# Report for 2004MT33B: Quantitative assessment of the effectivenes of post-fire erosion control techniques

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    - Groen A. and S. W. Woods. 2003. Quantitative assessment of the effectiveness of post-fire erosion control techniques. American Water Resources Association, Montana State Chapter 2003 Annual Meeting. Butte Montana, 4-5 October 2003.

Report Follows

## ABSTRACT

Various methods are available to reduce post fire erosion, but there is relatively little quantitative information on the effectiveness of these techniques. A rainfall simulator was used to compare erosion and runoff rates from 0.5 $m^2$ plots treated with aerial grass seeding (AG) or straw mulch (SM) to that from untreated control (UC) plots in an area burned by the 2002 Fox Creek Fire in western Montana. The objective was to determine the effectiveness of these treatments for controlling post-fire runoff and erosion. There were ten replicate plots of each treatment and the control, and simulated rainfall was applied to each plot for one hour at an intensity of ~80 mm/hr. In the first year after the fire, the mean total runoff from the AG and SM plots was 30 and 28 mm, respectively, compared to 44 mm for the UC plots. Peak runoff rates from the AG and SM plots had mean values of 41 mm/hr and 40 mm/hr, respectively, compared to 59 mm/hr for the control. Erosion rates from the AG and SM plots were reduced by 25 % and 87 %, respectively, relative to the control. Limited repeat measurements in the second year after the fire indicated a decline of up to 50 % in the peak runoff from the treatments since 2003, presumably due to a decline in fire induced water repellency. Erosion rates could not be measured in 2004 because wind blown silt had accumulated in the plots. While both aerial seeding and straw mulch reduce surface runoff and erosion, straw mulch is more than three times as effective in reducing surface erosion in the first year.

## INTRODUCTION AND BACKGROUND

Soil erosion rates in undisturbed forested watersheds are typically very low. However, substantial increases in erosion rates have been observed after forest fires due to the loss of the duff layer, and changes in the soil physical characteristics that increase the surface runoff rate (Helvey, 1980; Morris and Moses, 1987; Robichaud, 2000; DeBano, 2000). Post-fire increases in erosion are a concern due to the loss of soil productivity, and the ecological impacts of increased sedimentation in downstream water bodies (Robichaud et al., 2000). Various erosion control techniques are used to reduce the impact of post-fire erosion on soil and water resources, including: 1) hillslope treatments such as seeding, mulching and straw wattles; 2) in-stream treatments such as straw bales and log check dams; and 3) road rehabilitation treatments such as upgrading of culverts and ditches.

Hillslope treatments are regarded as the most beneficial because they control erosion near the point of origin, thus reducing the probability that eroded soil will reach downstream water bodies (Robichaud et al., 2000).

The costs associated with post-fire erosion control are very high; the U.S. Forest Service spent more than $83 million on its Burn Area Emergency Rehabilitation (BAER) program between 1970 and 2000, of which more than 60% was spent in the 1990s (Robichaud et al., 2000). Public concern over the impacts of forest fires, and the increasing likelihood of large fires near urban interfaces, means that expenditure on post-fire erosion control is likely to remain high. It is therefore essential that erosion control projects employ only the most effective treatments. However, few studies have determined the effectiveness of individual treatments, and most of the studies that have been conducted used only qualitative measures of effectiveness.

A recent review concluded that there is a need for quantitative, statistically defensible data on treatment effectiveness (Robichaud et al., 2000). There is a particular need to assess the effectiveness of hillslope treatments, such as aerial seeding and mulching. The need for research on erosion control treatment effectiveness is particularly great in the northern Rocky Mountain region, where wildfires have burned extensive areas of state and federal land in recent years. An increased understanding of the effectiveness of post-fire erosion control techniques will enable forest managers to achieve more effective post-fire management.

## OBJECTIVES

The objective of the study was to measure the effectiveness of aerial seeding and mulching for reducing plot-scale runoff and erosion rates relative to an untreated control.

