HYDROSEEDING APPLICATION ON DEGRADED SLOPES IN THE SOUTHERN MEDITERRANEAN AREA (SICILY)

M. Vallone, F. Pipitone, M. Alleri, P. Febo, P. Catania

ABSTRACT. *Hydroseeding is a technique increasingly used to establish vegetation on degraded areas in order to provide environmental protection. The objective of this article was to evaluate the effectiveness of four different hydroseeding methods (bonded fiber matrix hydroseeding, thick hydroseeding, reinforced hydroseeding plus water retention, and reinforced hydroseeding) on a degraded artificial slope in the southern Mediterranean area determining total vegetation cover, hydroseeding vegetation cover, hydroseeding success index (HSI), natural and hydroseeded vegetation height. The test area does not allow the use of any operating machinery for soil and vegetation management, and the only applicable technique is therefore hydroseeding. After hydroseeding was applied (in December 2010), 21 checks were carried out every 15 days (from January 2011-December 2011) to verify the occurrence and development of the hydroseeded species in order to evaluate the effectiveness of the different hydroseeding techniques in the study area. The results of the first experimentation performed in Sicily show that hydroseeding has good prospects of application on degraded areas in semiarid Mediterranean environments. In our study HSI > 0.8 was obtained only in test 2 (thick hydroseeding, period February-June 2011) where there was the simultaneous presence of earthworm humus and mulch.*

Keywords. *Degraded area, Hydroseeding, Reclamation, Semiarid climate.*

Hydroseeding is a technique which involves the application of a complex mixture of seeds, fertilizers, vegetable adhesives, mulch, and water on soils, through a suitable hydroseeding machine.

This is a technique increasingly used to establish vegetation on degraded areas in order to provide environmental protection; in EU countries it is primarily used for embankment and slope consolidation as well as for the recovery of abandoned quarries and landfill sites, and for the planting of lawns (Muzzi et al., 1997; Bochet and Garcìa-Fayos, 2004; Oliveira et al., 2011).

Traditional sowing, in fact, would be ineffective in some areas which are difficult to recover, and here the use of hydroseeding would represent a valid option within soil bioengineering. Therefore, hydroseeding is often applied in very difficult areas in terms of slope, because it does not require the passage of the machine in the entire plot to be treated, as it surpasses the limits of applicability of other revegetation techniques.

Many experimental studies have been conducted on hydroseeding technique and its applications (Albaladejo et al., 2000; Bradshaw, 2000; Matesanz et al., 2006; García-Palacios et al., 2010; Oliveira et al., 2011), but few cases are related to sites located in Italy, and no studies have been performed in the southern Mediterranean area. Hydroseeding application in Italy was carried out in the northern Appennine region in the context of reclamation and revegetation of former quarry land (Muzzi et al., 1997), obtaining poor results in terms of ground cover, species, runoff, and erosion. Other studies performed in Italy describe the functionality of hydroseeding machines with reference to the nozzle type and the homogenization of the mixture inside the tank (Balsari et al., 2005). It was found that the machines equipped with a mechanical mixer and small-sized tank (1000 L), provide good miscibility by comparison with higher capacity tanks. Machines with a hydraulic mixer were less efficient, showing lack of mixture homogeneity at all levels to fill the tank (Balsari et al., 2005).

In Spain, experimental tests were performed to minimize the environmental impact resulting from the construction of roads and to provide stability to the soil (Enriquez et al., 2004). It was noted that, in many cases, most of the sown commercial species disappear after the first growing season (Andrés and Jorba, 2000) and the total vegetation is usually too low to ensure erosion control, except in the most favorable conditions such as slight slope with north exposure (Bochet and García-Fayos, 2004). Native species may, therefore, be a good solution for the improvement of hydroseeding success on semi-arid slopes, bringing benefits to the environment, allowing the conservation of biodiversity and the formation of natural habitats for animals and plants, and helping to improve natural colonization (Novak and Prac, 2003; Petersen et al., 2004).

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It was also seen that the presence of an initial vegetative cover is important to start the stabilization process and the accumulation of fine material (Bradshaw, 2000; Parrotta and Knowles, 2001; Nicolau, 2002). In areas with a Mediterranean semi-arid climate, the low and uneven distribution of rainfall is the main factor limiting plant growth (Noy-Meir, 1973; Zohary, 1973) and vegetation cover tends to be low and sparse (Schlesinger et al., 1990).

In this study we present the first results of research carried out in Sicily, in a Mediterranean semi-arid environment, in order to test the revegetation of degraded slopes using hydroseeding and different types of implementation. We consider it necessary to apply different types of hydroseeding because this is the first study performed in Sicily and, therefore, we need to assess the effectiveness of the most widespread mixtures in our country.

The objective of this article is to evaluate the effectiveness of four different hydroseeding methods on a degraded artificial slope in the southern Mediterranean area by applying different mixtures, comparing them with each other in terms of hydroseeding vegetation cover, hydroseeding success index, hydroseeded vegetation height, and comparing them with the control, only in terms of total vegetation cover and natural vegetation height.

Materials and Method

Site Description

The tests were performed on 2 December 2010 in the territory of Sciacca, Italy (longitude 13° 5' E, latitude 37° 33' N). Autumn hydroseeding was expected to produce better plant establishment (Cano et al., 2002; Alday et al., 2008) so we considered it the best time to carry out the experiments. Vegetation sampling was carried out from January 2011 until December 2011.

The test area has an eastern exposure and the altitude is approximately 160 m above sea level; the distance from the Mediterranean Sea is approximately 1.5 km. The land is irregular and with a uniform slope of about 35°. It is a highly degraded area, subject to severe erosion, with poor and sparse vegetation, and so did not allow the use of any machinery for soil and vegetation management. The only applicable technique is, therefore, hydroseeding.

Prior to the tests an annual study was conducted, aimed at identifying the native plant species. This study showed the soil to be poor in vegetation in winter, while in spring the first spontaneous species were observed. The following varieties were identified: *Malva nicaensis, Anagallis arvensis, Avena barbata, Chrysanthemum coronarium, Convolvulus tricolor, Galactites tomentosa, Hirschfeldia incana, Melilotus sulcata, Oxalis pes-caprae, Papaver rhoeas, Picris echioides, Sonchus oleraceus, Melilotus segetalis, Hedysarum coronarium, Ridolfia segetum*. The percentage distribution in early May 2010 was: 60% *Avena barbata*, 30% *Hedysarum coronarium*, 10% the rest.

