Effects of Revolution on soil wetting, turf performance, and nitrogen efficiency of a fairway prone to soil water repellency

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and Coen J. Ritsema

Alterra special report

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Abstract

Oostindie K., Dekker L..W., Geissen V., and Ritsema C.J. 2013. *Effects of Revolution on soil wetting and turf performance of a fairway prone to soil water repellency.* Wageningen, Alterra special report, 70 pp**.,** 53 Figs, 55 References.
This study reports on the effects of applications of the surfactant Revolution on soil wetting and turf performance of fairway 10 of the Rosendaelsche Golfclub, located near Arnhem, The Netherlands. In addition, the influence of Revolution on soil water repellency and the nitrogen contents in grass leaves, roots and upper 18 cm of the soil profile was investigated. The sandy soil of the fairway exhibits a water repellent behavior resulting in a lot of localized dry spots and poor turf quality, especially during dry periods in spring and summer. The influence of the treatments on the wetting of the soil was studied by measuring the volumetric water content with a hand-held Time Domain Reflectometry (TDR) probe. Actual water repellency was assessed by putting water drops at regular distances along soil cores which were taken to a depth of 25 cm with a small, 1.5 cm diameter auger. The 4 plots treated with Revolution had overall higher soil water contents, less water repellency and a better grass performance than the 4 untreated plots. The application of Revolution had no evident influence upon the total nitrogen concentration in the leaves and roots of the grass vegetation. However, the mean amounts of total nitrogen in the grass leaves from the Revolution treated plots were respectively, 27.7% and 11% higher than in those from the untreated plots on 9 July and 15 August. The higher amounts are due to the larger amounts of plant tissue present on the columns sampled from the treated plots. The mean concentrations N-(NO_3+NO_2) in the topsoil samples from the treated plots were on 9 July 29.3% and on 15 August 54.5% higher in comparison with the untreated plots. The mean concentration N- NH4 was in the topsoil samples from the treated plot 27.8% higher than from the untreated plots on 15 August. Since microbial mediated N mineralization is affected by moisture content, the higher N concentrations in the soil are thought to be related to the higher and more homogeneous moisture levels in the treated versus untreated plots. Applications of the soil surfactant Revolution resulted in dramatically improved soil wetting and turf performance. In addition to improved moisture availability, the better turf performance is likely affected by the increased plant available N in the soil which resulted from the more desirable and uniform moisture levels. These results are of interest for management of turfgrass with lower water and fertilizer inputs.

Keywords: actual water repellency, water drop penetration time (WDPT) test, Time Domain Reflectometry (TDR), nitrogen analyses.

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Highlights

Application with Revolution leads to:

1) Improvement of water supply in the root zone;
2) A more homogenous wetting and elimination of both soil water repellency and preferential flow;
3) A remarkable improvement in turfgrass performance;
4) A better nitrogen supply due to higher decomposition and mineralization rates.

Summary

The present experiments were performed on fairway 10 of the Rosendaelsche Golf club, located on a sandy soil near Arnhem in the Netherlands, between 29 March and 20 November, 2012.

The sandy topsoil of fairway 10 exhibits extreme water repellency after a prolonged dry period. In 2012 the effects were studied of applications with the surfactant Revolution upon the wetting of the soil and the turf performance. The surfactant was applied 6 times to plots of 2 m by 2 m.

To study the effects of Revolution applications on the wetting of the soil, an experimental site was chosen on fairway 10. This site was divided into eight plots with an area of 2 m by 2 m. Four plots were randomly used as control and four plots were randomly treated with the surfactant Revolution. The surfactant was applied 6 times between 29 March and 4 September. In addition, the influence of Revolution on the nitrogen contents in grass leaves and roots, and in the upper 18 cm of the soil profile was investigated.

The influence of the treatments on the wetting of the soil was studied by measuring the volumetric water content with a hand-held Time Domain Reflectometry (TDR) probe. Actual water repellency was assessed by putting water drops at regular distances along soil cores which were taken to a depth of 25 cm with a small, 1.5 cm diameter auger.