## METHODS AND MATERIALS

### *Study Site*

The study was conducted within the area burned during the 2002 Fox Creek Fire, on the Blackfeet Indian Reservation in northwest Montana (Figure 1). The Fox Creek Fire was a mixed severity fire that burned 2550 ha of mixed spruce-fir forest. Soils in the study area are clayey-skeletal, mixed Typic Cryoboralfs of the Loberg Series (USDA, 1980). These are stony loams that formed out of glacial till and contain 30 to 60 % rock fragments by volume. The mean annual precipitation at St. Mary's, Montana, which lies 4 km west of the study site and 490 m lower in elevation, is 68 cm and the mean monthly temperature ranges from minus 6$^{o}$C in January to 17 $^{o}$C in July.

*Erosion Control Treatments*

Aerial grass seeding was conducted by the Bureau of Indian Affairs in the early spring of 2003, nine months after the fire, and covered an area of approximately 160 ha. Prior to the seeding operation, ten 9 m$^2$ plots within the area designated for seeding were covered with tarpaulins to provide comparable unseeded areas in which to establish the straw mulch and control plots. The tarpaulins were removed after seeding was completed, and seed that had blown under the tarpaulin sheets was removed from the plots. Straw mulch was then applied by hand across approximately half of each plot, following the procedures in USDA (1995). The other half of each plot was used as the untreated control.

*Erosion measurements*

Runoff and erosion measurements were conducted in July 2003 and August 2004 by applying simulated rainfall to 0.5 m$^2$ plots within the two treatments and the control. Each erosion plot consisted of a 0.71 x 0.71 meter square frame made from 15 cm wide steel sheeting. Plots were installed parallel to the slope with ~5 cm of the plot walls extending below the surface. There were ten replicate plots in each of the two treatments and the control. Rainfall was applied using a Norton type rainfall simulator at an intensity of ~ 80 mm/hr for one hour. Prior to each simulation the rainfall intensity was measured over a 5-minute period using a 0.5 m$^2$ calibration pan that fitted over the top of the erosion plot. During the simulations, samples were collected every 1 minute for the first 10 minutes and every 2 minutes thereafter in 1-liter Nalgene bottles. Runoff sample volumes were used to calculate the total runoff (mm) and the peak runoff rate (mm/hr). The mass of sediment eroded from the plot (kg/m$^2$) was determined by filtering the runoff through Whatman 40 Grade (8 µm) filter papers, drying the filter papers in a 105$^{o}$ oven for 24 hours and then weighing them to an accuracy of ± 0.01 g.

*Ancillary data*

Plot slope was measured using a clinometer laid along the side of the plots. Prior to the start of each rainfall simulation, the antecedent volumetric soil moisture content was calculated from the mean of three measurements conducted within each plot using a Hydrosense soil moisture probe (Campbell Scientific Inc.). Percent vegetation cover was determined by overlaying a grid of 100 points across the plot, and counting the presence or absence of surface vegetation at each point. Soil texture was determined from samples collected adjacent to the plots in accordance with Gee and Bauder (1986) and USDA (1994).

*Data analysis*

Analysis of variance (ANOVA) was used to compare the following characteristics among the two treatments and the control: slope, antecedent moisture content, vegetation cover, simulated rainfall rate, total runoff, peak runoff and total mass of sediment eroded. Prior to ANOVA the variables were tested for normality using the Kolmogorov-Smirnov test, and transformed where necessary to obtain normality in the dataset. Multiple comparisons (Ott, 1993) were used to determine which means were significantly different, and the Bonferroni adjustment was used to control the experiment-wise error rate at an alpha level of 0.05 (Ott, 1993). All analyses were performed using the SPSS Version 10.0.5 statistical software (SPSS Inc., 1999).