Climate

The evolution of the main weather-climatic parameters (temperature, relative humidity, precipitation) was studied in the period before the intervention (1 Nov. 2008 – 1 Dec. 2010), in order to assess any critical points in the seed germination and subsequent growth of plants. It was also monitored after the intervention, until December 2011.

The data provided by the fixed meteorological station of the local government agency (SIAS – Sicilian Region) were examined with reference to the station located in Sciacca, which was the closest to the experimental site.

Soil Sampling

Soil was sampled, using a soil auger, to a depth of 0.10 m before hydroseeding was applied; soil was taken at three random points inside the study area, then bulked and mixed to obtain a representative soil sample. The following soil physico-chemical properties were determined: particle size distribution, pH, electrical conductivity, salinity, total and active calcium carbonate, organic carbon, total organic matter, macro and micro elements (table 1).

Hydroseeding Machine

The machine used for hydroseeding (model 500L, Agrotec, Padua, Italy) consists of a steel frame with a 500 L polyethylene tank, with a mechanical system to shake the mixture, a pump (flow 120 L min^{-1}, head 15 m), a motor for the pump, and a system for distributing the mixture. The hydroseeder has a B&S single cylinder engine, 7.7 kW powered, air-cooled. During the tests the machine was placed on a trailer pulled by a tractor located on the field side. The water and mulch slurry was distributed through a 30 m length pipe equipped with a fan nozzle.

Experimental design and hydroseeding mixtures

After studying the geomorphologic, soil and climate characteristics of the area, we identified five experimental treatments. Three 9 × 21 m blocks were located and divided into five subplots, 3 × 7 m each, where the treatments were randomly performed (fig. 1). An untreated strip 1 m width was left around the subplots. The following treatments were applied:

- Test 1, bonded fiber matrix hydroseeding;
- Test 2, thick hydroseeding;
- Test 3, reinforced hydroseeding plus water retention;

Table 1. Soil physico-chemical properties.[a]

Soil Properties	Value
Sand (%)	14±0.88
Silt (%)	20±0.67
Clay (%)	66±0.33
pH	7.54±0.04
Electrical conductivity (mS cm^{-1})	7.9±0.02
Salinity (mg kg^{-1})	2.2±0.01
Total $CaCO_3$ (%)	32±1.10
Active $CaCO_3$ (%)	6.7±0.02
Organic carbon (%)	0.19±0.01
Total organic matter (%)	0.32±0.01
Exchangeable potassium (K_2O) (mg kg^{-1})	305±11
Total nitrogen (NH_4^+) (mg kg^{-1})	363±10
Available phosphorus (P_2O_5) (mg kg^{-1})	7.3±0.02

[a] Numeric values are means ± standard error of three replicates.

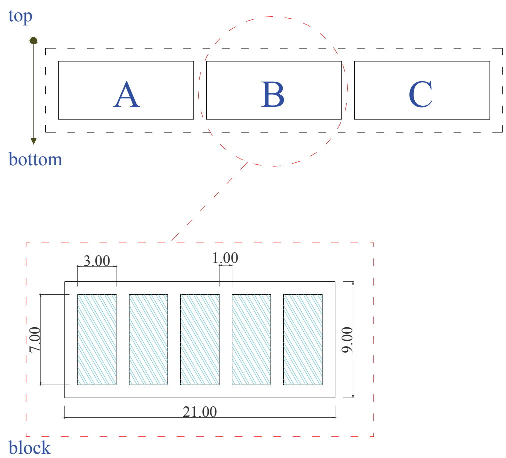

Figure 1. Experimental design. The three 9 × 21 m blocks (A, B, C) were randomly established; each block contained the five randomly assigned treatments performed on five 3 × 7 m subplots (lower illustration). An untreated strip 1 m width was left around each subplot.

- Test 4, reinforced hydroseeding;
- Test 5, control (no hydroseeding).

The composition of the mixtures distributed in the different tests are listed below in detail.

- Test 1, bonded fiber matrix hydroseeding: water (8 L m^{-2}), Dung fertilizer (470 g m^{-2}), Idrostart fertilizer (15 g m^{-2}), Biosol organic fertilizer (120 g m^{-2}), Soilguard Hydromat biomat (400 g m^{-2}), seed mixture (30 g m^{-2}).
- Test 2, thick hydroseeding: water (9 L m^{-2}), Dung fertilizer (200 g m^{-2}), Idrostart fertilizer (15 g m^{-2}), Biosol organic fertilizer (400 g m^{-2}), earthworm humus (400 g m^{-2}), full-tack adhesive (15 g m^{-2}), seed mixture (30 g m^{-2}), mulch (200 g m^{-2}).
- Test 3, reinforced hydroseeding plus water retention: water (3 L m^{-2}), Dung fertilizer (95 g m^{-2}), Biosol organic fertilizer (80 g m^{-2}), full-tack adhesive (10 g m^{-2}), seed mixture (30 g m^{-2}), mulch (95 g m^{-2}), Idrogel water retention (5 g m^{-2}).
- Test 4, reinforced hydroseeding: water (3 L m^{-2}), Dung fertilizer (95 g m^{-2}), Biosol organic fertilizer (80 g m^{-2}), full-tack adhesive (10 g m^{-2}), seed mixture (30 g m^{-2}), mulch (95 g m^{-2}).

The species composition of the commercial seed mixture used in the hydroseeding treatments is shown in table 2; the choice of a commercial mixture was recently supported by Oliveira et al. (2011) who revealed some drawbacks in the use of native species as relatively slow germination, seasonality, and seed dormancy-breaking requirements. However, we note that many studies recommend the use of native species in performing hydroseeding (Paschke et al., 2000; Matesanz et al., 2006; Tinsley et al., 2006; Tormo et al., 2007; Bochet et al., 2010a, 2010b; Garcia-Palacios et al., 2010; Madruga-Andreu et al., 2011) comparing them to commercial ones, and deriving from native species a better plant cover in exchange for a higher initial cost.

