((n = 5)\). TN loss was significantly different among treatment \((F = 2.1, p < 0.05)\), sampling dates \((F = 2.92, p < 0.05)\), and treatments \(\times\) sampling dates interaction \((F = 2.1, p < 0.05)\). In C and HS treatments, no significant differences among sampling dates were observed. At 25, 52, 85, 155,
and 247 DAB, TN loss was significantly higher in MS treatment than on other dates. Likewise, TN loss in MS treatment was significantly higher at 25 and 52 than at 5, 25, 65, 85, 122, 180, 208, and 247 DAB (Figure 9).

![Figure 9](image)

**Figure 9.** Treatment effect under control (C), moderate severity (MS), and high severity (HS) burn on total Nitrogen (TN) loss between 5 and 247 days after pile burning. Mean values followed by the different lowercase letters show statistically significant differences within the same date. Mean values followed by the different uppercase letters show statistically significant differences within the same treatment. Significant differences were observed at *p* < 0.05. Hanging bars represent the standard error (*n* = 5).

### 3.6. Principal Component Analysis

The first three factors explained 72.7% of the total variance (Table S1 in Supplementary Material). Factor 1 explained 33.2%, and Factors 2 and 3 explained 23%, and 16.5%, respectively. The PCA identified three groups:

- Sediment concentration, sediment yield, TN loss, and runoff;
- Rainfall amount and intensity, NH₄-N concentration and NH₄-N losses;
- Runoff, NO₃-N concentrations, and NO₃-N losses.

Factor 1 had high negative loadings in sediment yield, TN loss, sediment concentration, and runoff. Factor 2 had high negative loadings in rainfall amount, rain intensity, NH₄-N loss, and concentration. Finally, Factor 3 had positive loadings in NO₃-N concentration and loss. The intersection between Factor 1 and Factor 2 shows that sediment yield, TN loss, sediment concentration, and runoff are inversely related to most other variables, especially to rainfall amount and intensity (Figure 10A). The impact of all treatments is noticeably different. The variability is noted in all treatments, although MS can be singled out as the most variable (Figure 10B).

![Figure 10](image)

**Figure 10. Cont.**
4. Discussion

4.1. Ash and Soil TN Dynamics

Five DAB, soil TN content in C treatment was significantly higher than in burn treatments. This was attributed to the fact that topsoil TN decreased in burned soils due to volatilization [14,27,28]. However, soils did not recover TN in the period post-burn. Usually, topsoil TN response in the post-burn period varies among burn severities and due to possible different extent of ash incorporation into the soil [14,29]. In this research, ash TN was similar at MS and HS treatment, although ash color varied between MS (black to dark grey, 10 YR 2/1, 10 YR 3/1) and HS (dark grey to light grey, 10 YR 4/1, 10 YR 7/1) treatments. Previous works observed that medium to high severity burn may produce a similar effect on the burned biomass and, consequently, surface soil [30]. In a study by Francos et al. [31], soil TN content was not significantly different among low, high severity burn, and unburned plots. Moreover, other works also confirmed similar TN contents in burned and unburned soils in the first years after burn [32,33].

4.2. Hydrological Response to Pile Burns

Five, 25, 122, and 247 DAB, a significantly higher runoff was identified in HS treatment, while higher runoff on MS treatment was noted 52, 65, 85, and 155 DAB, compared to other dates. A significantly higher runoff in burn treatments was identified at 25, 52, 65, 155, and 247 DAB than in C treatment (Figure 2). The highest sediment yield was observed in MS treatment at 155 DAB, followed by 25 and 52 DAB (Figure 3). Both burned treatments showed several orders of magnitude higher sediment yields than the unburned, which agrees with previous studies [34,35], although HS treatment did not show significant high values. Moreover, previous studies found that high severity burn did not have significant differences in runoff rate compared to moderate severity burn, even to low severity burn [36,37]. Gimeno-Garcia et al. [38] found that in the first months after an experimental burn, high severity burn increased runoff and soil loss compared to moderate burn, although the differences between them were not statistically significant. The variability of runoff and sediment loss on MS and HS treatments is very likely due to differences in small scale variability in ash thickness [39] or soil. The soil type in our study was classified as Leptosols, that are known for their low susceptibility to water repellency [40]. Ash might alter soil hydrological properties, increasing water retention and reducing sediment loss [41]. However, ash can also clog soil pores and increase surface erosion [42].