The Revolution treated plots contained notably higher mean soil water contents in the surface layer than the untreated plots after three Revolution applications and through the end of the experiment. Also the grass performance was significantly better on the Revolution treated plots in comparison with the untreated plots on the four sampling dates in July and August.

The application of Revolution had no evident influence upon the total nitrogen concentration in the leaves and roots of the grass vegetation on a straight forward g/kg basis. The mean nitrogen concentration in the leaf samples from the untreated and treated plots ranged, on all three sampling dates, between 13 and 21 g/kg. The range in the root samples was between 15 and 18 g/kg. However, the mean amounts of total nitrogen in the grass leaves from the Revolution treated plots were respectively, 27.7% and 11% higher than in those from the untreated plots on 9 July and 15 August. The higher amounts are due to the larger amount of plant tissue present on the columns sampled in the treated plots.

The organic matter content of the topsoil, which is important for the nitrogen cycle, was relatively high, with mean contents of 8.2% in the untreated and

8.3% in the treated plots. No significant differences in nitrogen analyses (Nt., N-NH_4, N-(NO_3+NO_2) and total soluble nitrogen) were assessed for topsoil and subsoil samples from untreated and treated plots, and for samples with lower and higher water content, on all three sampling dates.

The great differences in soil water content of the topsoil samples in the untreated plots is assumed to be caused by the presence of soil water repellency, which was only scarcely present in the treated plots. Also the greater heterogeneity of the wetting of the subsoil in the untreated plots in comparison with the treated plots, for example on 9 July, is assumed to be the consequence of the occurrence of soil water repellency and related preferential flow.

Higher water contents in topsoil and subsoil tended to result in higher N-(NO_3+NO_2) contents, presumably due to lateral water flow in the surface layer and the development of preferential flow paths into the subsoil.

On the Revolution treated plots the greenkeepers mowed and removed many more clippings (including nitrogen) than on the untreated plots. This was a consequence of the better grass performance during the growing season, especially in July, August, and September.

1. Introduction

The phenomenon of soil water repellency has been recognized in sand, sandy loam, loam, clay, peaty clay, clayey peat and sandy peat soils all over the world (Dekker *et al.*, 2005b). However, the phenomenon is most pronounced in course textured soils and is common in sandy soils supporting turf or pasture grasses (Wilkinson and Miller, 1978; York and Canaway, 2000; Karnok and Tucker, 2001a; Dekker *et al.*, 1998; Oostindie *et al.*, 2005a, b, 2006, 2007a, 2008b, c). It results in ongoing management problems on sand-based turfgrass systems (Cisar *et al*., 2000; Dekker *et al.*, 2004, 2008; Oostindie *et al.*, 2008a, 2009a, b).

Water repellency is influenced by season and soil water content. In most cases, repellency decreases during wet autumn and winter months and is most severe during dry periods in spring and summer. This seasonal variation may be due to soil moisture conditions. Extended dry periods accelerate the formation of water repellent soils. Likewise, extremely wet weather has been found to lessen or even eliminate water repellent behavior for several weeks. Research has identified that there is a critical soil water content for each layer in a water repellent soil, below which the soil is water repellent and above which the soil is wettable (Dekker and Ritsema, 1994; Dekker *et al.*, 2001b; Ritsema *et al.*, 2008).

Soil water repellency may dramatically affect field-scale water and solute movement and has often been underestimated (Bauters *et al.*, 2000). Water repellency and its spatial variability have been shown to cause a reduction in infiltration of irrigation water and precipitation, non-uniform wetting of soil profiles, increased runoff, and leaching due to preferential flow (Ritsema and Dekker, 1995, 1996, 2000; Ritsema *et al.*, 1993, 2004; Dekker *et al.*, 2001a; Oostindie *et al.*, 2007b). As water is a major transport mechanism for solutes, the presence of soil water repellency will have the same negative effects on solute transport and distribution.