Our seed mixture contains four varieties belonging to *Gramineae* (*Lolium perenne, Festuca arundinacea, Cynodon dactilis,* and *Paspalum notatum*) and three varieties belonging to *Leguminosae* (*Trifolium repens, Vicia villosa,* and *Lotus corniculatus*). Grasses are the most abundant as they constitute 70% of the total mixture, 30% of which is represented by *Lolium perenne*. The remaining 30% are legumes, 15% of which is Trifolium repens. Among the species used, *Lolium perenne* is three times more productive than *Trifolium repens* and is commonly used for reclamation also because it does not have dormant seeds (Strasburger et al., 1986).

Table 2. Composition of the seed mixture used in the hydroseeding treatments.

Family	Species	% of Seeds
Gramineae	*Lolium perenne*	30
	Festuca arundinacea	25
	Cynodon dactilis	10
	Paspalum notatum	5
Laguminosae	*Trifolium repens*	15
	Vicia villosa	10
	Lotus corniculatus	5

Two fertilizers were used for hydroseeding: Dung® and Biosol®, whose compositions are respectively shown in tables 3 and 4.

The microgranular binary fertilizer Idrostarter, chlorine low content and high phosphorus content (table 5), is specific for hydroseeding; it promotes root formation and stimulates bud growth. Trace elements such as molybdenum and zinc (completely soluble), play an intense action starter, accentuating the plastic function of the formulation.

Table 3. Dung® organo-mineral fertilizer composition.

Component	Percentage (w/w)
Total nitrogen	12
Organic nitrogen	4.5
Ammonia nitrogen	4.5
Urea nitrogen	3
Total phosphorus pentoxide	12
Phosphorus pentoxide (soluble in neutral ammonium citrate and water)	10
Water-soluble potassium oxide	17
Water-soluble phosphorus pentoxide	15
Organic carbon of biological origin	18
Raw materials: organic matrices	Feathers, dried blood
Raw materials: mineral matrices	Urea, diammonium phosphate, potassium sulphate

Table 4. Biosol® fertilizer composition.

Component	Percentage (w/w)
Water	4
Organic substances	85
Total nitrogen	6-8
Water-soluble nitrogen (NO^{3-})	< 0.5
Phosphorus (P_2O_5)	0.5-1.5
Potassium (K_2O)	0.5-1.5
Ratio C/N	6 : 1

Table 5. Idrostarter fertilizer composition.

Component	Percentage (w/w)
Total nitrogen	8
Ammonia nitrogen	8
Phosphorus pentoxide (soluble in neutral ammonium citrate and water)	40
Water-soluble phosphorus pentoxide	36
Water-soluble molybdenum	0.002
Water-soluble zinc	2

Table 6. Hydro-retainer Idrogel composition.

Component	Description
Composition	Polyacrylamide potassium based polymer
Appearance	White granules
Particle diameter	1-1.5 mm
Active content	90%
Specific gravity of dry polymer	1.08
Density (g cm^{-3})	0.85
Solubility	Insoluble in water, ether, alcohol, acetone and other organic solvents
Absorption capacity	500 times the dry weight
Available water for plants	95%-96%
Water absorbed pH	6-7
Effective life in the soil	2-5 years

Other materials used for realizing the mixtures were earthworm humus, a synthetic hydro-retainer Idrogel, the Hydrofibre mulch, the full-tack adhesive and the hydraulic biomat, Soilguard Hydromat, described below. Idrogel (table 6) is a non-toxic, non-hazardous, polyacrylamide potassium-based polymer.

The mulch used in the experiments is made up of 100% wood fiber (table 7); it helps to reduce erosion, retain moisture and facilitate germination.

Full-tack adhesive (table 8) is organic and formed by 86.5% of Guar dust.

The hydraulic biomat Soilguard Hydromat is composed of special vegetable fibers, adhesive and activator, which create (when dry) an anti-erosive biomat perfectly adherent to the ground. The matrix has a high water retention capacity, reducing leaching and facilitating germination.

VEGETATION SAMPLING

After hydroseeding was applied (December 2010), 21 checks were carried out every 15 days (from January 2011 to December 2011) to verify the occurrence and development of the hydroseeded species in order to evaluate the effectiveness of the different hydroseeding techniques in the study area. The observations were performed in three 1 × 1 m squares in each of the replicated treatments. All the parameters were calculated as the mean of the three replicates in each test.

The checks consisted of assessing the vegetation in all the plots, distinguishing between the hydroseeded species vegetation cover and the native species vegetation cover.

The vegetation cover due to all of the species present in each plot (total vegetation cover) and the cover of the hydroseeded species were visually estimated by the same observer (Matesanz et al., 2006; Martinez-Ruiz et al., 2007; Alday et al., 2008; Garcia-Palacios et al., 2010). The hydroseeding success index (HSI, ranging from 0 to 1) of Matesanz et al. (2006) was used to determine the relative contribution of hydroseeding to the community as:

$$HSI = HydC/TC \quad (1)$$

where HydC is the absolute cover of hydroseeded species and TC is the total vegetation cover of the plot in percentage. HSI was taken into account because it allows the evaluation of the success of the hydroseeded species in relation to the total vegetation cover (total vegetation cover as the sum of hydroseeded vegetation cover and native vegetation cover).

Natural vegetation height, hydroseeded vegetation height distinguished between grasses (*Gramineae*) and legumes (*Leguminosae*), were also recorded on the same dates.

STATISTICAL ANALYSES

The effects of block, check date, and test and their interactions on total vegetation cover, hydroseeded vegetation cover, HSI, natural vegetation height, hydroseeded vegetation height, distinguished between grasses and legumes, were analyzed by a general linear model (GLM). This is a methodology developed to build a statistical model describing the impact of one or more factors on one or more dependent variables; it is to be assumed that the errors follow a normal distribution.