## RESULTS

*Plot characteristics*

The treatment and control plots had similar slope, antecedent moisture content and vegetation cover characteristics (Table 1). Plot slopes ranged from 16 to 36 %, but none of the mean slopes for the two treatments and the control was significantly different ($p = 0.638$). In 2003, the mean antecedent moisture contents ranged from 6.0 % in the mulch plots to 7.3 % in the control, and none of the means was significantly different ($p = 0.197$).

The values for mean vegetation cover in the treatment and control plots were within 1.5 %, and none of the means was significantly different (p = 0.894).

*Rainfall and runoff rates*

In July 2003, the mean rainfall intensities for the simulations performed in the aerial seeded, straw mulch and control plots were 82, 84 and 83 mm/hr, respectively, and these values were not significantly different (p = 0.720), indicating that the plots were subjected to similar rainfall inputs.

All of the plots produced a similarly shaped hydrograph, although the runoff rate and timing varied within and between treatments. The early part of the hydrograph consisted of a short period, typically less than 1 minute, with no runoff followed by a steep rising limb with a time to equilibrium (time from start of rainfall to plateau of runoff hydrograph) of between 8 and 30 minutes (Figure 2). The mean time to equilibrium in the control and mulch plots was similar (15.5 and 16.0 minutes, respectively), but it was ~4 minutes longer in the seeded plots (Table 2). Mean values for time to equilibrium were not significantly different (p = 0.275). In all but two of the plots, the runoff rate gradually declined after the initial plateau runoff rate had been reached, indicating a hydrophobic response in the soil.

The mean values for total runoff from aerial seeded and straw mulch plots were 30 and 28 mm, respectively, compared to 44 mm for the control plots (Figure 3). Due to high within treatment variability, the means were not significantly different (p = 0.090). Peak runoff rates from aerial seeded and straw mulch plots had mean values of 41 mm/hr and 40 mm/hr, respectively, compared to 59 mm/hr for the control (Figure 4). Again, the means were not significantly different (p = 0.092).

In 2004, the peak runoff rates from plots were reduced by up to 50 % when compared with 2003 (Figure 5), suggesting that the hydrophobic soil layer was breaking down.

*Erosion rates*

Total erosion from the plots ($kg/m^2$) was log normally distributed, so a log transformation was used to normalize the erosion data prior to analysis.  In 2003, the mean treatment values were 0.10 $kg/m^2$, 0.59 $kg/m^2$, and 0.79 $kg/m^2$ in the mulched, aerial seeded and control plots, respectively (Table 2, Figure 6). Total erosion from the mulched plots was significantly lower than both the control ($p = 0.001$) and the seeded plots ($p = 0.013$), while total erosion from the seeded plots was not significantly different from the control. In 2004, the accumulation of wind blown silt in the plots prevented measurement of the erosion rates.

## DISCUSSION

One of the primary causes of increased erosion from burned areas is the loss of vegetative cover and the protective duff layer, resulting in more rainsplash. Consequently, the effectiveness of aerial seeding and mulching in reducing erosion is largely dependent on the amount of additional ground cover that the treatment produces. In our study area, seeding was not conducted until nine months after the fire because of logistical and climatic limitations, so that there was only a three month period between the application of the grass seed and the rainfall simulations. The mean vegetation cover in the seeded plots was no greater than in the control plots at the time of the 2003 simulations, and the seeding treatment had a correspondingly limited effect in reducing erosion. Application of the seeding treatment prior to snowfall in the same year as the fire may have increased its effectiveness in reducing erosion the following year. The limited additional ground cover created by the aerial grass seeding in 2003 may have also been partly due to the exceptionally dry conditions; total precipitation at Babb, Montana for 1 June – 31 July 2003 was just 42% of average. Greater success might be expected in a wetter year, although the effect of increased ground cover might be offset by the increased rainfall erosivity. Overall the results confirm other studies, which suggest that seeding has only a limited beneficial effect on erosion rates in the first year after a fire (Amaranthus, 1989; Orr, 1970). Since erosion rates are typically at their highest in the first year because of the lack of cover, high rates of overland flow and high sediment availability, this represents a serious limitation in the effectiveness of grass seeding. Grass seeding may not be an appropriate treatment in many burned areas.