Soil surfactants have been developed as a means for overcoming the problems of water repellency in soils (Letey *et al*., 1962; Moore, 1981; Rieke, 1981; Kostka *et al.,* 1997; Kostka, 2000; Thomas and Karcher, 2000; Oostindie *et al*., 2002, 2003; Dekker *et al*., 2000, 2005a). Soil surfactants can be formulated to have a strong affinity for the surfaces of hydrophobic soil particles allowing them to adsorb to those surfaces and enhance infiltration and water distribution in the regions of the soil where they have been applied. Soil surfactants are well documented for the management of water repellency in thatch and surface layers in sandy soils and for the enhancement of soil hydration in managed turfgrass (Karnok and Tucker, 2001b; Dekker *et al*., 2003; Oostindie *et al.*, 2008d, 2010a, b). An interesting overview of the evolution of soil wetting agents for managing soil water repellency has been published by Moore and Moore, 2005.

Maintenance of turf quality and simultaneous optimization of irrigation and conservation of water are goals of turfgrass managers, especially under dry conditions. Water may be conserved by maximizing the effectiveness of irrigation and precipitation as well as by minimizing the losses of water to surface runoff and leaching or drainage below the rooting zone. Soil surfactants may have a role to play in this (Kostka et al., 2007a, b, 2008; Oostindie *et al.*, 2008a, 2011).

Several field experiments executed during the last couple of years at different sites around the world indicate that regular applications of the soil surfactant (Revolution), substantially improve water infiltration processes in turfgrass rooting systems, leading to more homogeneous wetting and increased grass performance. Turfgrass on treated sites appears to have a much better and more uniform quality, and shows darker green leaves than found on untreated plots. It is hypothesized that the observed positive effects of regular Revolution treatments are caused by the combined effect of improved water availability for the grass, as well as increased nitrogen (N) availability. Decreases in soil water availability decreases microbial mobility and growth, which in turn are responsible for promoting N mineralization (Araya *et al*., 2012). In past experiments attention has been paid to the effect of Revolution applications upon the hydrological regime in rooting systems, however the potential effects of increased N availability have not received the required attention up to date.

The discussion of the fate of N applied to turfgrass will cover the five major categories of the N cycle : plant uptake, atmospheric loss, soil storage, leaching, and runoff. As illustrated in Fig. 1, N can be found in both organic and inorganic forms in the turfgrass plant-soil system. Inputs of N into the system are primarily from fertilizers but to a lesser extent from rainfall, irrigation, and biological N_2 fixation. Once the N is in the turfgrass plant-soil system it may be found in one of the N pools of NO_3, NH_4, soil organic N or in part of the turfgrass plant. Nitrogen leaves the system via several routes: gaseous loss to the atmosphere (NH_3 volatilization and denitrification), leaching into groundwater, runoff into surface water, and removal in the clippings of the turfgrass plant. Thatch, clippings and soil organic matter are significant sinks for N in turfgrass systems (Petrovic, 1990; Barton and Colmer, 2006; Araya *et al*., 2012).

In this study, specific attention has been paid trying to unravel the effects of regular Revolution applications on the nitrogen cycle (Fig. 1) in the turfgrass rooting system and the impact on N availability and N uptake by the grass between treated and untreated plots. For this purpose a series of field experiments were executed on fairway 10 of the Rosendaelsche golf club, representative of conditions found under regular golf course field conditions in the Netherlands and other areas of the world where golf is played.