The analysis was separately performed for all the measured parameters listed above. They were included in the model as dependent variables, always considering the block, the date and the test as independent variables. The variable "block" represents each of the three randomized blocks (named A, B, and C) identified in the area of intervention, inside of which the five tests were randomly repeated. The variable "date" is the date of the survey progressively carried out on vegetation. In total 21 measurements were performed every 15 days from the date of hydroseeding execution until the end of the monitoring period. The variable "test" represents the test performed, corresponding to the different type of hydroseeding applied (tests from 1 to 4). In some analyses the control was also included (test 5). Therefore we have three input factors (block, date, test) in the model and a response factor corresponding to one of the measured parameters. We considered the three input factors and studied the effects they have on the model and the interactions between the factors, considered two at a time. In the present case we studied the block, date, and test effects, and the block-date, block-test, date-test interactions. We also studied the Durbin-Watson statistic; it tests the residuals to determine the presence of any significant correlation from the regression analysis.

All the analyses were performed with the statistical software package Statgraphics centurion, version XV, Statpoint Inc. (Warrenton, Va., 2005).

Table 7. Hydrofibre mulch composition.

Component/Characteristics	Percentage/Description
Organic matter	98%
Ashes	2%
Color	green

Table 8. Full-tack adhesive composition.

Component	Percentage
Water	8
Fiber	0.5
Grass	0.5
Proteins	4
Ashes	0.5
Guar dust	86.5

Results

Meteorological Data

Mean monthly temperature and relative humidity (maximum and minimum) and total monthly precipitation derived from the Sicilian Region database (SIAS) in the period 1 November 2008 to 30 November 2010 before the intervention and 1 December 2010 to 31 December 2011 after hydroseeding application referred to Sciacca weather station, are shown in figures 2, 3, and 4.

From the meteorological data it emerges that the climate is semiarid, characterized by mild winters with rainfall concentrated in a short period and a long drought period from May to September. In particular, air temperature ranged from 5°C to 21°C (minima) and 14°C to 34°C (maxima); relative humidity ranged from 20% to 58% (minima) and 73% to 98% (maxima). Total monthly rainfall ranged from 0 (July 2009 and 2010) to 140 mm in January and October 2009.

Hydroseeded Vegetation Cover

Hydroseeded vegetation cover (%) was monitored for the four hydroseeding types applied (fig. 5). The highest values of this parameter were obtained in test 2, where thick hydroseeding was performed. In particular, in the period from February to May 2011, 80% of coverage was due to the hydroseeded species. Test 1, bonded fiber matrix hydroseeding, shows the second best result as it reached the value of 50% coverage due to hydroseeding, but only in correspondence to the control performed on 24 March 2011. Subsequently, it sharply decreases to 10% in April-May 2011. Tests 3 and 4 gave very similar results; in the period from February to May 2011 the hydroseeded vegetation cover was 30%.

All the tests show no coverage due to hydroseeding in the dry season (June-September 2011); in October we have the resumption of the hydroseeded species activities with increasing coverage values until the end of the survey (December 2011). The results of the statistical analysis for hydroseeded vegetation cover are shown in table 9 where

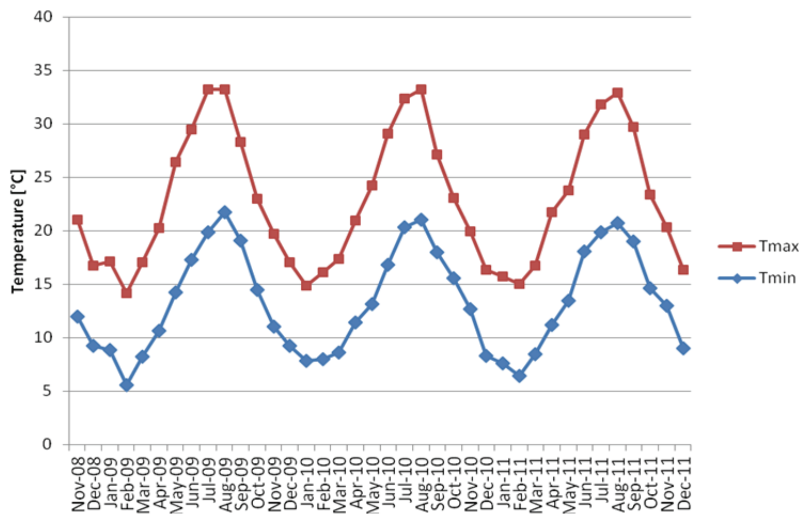

Figure 2. Mean monthly temperature (minimum and maximum) in the period 1 Nov. 2008 - 31 Dec. 2011. Data from the meteorological station of Sciacca belonging to the local government agency (SIAS).

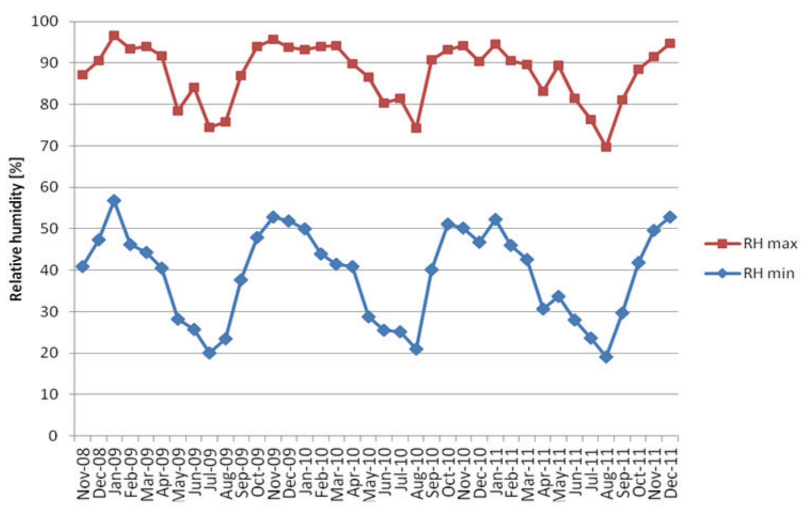

Figure 3. Mean monthly relative humidity (minimum and maximum) in the period 1 Nov. 2008 - 31 Dec. 2011. Data from the meteorological station of Sciacca belonging to the local government agency (SIAS).