In contrast with the grass seeding treatment, straw mulching was highly effective in reducing erosion in the first year after the fire. The effectiveness of straw mulch for reducing erosion has long been recognized in agriculture and the construction industry. The effectiveness of mulching has also been noted in the limited number of studies conducted in burned areas. Wheat straw mulch applied to fill slopes adjacent to perennial streams, firelines and areas of high erosion hazard reduced erosion rates by 11 to 19 $m^3$ $ac^{-1}$ compared to untreated sites (Miles et al., 1989). Edwards et al., (1995) noted significant reductions in soil loss between sites where mulch was applied at rates of 0.9 and 1.8 t $ac^{-1}$ on slopes ranging from 5 to 9 percent. Erosion rates from the mulched plots were reduced by 87 % relative to the control, a result that is consistent with the limited number of previous studies conducted in burned areas. The effectiveness of the mulching treatment can be attributed primarily to the immediate increase in ground cover that it provides, and the consequent decrease in rainsplash erosion. However, the mulch treatment also reduced the total runoff and the peak runoff from the plots indicating that erosion rates may have been further reduced by a decrease in the rate of overland flow. Presumably the mulch layer acts much like the duff layer in an undisturbed forest soil profile, providing a temporary storage reservoir for rainfall which then infiltrates the ground over a longer time period.

We noted a tendency for mulch to be blown off the site by high winds, and this could be a problem when using mulch as an erosion control treatment. Many areas that were mulched in late May were completely bare by early August. Loss of the mulch would likely be less of a problem where a larger area was treated because mulch blown from one area would be replaced by mulch blown from elsewhere. However, periodic maintenance is needed to ensure that the mulch remains effective during the first summer after a fire, when vegetation cover is at a minimum. We reduced loss rates from the mulched plots by spreading nylon netting across the plots, and a similar approach could be employed in areas being treated on a larger scale.

Accumulation of wind blown silt in the plots prevented us from measuring erosion rates in the second year of the study. We were therefore unable to determine whether the treatments had a longer term effect on erosion rates. Seeding may have a positive effect in that it eventually provides more ground cover than on untreated sites. However, seeding can have a detrimental effect on long term recovery because it can inhibit the regrowth of native vegetation. None of our sites had any straw mulch visible in the second year due to a combination of decomposition and being blown away by wind. In-situ decomposition of mulch may enhance regrowth by increasing the soil's organic and nutrient content, but we did not quantify such an effect. More research is needed on the longer term effectiveness of erosion control treatments.

In addition to measuring the effectiveness of the treatments, the study provided insight to the infiltration and runoff process in burned areas. Increases in erosion from burned areas are due in part to an increased rate and frequency of overland flow, resulting in more sheet and rill erosion. The increased overland flow has been largely attributed to the presence of water repellent (hydrophobic) soils. In our study, most of the 2003 runoff hydrographs exhibited a declining runoff rate after the initial peak, indicating gradual wetting of a hydrophobic soil layer and resultant increase in the infiltration rate. This increase in infiltration with time is the opposite of what is typically observed in unsaturated hydrophytic soils, and has been observed in previous studies of post-fire infiltration (Benavides-Solorio and Mac Donald, 2001).

The 2004 runoff rates were substantially lower than those observed in 2003, indicating that the hydrophobic layer was at least partially broken down. In most cases, hydrophobic soils tend to disappear within one year after the fire, although the rate of breakdown varies with the initial fire intensity and the amount of precipitation. The increase in infiltration that accompanies breakup of the hydrophobic layer along with the increased vegetation cover will eventually lead to a decline in runoff and erosion rates from burned areas. However, studies conducted in Colorado indicate that higher erosion rates can persist for at least four years in burned areas, far beyond the period in which hydrophobicity is expected to persist (Dr. Lee MacDonald, *pers. comm.*). The implication is that reductions in infiltration after a fire may be due to factors other than the presence of water repellent soils, such as sealing of the surface by fine organic and mineral material. More research is needed to investigate the factors controlling post-fire infiltration and runoff.