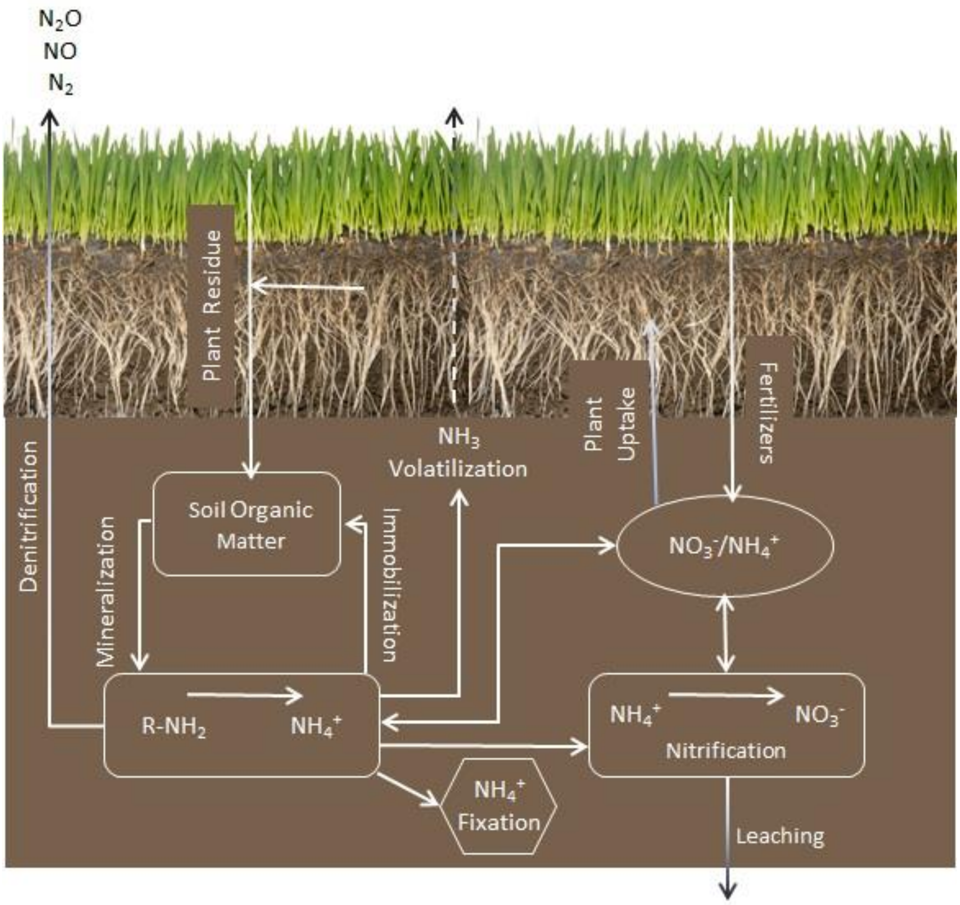

Figure 1 The nitrogen cycle in the rooting zone of the grass-covered soil of the fairway.

2. Soil and Measurements

2.1. The Experimental Site and Soil Profile

The present study was performed on the sandy fairway 10 of the Rosendaelsche Golf club, situated near Arnhem in the Netherlands, during the period 29 March to 20 November, 2012. The soil of the fairway consists of fine non-calcareous sand with less than 3% clay to a depth of more than 2 m. The sandy topsoil of fairway 10 is prone to water repellency after prolonged dry periods (Fig. 2.1).

Figure 2.1 The phenomenon of localized dry spots, due to soil water repellency, on fairway 10.

2.2. Surfactant Applications

To study the effects of surfactant applications on the wetting of the soil, an experimental site was chosen on this fairway (Fig. 2.2). The site was divided into eight plots with an area of 2 m by 2 m, with a distance of 0.5 m between the plots. Four plots were randomly used as control and four plots were randomly treated with the surfactant Revolution (Aquatrols, Paulsboro, New Jersey, USA). The surfactant was applied 6 times between 29 March and 4 September, 2012 at a rate of 1.9 ml/m^2 in a water volume of 70 ml/m^2, using a backpack sprayer. The 6 dates of applications are given in Table 2.1. On the same occasions an identical amount of water (70 ml/m^2 equal to 0.07 mm) has been applied to the untreated control plots.