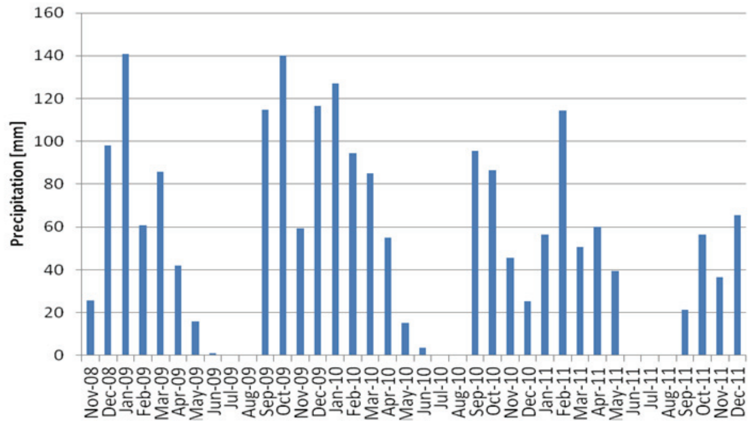

Figure 4. Total monthly precipitation in the period 1 Nov. 2008 - 31 Dec. 2011. Data from the meteorological station of Sciacca belonging to the local government agency (SIAS).

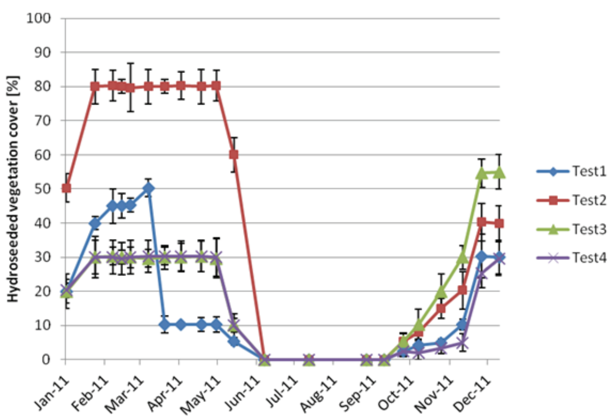

Figure 5. Hydroseeded vegetation cover during the period of observation (January 2011 -December 2011) in tests 1 to 4. Data are reported as means ± standard deviations of the three replicates. The observations were performed in three 1 m x 1 m squares in each of the replicated treatments.

the statistical significance of each of the factors is tested as it was entered into the model. Notice that the highest p-value is 0.6973, belonging to block-test interaction, therefore that term is not statistically significant at the 95.0% confidence level; the same for block-date interaction (p=0.2199) and the effect of the block (p=0.1379). The R-squared statistic indicates that the model as fitted explains 98.8282% of the variability in hydroseeded vegetation cover. The standard error of the estimate shows the standard deviation of the residuals to be 3.88356. The mean absolute error of 1.97578 is the average value of the residuals. Since the Durbin-Watson statistic p-value is 0.9985, there is no indication of serial autocorrelation in the residuals.

Hydroseeded vegetation consists of grasses and legumes; their contribution to the vegetation cover was separately assessed in the four experimental tests (fig. 6). The presence of grass is always higher than legumes; in particular, in tests 2, 3, and 4, 70% of the hydroseeded vegetation cover is attributable to grasses. Only in test 1, in the period from January to March, the grass cover due to grasses reached 90%.

Total Vegetation Cover

The values for total vegetation cover (%) observed in the monitoring period for the five tests are shown in figure 7. Total coverage includes both natural and hydroseeded vegetation. At the beginning of the monitoring period, December 2010, total vegetation cover gradually increased and reached 100% in the period between February and May 2011. Between June and September, the plant cover disappeared, and then came back with increasing trend until the end of the observation period.

Table 9. Results of the analysis of variance (GLM) performed for hydroseeded vegetation cover.

Source	Sum of Squares	Df	Mean Square	F-Ratio	p-value
Block	60.7698	2	30.3849	2.01	0.1379
Date	82038.5	20	4101.92	271.97	0.0000
Test	33827.3	3	11275.8	747.63	0.0000
block*date	726.73	40	18.1683	1.20	0.2199
block*test	57.9921	6	9.66534	0.64	0.6973
date*test	35929.9	60	598.832	39.71	0.0000
Residual	1809.84	120	15.082		
Total (corrected)	154451.	251			

Statistical Parameter	Value
R-squared	98.8282 %
Standard error of est	3.88356
Mean absolute error	1.97578
Durbin-Watson statistic	2.37094 (P = 0.9985)