## CONCLUSIONS

Various methods are available to reduce post fire erosion, but there is relatively little quantitative information on the effectiveness of these techniques. A rainfall simulator was used to compare erosion and runoff rates from 0.5 $m^2$ plots treated with aerial grass seeding or straw mulch to that from untreated control plots in an area burned by the 2002 Fox Creek Fire in western Montana. The objective was to determine the effectiveness of these treatments for controlling post-fire runoff and erosion. The results indicate that seeding and mulch both reduce total runoff, peak runoff and erosion from burned areas. However, mulching is more than three times more effective in reducing erosion than seeding. Mulching may therefore be a more desirable treatment than seeding in situations where both treatments are being considered. Additional research is warranted to determine the longer term effectiveness of these treatments, and their effect on natural revegetation rates.

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**Table 1.** Mean plus or minus (±) one standard deviation of slope, moisture content, and vegetation cover in the control and treatment plots in 2003.

| **Treatment** | **Slope (%)** | **Moisture content (%)** | **Vegetation cover (%)** |
|---|---|---|---|
| **Control** | 27.2 ± 4.3 | 7.3 ± 1.5 | 14.8 ± 9.0 |
| **Mulch** | 25.3 ± 5.4 | 6.0 ± 1.9 | 16.6 ± 8.2 |
| **Seed** | 25.7 ± 4.1 | 6.3 ± 1.4 | 15.1 ± 9.9 |

**Table 2.** Total runoff, peak runoff and total erosion in treatment and control plots in 2003. Treatments: AG = aerial grass seeding, SM = straw mulching, UC = untreated control.

| | Treatment | Range | Mean | Coefficient of Variability (%) |
|---|---|---|---|---|
| Time to equilibrium (minutes) | Control | 7 – 28 | 15.5 | 42 |
| | Mulch | 8 – 26 | 16.0 | 33 |

| | | | | |
|---|---|---|---|---|
| | Seed | 8 – 36 | 20.6 | 48 |
| Total runoff (mm) | Control | 12 – 64 | 44 | 40 |
| | Mulch | 1.4 – 56 | 28 | 69 |
| | Seed | 7.1 –52 | 30 | 46 |
| Peak runoff (mm/hr) | Control | 18 – 79 | 59 | 32 |
| | Mulch | 4 – 75 | 40 | 63 |
| | Seed | 12 – 62 | 41 | 39 |
| Total erosion ($kg/m^2$) | Control | 0.04 – 1.2 | 0.79 | 54 |
| | Mulch | 0.01 – 0.25 | 0.10 | 89 |
| | Seed | 0.01 – 1.75 | 0.59 | 83 |