The direct comparison of runoff and sediment losses with other studies is almost impossible considering the large variability in reported post-burn runoff and erosion rates, mostly due to the type of burn-event (pile burn, prescribed, or wildfire), vast ranges of landscapes and climates where burns occur. Sediment concentrations were variable between measurement dates. However, they were notably highest in MS. In MS treatment, higher sediment concentration was observed on first dates then in later dates post-burn. Considering both erosion rates, in MS treatment at 85 DAB, sediment concentration was not significantly different from 52 and 155 DAB (Figure 4), unlike sediment yield observed at 85 DAB.
It seems that high rainfall intensity, which occurred at 85 DAB (Figure 1), was responsible for the increase in sediment concentration in MS. The highest amount and rainfall intensity, which was observed at 247 DAB, did not significantly influence the overland flow and erosion rate. This was very likely due to sediment exhaustion as a consequence of the previous rainfall events. Our results agree with previous studies that showed decreasing erosion rate in the later post-burn period [13,34,38].

### 4.3. The N losses in the Post-Burn Period

The two distinct NH$_4$-N concentrations in C treatment at 180 and 247 DAB can be explained due to rainfall patterns and related soil saturation (Figure 5) [43]. In the C treatment, the organic matter includes a diverse composition of flora population, so it was assumed that these contributed to higher soil saturation and related increased NH$_4$-N concentrations [14,43]. Regarding the burn treatments, the major NH$_4$-N concentrations in MS treatment were observed at 208 DAB, and in HS treatment at 65 DAB, although not significantly different. According to our results, precipitation intensity did not influence the hydrological response and related NH$_4$-N concentrations in all treatments. Several authors confirmed a high NH$_4$-N concentration in overland flow immediately after a high severity burn [14–16,44]. In this work, this was not the case. However, NO$_3$-N is not produced directly by heating but is formed during subsequent nitrification of NH$_4$-N as a result of the burning [10,11,45]. These results indicate that HS treatment had a severe effect on NO$_3$-N concentrations in runoff, as the significantly higher values were observed in HS treatment. A more significant NO$_3$-N availability and movement are frequent when the nitrifying population recovers [19]. According to Koyama et al. [21], high severity burn led to higher NO$_3$-N concentrations compared to low severity burn, which was the case in our experiment. In this context, microbial population after burn become functionally more diverse, and certain nitrifying bacteria increase 10 times more than levels in unburned areas, thereby increasing NO$_3$-N concentration, which is assumed to be the reason for high NO$_3$-N concentration in HS compared to C treatment [45]. The NH$_4$-N and NO$_3$-N loss (Figures 7 and 8) follow the patterns of N concentrations in runoff as the loss is mainly influenced by N-form concentration behavior [23,46]. However, differences in N losses between treatments were more apparent than the differences in the N concentrations. Our results showed high variability in the loss of NO$_3$-N than in the loss of NH$_4$-N. This phenomenon occurs due to post-burn transformation of NH$_4$-N to NO$_3$-N by nitrifying bacteria, increasing the transport of inorganic N [20]. NH$_4$-N is in the N soluble form, and it is adsorbed on the negatively charged soil cation exchange site, and thus is less mobile than anions. NO$_3$-N cannot bind to soil adsorption complexes and, therefore, is more vulnerable to leaching [14,19]. In MS treatment highest NO$_3$-N loss was observed at 52 and 65 DAB, unlike NH$_4$-N concentrations on the same dates. NO$_3$-N losses follow the patterns of erosion. According to Thomas et al. [9], the amount of sediment yield is the main factor controlling the N loss rather than any N concentration change in the sediment or runoff.

The TN loss was highest 155 DAB, followed by first sampling dates at 25 and 52 DAB in MS treatment. The highest peaks of TN losses were a consequence of extreme rainfall events, as is noted by Field et al. [46], Ferreira et al. [23], or Hosseini et al. [47]. After the first months, peak losses are restricted to extreme rainfall, which can mobilize ash and soil [30]. High runoff and erosion events in MS treatment are responsible for the increments of TN and NO$_3$-N loss at 52, 65, and 85 DAB [23]. Regarding the NO$_3$-N loss 122 and 155 DAB, this may be attributed to the burn severity, rather than erosion, since HS treatment’s highest losses occurred when low sediment yield was observed. The sediment yield and runoff rate increase with rainfall amount as confirmed in other works in fire-affected areas [23,38]. In the study by Hosseini et al. [47], the N loss was mainly due to rainfall patterns and runoff. In this research, maximum rainfall intensity was noted at 247 DAB but did not influence sediment yield, TN, and NO$_3$-N loss at 155 DAB. This could be attributed to sediment and nutrient exhaustion and plant consumption [13,38]. The second highest rainfall event with high intensity was observed at 155 DAB and increased sediment yield and, consequently, N loss. In our work, sediment yield has more effects on N loss rather than sediment concentrations. The sediment
concentration was more influenced by firsts runoff events, at 25 and 52 DAB, and did not have the same patterns as sediment yield (Figure 4), as was found in previous research [36].