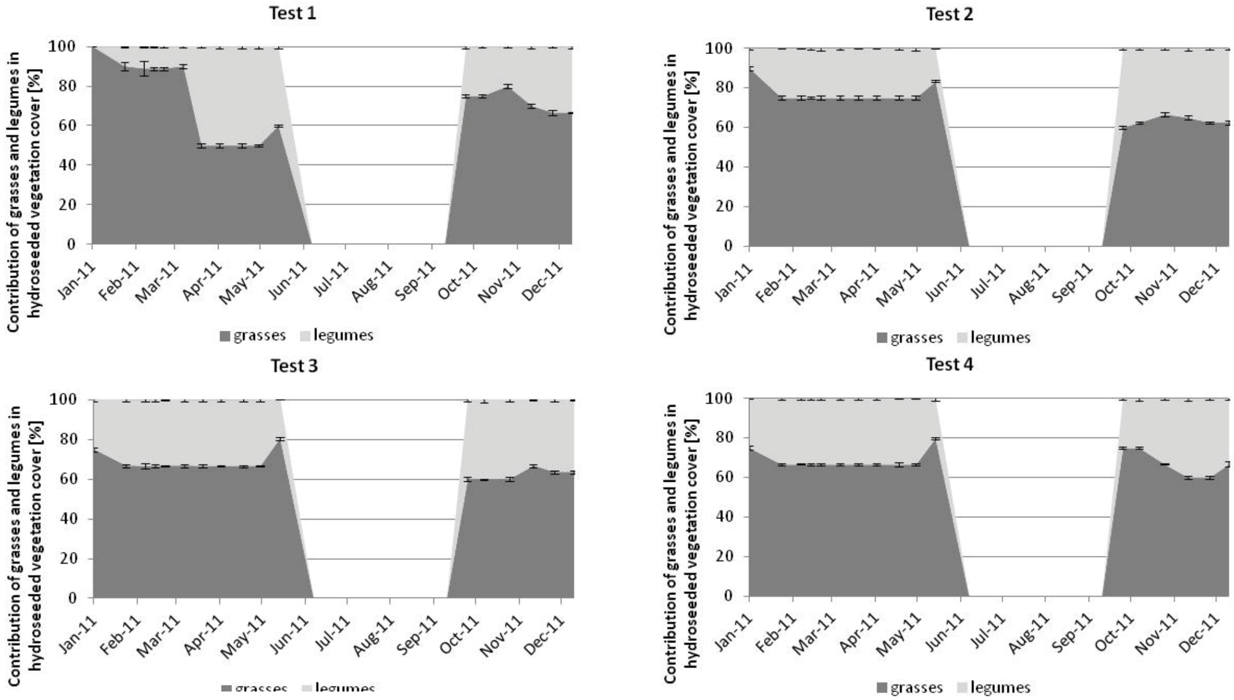

Figure 6. Contribution of grasses and legumes in hydroseeded vegetation cover during the period of observation (January 2011-December 2011) in tests 1 to 4. Data are reported as means ± standard deviations of the three replicates.

Table 10. Results of the analysis of variance (GLM) performed for total vegetation cover.

Source	Sum of Squares	Df	Mean Square	F-Ratio	p-value
Block	270.559	2	135.279	15.93	0.0000
Date	494836	20	24741.8	2913.67	0.0000
Test	3236.39	4	809.098	95.28	0.0000
block*date	586.641	40	14.666	1.73	0.0095
block*test	78.1397	8	9.76746	1.15	0.3328
date*test	10210.4	80	127.63	15.03	0.0000
Residual	1358.66	160	8.49163		
Total (corrected)	510577	314			
Statistical Parameter	Value				
R-squared	99.7339 %				
Standard error of est	2.91404				
Mean absolute error	1.4195				
Durbin-Watson statistic	2.53539 (P = 1.0000)				

The results of the statistical analysis performed in reference to total vegetation cover are reported in table 10.

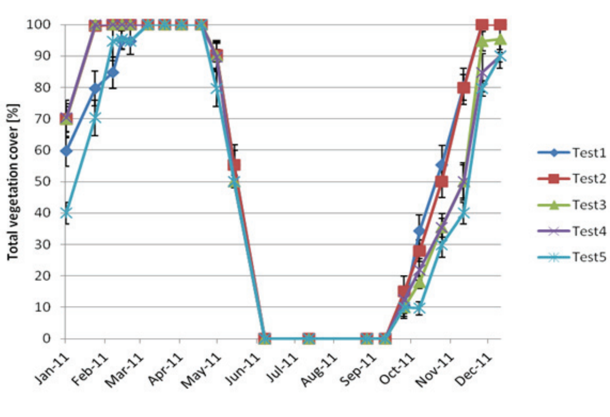

Figure 7. Total vegetation cover in the five tests during the period of observation (January 2011-December 2011). Data are reported as means ± standard deviations of the three replicates. The observations were performed in three 1 × 1 m squares in each of the replicated treatments.

Notice that the highest p-value is 0.3328, belonging to block-test interaction. The R-squared statistic indicates that the model fits the data very well; the standard deviation of the residuals is 2.91404 while the average value is 1.4195. The Durbin-Watson statistic shows that there is no indication of serial autocorrelation in the residuals.

HYDROSEEDING SUCCESS INDEX (HSI)

HSI gives information about the effectiveness of hydroseeding because it relates the hydroseeded vegetation cover to total cover which aids in highlighting the role played by hydroseeding on the restoration process of the study area. From the observations it emerges (fig. 8) that the most successful test in the period January-June is test 2 (thick hydroseeding), while tests 3 and 4 show lower success in the same period. Test 1 is placed in an intermediate position between tests 3 and 4. In the period from October to December, HSI increases and reaches 0.60 only in test 3, while test 2 is merely 0.4.

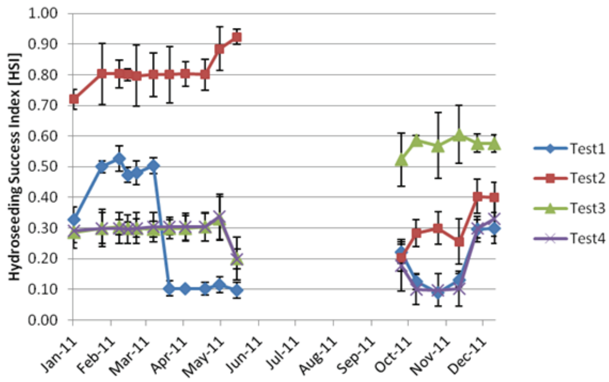

Figure 8. Hydroseeding Success Index in the 4 tests during the period of observation (January 2011 -December 2011). Data are reported as means ± standard deviations of the three replicates. The observations were performed in three 1 × 1 m squares in each of the replicated treatments.

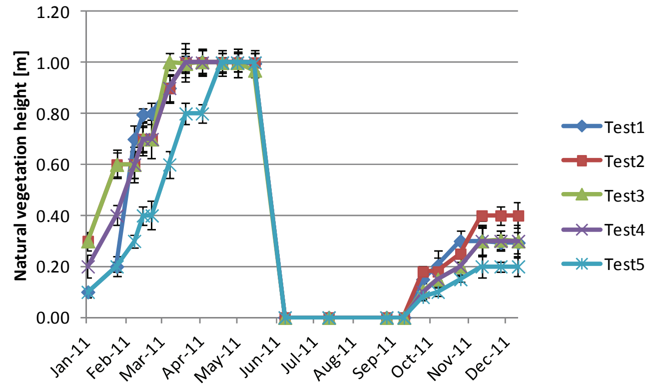

Figure 9. Natural vegetation height in the 4 tests during the period of observation (January 2011-December 2011). Data are reported as means ± standard deviations of the three replicates. The observations were performed in three 1 × 1 m squares in each of the replicated treatments.