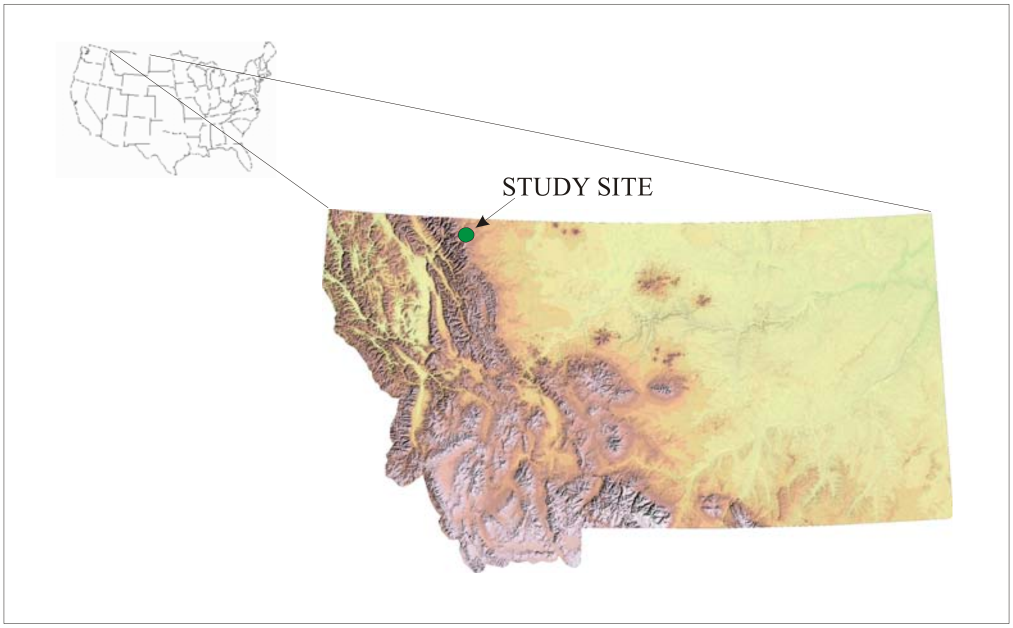


**Figure 1.** Location map of study area in northern Montana.

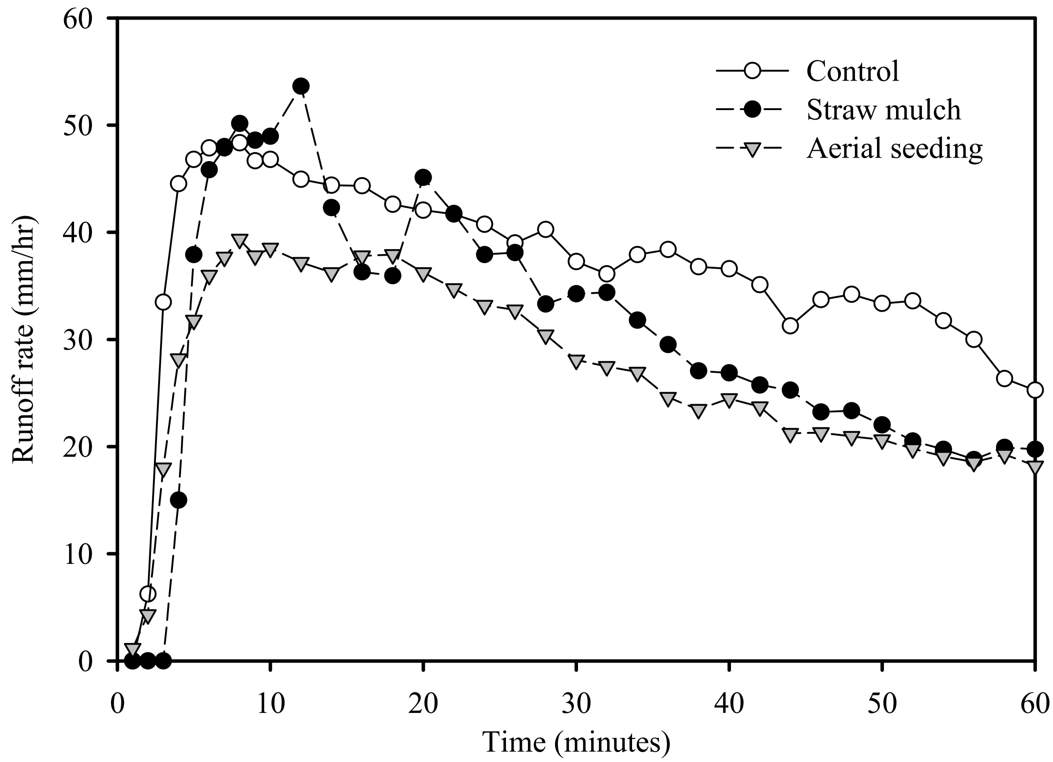


**Figure 2.** Mean runoff hydrographs for control, straw mulch and aerial seeding treatments in 2003.

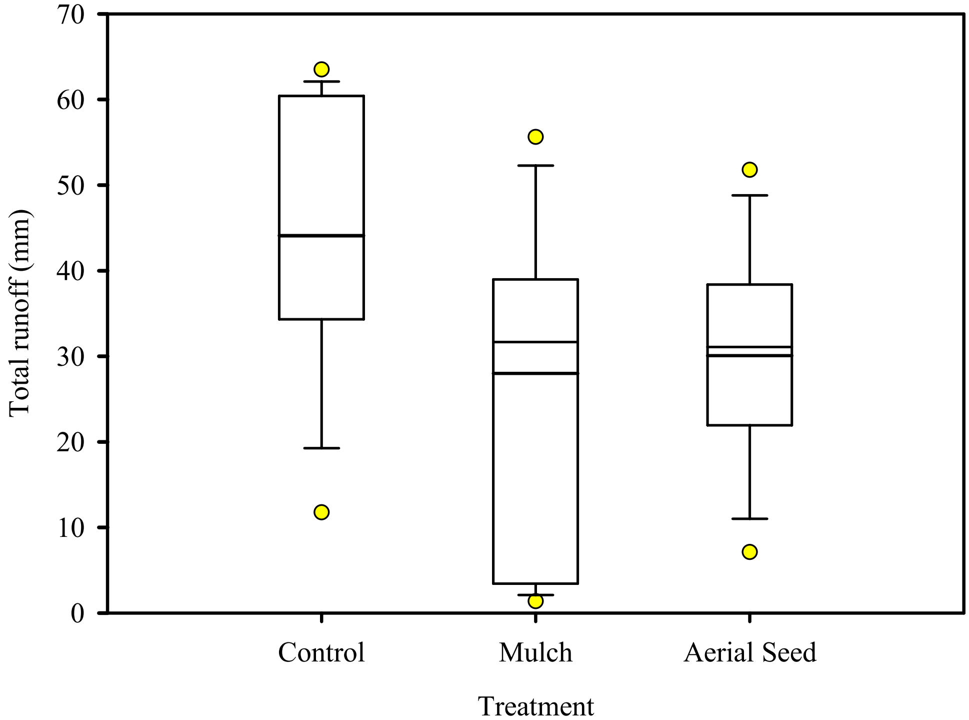


**Figure 3.** Total runoff from control, mulch and aerial seeded plots in 2003. Thin line inside box indicates mean, thick line indicates median. Box ends indicate 25th and 75th percentiles. Whiskers indicate 10th and 90th percentiles. Circles denote outliers.