4.4. Interrelations between Hydrological Variables

Factor 1 of PCA grouped most of the erosion variables, i.e., sediment yield, concentration, runoff, and TN losses, respectively. The erosion was higher in MS compared to C and HS treatments. The sediment yield and concentration, runoff, and TN loss are the best indicators to assess the impacts of pile burn effects, rather than NH$_4$-N concentration and loss and NO$_3$-N concentration and loss, respectively. The erosion parameters are well documented in other studies as the main features for the identification of soil degradation in the post-burn period [13,34]. Factor 2 grouped the precipitation parameters (amount and intensity), and NH$_4$-N concentration and loss. This can be attributed to the lack of significant differences in burn treatments, with the highest in C treatment for the NH$_4$-N variables. The highest NH$_4$-N values were observed at 247 DAB in C treatment when the highest rainfall amount and intensity were identified. NH$_4$-N loss and concentration patterns differed considerably from those of NO$_3$-N, which were identified in Factor 3. The NO$_3$-N concentration had positive values. For NO$_3$-N values, diverse concentration and loss in both burn treatments were observed, and it was not recognized as the main factor for validation of the pile burn effects. Pile burn leaves only localized soil impact and nutrient effects. However, the effects are substantial.

4.5. Implications for Land Management

The accumulation of organic feedstock material in Mediterranean rural areas has become an environmental problem. There has been a need to manage unwanted harvest to avoid large wildfires and minimize their impact at all levels [48]. Pile burn is recognized as an economical treatment for disposing of harvested residues [5], but the critical question in terms of the sustainability of their practice is to what extent will it alter soil functions and cause soil degradation? Should soils before burning be protected somehow, or do the benefits of pile burning outweigh the possible impact on soil? A fundamental guideline in discussing the effects of pile burning is the knowledge that soil is not renewable in our lifetime, which comes to the fore in the Mediterranean’s endangered area. The post-burn N dynamic and N losses are useful indicators to rank pile burn effects in terms of consequences to soil fertility and soil degradation [10]. Relatively small and localized burned areas give preference to these practices. Pile burning can be used as a conservative approach that protects natural resources, which should be a priority in land management, but do not neglect their soil [49]. Different experiment designs focused on more closely controlling fuel characteristics (amount, type, and moisture), the season of burning, weather variables, and possible slope gradient are necessary to more clearly understand the period in which these practices are best to conduct [50].

5. Conclusions

The short-term effect showed a substantial impact on N loss in both burn treatments. However, severe impact on N loss was noted at MS treatment. The C treatment had peak NH$_4$-N concentrations, which may be attributed to the natural biological process and soil saturation. This work’s outcomes showed that rainfall amount and intensity in the first months of post-burn had a major effect on N loss compared to more severe rainfall patterns in later months. Therefore, pile burning has significant effects in a short-term study on N loss by runoff and erosion process. MS had the strongest effects on N loss in the post-burn period. Sediment yield can be used as an important indicator for the determination of soil degradation in the post-burn period. The future work with included analyses of physical and chemical soil and water parameters is obligatory for deeper insights into the effects of pile burn practice on the environment.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/9/1340/s1, Table S1: Loadings matrix with first three factors extracted from the PCA analysis.
Author Contributions: Conceptualization, D.D. and P.P.; methodology, D.D.; validation, I.B. and P.P.; formal analysis, D.D.; investigation, D.D., I.K., and I.B.; resources, I.K.; data curation, D.D. and I.B.; writing—original draft preparation, D.D.; writing—review and editing, D.D., I.B., and P.P.; visualization, D.D., I.B., and P.P.; supervision, P.P. and I.K.; project administration, I.K.; funding acquisition, I.K. All authors have read and agreed to the published version of the manuscript.

Funding: The work was supported by the Croatian science foundation under the project “Influence of Summer Fire on Soil and Water Quality” (IP-2018-01-1645).

Acknowledgments: Željka Zgorelec and Aleksandra Perčin are acknowledged for their cooperation during the laboratory work.

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

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