The statistical analysis for HSI (table 11) shows the highest p-value to be 0.8343, belonging to block factor. This term is not statistically significant at the 95.0% confidence level; the same for block-date interaction (p=0.1118) and block-test interaction (p=0.1392). The model explains 96.3078 % of the variability (R-Squared statistic) in HSI. The standard error of the estimate shows the standard deviation of the residuals to be 0.0679231. The mean absolute error of 0.0353561 is the average value of the residuals. The Durbin-Watson statistic tests no indication of serial autocorrelation in the residuals.

Natural Vegetation Height

Natural vegetation height reaches 1.00 m in April in the four hydroseeding tests before the control, where this value can be observed from May onwards (fig. 9). This is probably due to the effect of the fertilizers used in the mixture for hydroseeding, which has contributed positively to the height of vegetation growth. Albaladejo et al. (2000) had the same result.

The statistical analysis for natural vegetation height (table 12) shows the highest p-value to be 0.3545, belonging to block-date interaction, and 0.1234 for block-test interaction; these terms are not statistically significant

Table 11. Results of the analysis of variance (GLM) performed for HSI..

Source	Sum of Squares	Df	Mean Square	F-Ratio	p-value
Block	0.00167451	2	0.000837255	0.18	0.8343
Date	1.10282	16	0.0689263	14.94	0.0000
Test	5.01697	3	1.67232	362.48	0.0000
block*date	0.205409	32	0.00641903	1.39	0.1118
block*test	0.045949	6	0.00765817	1.66	0.1392
date*test	5.17978	48	0.107912	23.39	0.0000
Residual	0.442901	96	0.00461355		
Total (corrected)	11.9955	203			

Statistical Parameter	Value
R-squared	96.3078 %
Standard Error of Est	0.0679231
Mean absolute error	0.0353561
Durbin-Watson statistic	2.32145 (P = 0.9893)

Table 12. Results of the analysis of variance (GLM) performed for natural vegetation height.

Source	Sum of Squares	Df	Mean Square	F-Ratio	p-value
Block	415.257	2	207.629	10.32	0.0001
Date	432928.	20	21646.4	1075.96	0.0000
Test	8557.84	4	2139.46	106.34	0.0000
block*date	872.076	40	21.8019	1.08	0.3545
block*test	260.425	8	32.5532	1.62	0.1234
date*test	13011.6	80	162.645	8.08	0.0000
Residual	3218.91	160	20.1182		
Total (corrected)	459264	314	207.629		

Statistical Parameter	Value
R-squared	99.2991 %
Standard error of est	4.48533
Mean absolute error	2.29227
Durbin-Watson statistic	2.87718 (P = 1.0000)

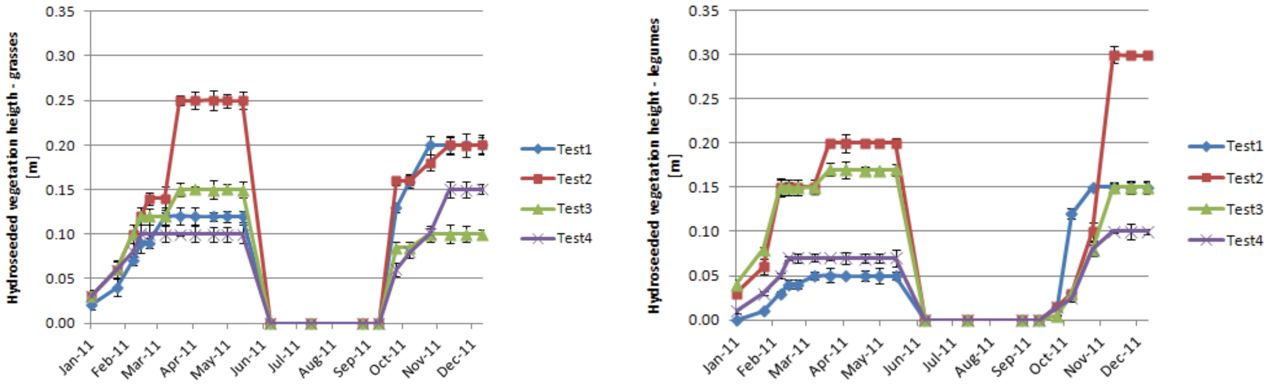

Figure 10. Hydroseeded vegetation height in the four tests during the period of observation (January 2011-December 2011) distinguished between grasses and legumes. Data are reported as means ± standard deviations of the three replicates. The observations were performed in three 1 × 1 m squares in each of the replicated treatments.

at the 95.0% confidence level. The model explains 99.2991% of the variability in natural vegetation height; the standard error of the estimate shows the standard deviation of the residuals to be 4.48533. The average value of the residuals is 2.29227 and the Durbin-Watson statistic gives no indication of serial autocorrelation in the residuals.

Hydroseeded Vegetation Height

Hydroseeded vegetation height was also examined (fig. 10) distinguishing between grasses (*Gramineae*) and legumes (*Leguminosae*). Grasses reached the maximum height of 0.25 m in test 2 in the period April-May; in the same period the other tests obtained values between 0.10 and 0.15 m in height. After the summer, the vegetation started growing and reached the maximum height of 0.20 m in tests 1 and 2. Legumes did not exceed the height of 0.20 m (test 2, April-May), always remaining lower than grasses except in test 3 (grasses-legumes height difference of 0.02 m). Note the considerable growth of legumes found in test 2 in the period from late November to late December. Overall, it can be stated that test 2 showed the greatest development in height.

The statistical analysis for grass height (table 13) shows that block-date interaction and block-test interaction are not statistically significant at the 95.0% confidence level, since the related p-values are 0.2046, and 0.099, respectively. The model explains 99.5519% of the variability in grass height and the standard deviation of the residuals is 0.689114, while the average value of the residuals is 0.355978. The Durbin-Watson statistic indicates that there is no serial autocorrelation in the residuals.

Table 14 tests the statistical significance of each of the considered factors for legume height. Notice that the highest p-values belong to block-date and block-test interactions (0.5736 and 0.9761, respectively); these terms are not statistically significant at the 95.0% confidence level. The model as fitted explains 99.7788 % of the variability in legumes height. The standard error of the estimate is 0.525514 and the average value of the residuals is 0.263968. The Durbin-Watson statistic tests that there is no significant correlation in the residuals.