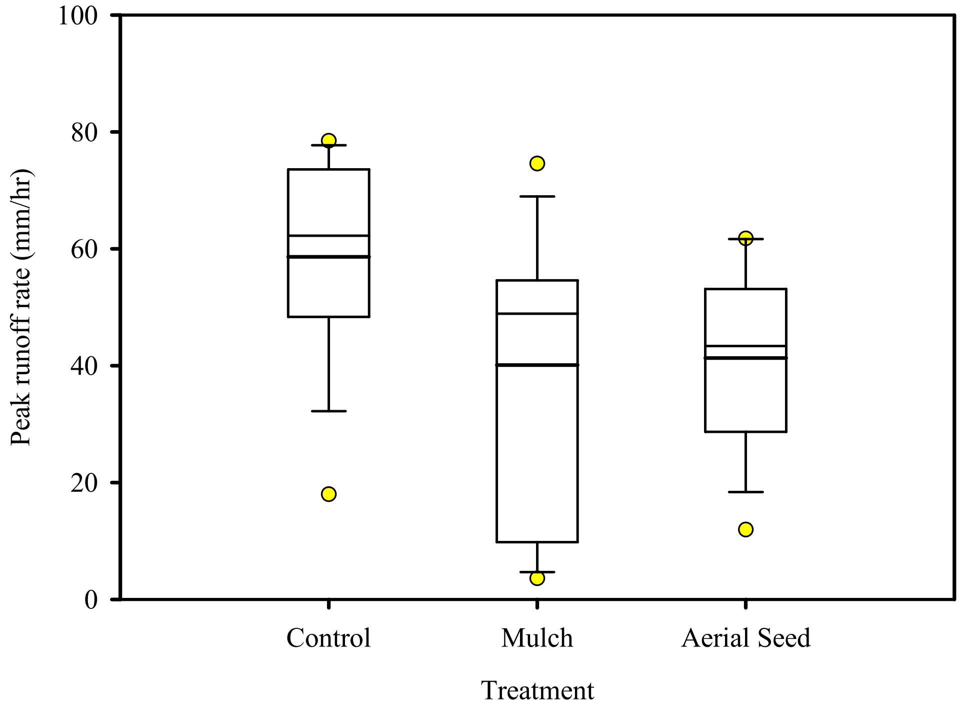


**Figure 4.** Peak runoff from control, mulch and aerial seeded plots in 2003. Thin line inside box indicates mean, thick line indicates median. Box ends indicate 25th and 75th percentiles. Whiskers indicate 10th and 90th percentiles. Circles denote outliers.

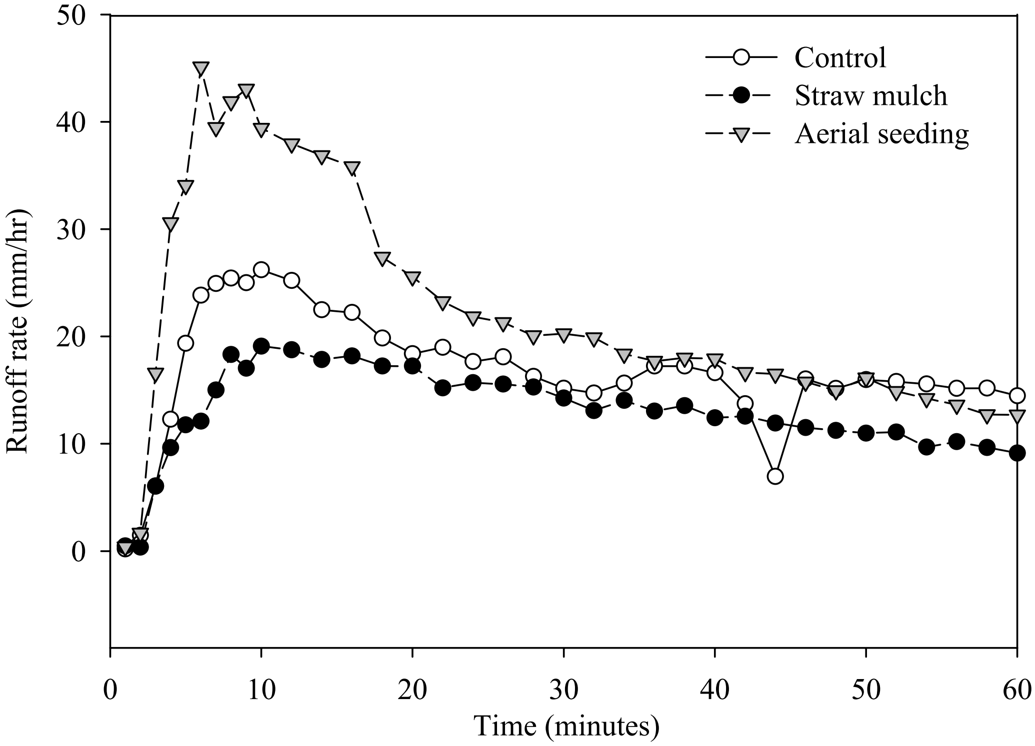


Figure 5. **Mean runoff hydrographs for control, straw mulch and aerial seeding treatments in 2004**