Discussion

The results of the first experimentation performed in Sicily show that hydroseeding has good prospects of application on degraded areas in semiarid Mediterranean environments.

In our study HSI > 0.8 was obtained only in test 2 (thick hydroseeding, period February-June 2011) where there was the simultaneous presence of earthworm humus and mulch in addition to the components present in the other tests.

In this case we can consider that the environmental protection function of hydroseeding can be considered achieved as HSI reaches at least the value of 0.8, as stated by Alday et al. (2008). In our study the presence of mulch improved the effectiveness of hydroseeding, as Albaladejo et al. (2000) and Muzzi et al. (1997) have found.

Table 13. Results of the analysis of variance (GLM) performed for grass height.

Source	Sum of Squares	Df	Mean Square	F-Ratio	p-value
Block	7.75532	2	3.87766	8.17	0.0005
Date	9283.23	20	464.162	977.43	0.0000
Test	1345.19	3	448.395	944.23	0.0000
block*date	23.188	40	0.5797	1.22	0.2046
block*test	5.21135	6	0.868558	1.83	0.0990
date*test	1995.29	60	33.2548	70.03	0.0000
Residual	56.9853	120	0.474878		
Total (corrected)	12716.8	251			

Statistical Parameter	Value
R-squared	99.5519 %
Standard error of est	0.689114
Mean absolute error	0.355978
Durbin-Watson statistic	2.53379 (P = 1.000)

Table 14. Results of the analysis of variance (GLM) performed for legume height.

Source	Sum of Squares	Df	Mean Square	F-Ratio	p-value
Block	2.40722	2	1.20361	4.36	0.0149
Date	8870.28	20	443.514	1605.97	0.0000
Test	2762.86	3	920.954	3334.79	0.0000
block*date	10.4078	40	0.260194	0.94	0.5736
block*test	0.331825	6	0.0553042	0.20	0.9761
date*test	3301.76	60	55.0293	199.26	0.0000
Residual	33.1398	120	0.276165		
Total (corrected)	14981.2	251			

Statistical Parameter	Value
R-squared	99.7788 %
Standard error of est	0.525514
Mean absolute error	0.263968
Durbin-Watson statistic	2.78002 (P = 1.000)

Comparing the experimental tests we carried out, we note that during the rainy season, between January and March, the highest percentage of total vegetation cover was obtained in test 2. In the same period, the control test shows lower values of total vegetation cover up to 30% less than test 2. Similar results occurred in the period October - December. Therefore, test 2 gives the best results in terms of soil stabilization.

From the results of total vegetation cover, it appears that the biggest benefit of hydroseeding could be short-term soil stabilization. In fact, the largest difference in cover is observed before March, 2011.

Comparing our results with those of Alday et al. (2008), who successfully performed hydroseeding in autumn, we can say that our revegetation results are positive despite precipitation being no greater than average during, and just after, sowing.

In this first study irrigation was not taken into account as a technique to be applied after hydroseeding because the objective was to assess hydroseeding application under dry conditions.

Despite the success of test 2, the achievement of some of our tests was low (tests 3 and 4 throughout the period of observation and test 1 in October-December) and they would certainly be improved using irrigation as many authors suggest (García-Fayos et al., 2000; Tormo et al., 2006).

Many authors found that the main limiting factor affecting plant colonization in semiarid environments is water stress, causing low vegetal cover and sparse plant patterns (Tormo et al., 2006, 2008; Bochet et al., 2007). Even Garcia-Palacios et al. (2010) claim that when plant cover is higher than 50% in semiarid Mediterranean embankments, no treatments are necessary to control soil erosion, and that irrigation contributes to reducing it. Our trials gave total plant cover values lower than 50% in all of the tests in the June-October period, when it would be necessary to perform irrigation. In our latitudes, irrigation during the summer period would maintain a higher vegetative cover and obtain greater soil stability in autumn with the onset of the rainy season. Therefore, this possibility has to be taken into consideration in future trials to be performed in our latitudes.

These results are encouraging for the future because hydroseeding success would ensure a good growth of native species in the years after its application. This consideration is supported by Alday et al. (2011), as the success of the initial restoration treatments provides the starting species pool for the subsequent succession; indeed commercial seed mixtures act as facilitating species, growing rapidly for the first few years after hydroseeding, and gradually vanishing as more competitive or better adapted species colonize.

This contributes to implementation of the restoration process of the study area and could represent the value of hydroseeding success. In our study this could be verified by medium-term site monitoring. The results presented in this study are, in fact, related to an observation period of one year after hydroseeding; additional considerations will be made hereafter, as many authors have done in the medium term (Bochet et al., 2010b; Madruga-Andreu et al., 2011).

CONCLUSIONS

The results of different types of hydroseeding applied on a highly degraded area with a difficult climate allowed us to draw interesting conclusions.

Hydroseeding is applicable with satisfactory results in Sicily, where there is a typical southern Mediterranean climate characterized by mild winters and dry summers. This allows for recovery of highly degraded areas on which traditional machines trailed by or mounted on a tractor for soil and vegetation management cannot be used.

The study revealed that hydroseeding success is conditioned by the choice of the mixture components. In fact, on equal terms, the mixture including earthworm humus and mulch provided the best results in terms of vegetation cover. Regarding the mixtures that have not provided satisfactory vegetation cover, irrigation is essential as stated by other authors (García-Fayos et al., 2000; Tormo et al., 2006). The next step in determining the effectiveness of the four hydroseeding methods we applied in our region would be irrigation in the summer in order to maintain the vegetation cover reached in the spring period. This would contribute to obtaining higher soil stability in autumn with the onset of the rainy season. Our study shows that hydroseeding in our region can be applied, providing that mixtures containing mulch and humus are used, and that irrigation is carried out in the dry period.

The use of hydroseeding in degraded areas thus makes it possible to minimize the environmental impact of works and/or anthropic processes while giving stability to the ground. This is very relevant to our region, rich in archaeological, historical and artistic places of great value, as well as precious environmental resources which, in recent decades, have not always been respected by anthropogenic actions.

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