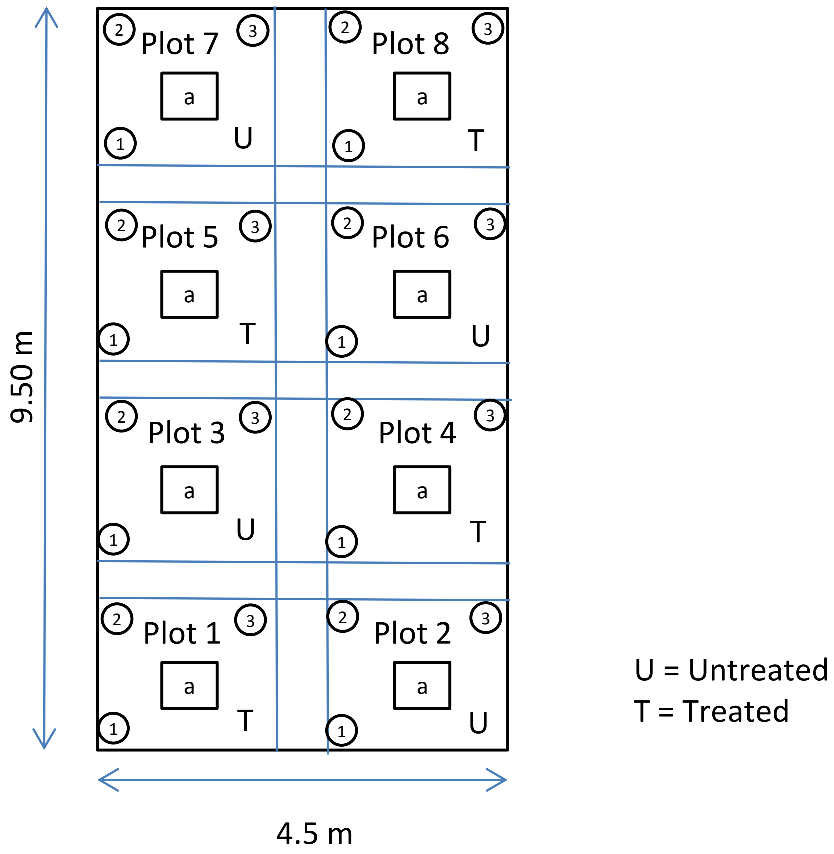

Figure 2.2 Layout of the experimental field with four plots for Revolution application and four plots for control. Turf performance estimation, soil water content measurement at 0-5 cm depth, and soil column sampling were carried out on 29 March, 9 July, and 15 August in the corners of the plots, respectively indicated with 1, 2, and 3. On the other six occasions turf performance estimation and soil water content measurements were carried out in the central part of the plots.

Table 2.1 Dates of treatment with Revolution and dates of estimation turf performance and measuring soil water content at depths of 0-5 cm with a TDR-device in 2012.

Application Revolution	Date	Measurements: Turf performance Soil water content	Date
1	29 March	1	29 March
2	27 April	2	27 April
3	29 May	3	29 May
4	3 July	4	3 July
5	30 July	5	9 July
6	4 September	6	30 July
		7	15 August
		8	4 September
		9	20 November

N.B. Dates of soil column sampling are indicated in red.

2.3. Estimation of Turf Performance

The turf performance of the 8 plots was mapped 9 times between 29 March and 20 November, 2008 (Table 2.1). For this purpose we made use of an iron grid of 50 cm by 50 cm consisting of 10 cm by 10 cm cutting faces (see Fig. 2.3). In any of the 25 compartments the percentage of green grass was estimated by using the following classes: >80%, 50-80%, and <50% green grass. To restrict disturbance of the plots from collecting of soil columns with the cup-cutter, on 29 March, 9 July, and 15 August the turf performance was estimated in one of the corners of the plots (see Fig. 2.2). On the other six occasions the turf performance was always estimated in the central part of the plots. The estimations in the 25 compartments were used for transforming the data into contour plots.

2.4. Measurement of Soil Water Content in the Surface Layer (0-5 cm)

Beginning on 29 March, 2012 volumetric soil water contents were measured in the surface layer at depths of 0-5 cm using a portable TDR-device (Fig. 2.4). The measurements were done in the 25 compartments of the iron grid, directly after the estimation of the turf performance. Thus, on 29 March, 9 July, and 15 August twenty five soil water contents were measured in one of the corners of the plots and on the other sampling occasions in the central part of the plots. The compartment with the lowest and the compartment with the highest soil water content on 29 March, 9 July, and 15 August were chosen for the soil core sampling with the cup-cutter. The soil water content data of the surface layer have been transformed into contour plots and used for making frequency distributions, with soil water content classes between 10 and 45 vol.% at intervals of 5 vol.%.

Figure 2.3 Estimation of the percentage green grass in adjacent compartments, squares of 10 cm by 10 cm, by using an iron grid of 1 m by 1 m.

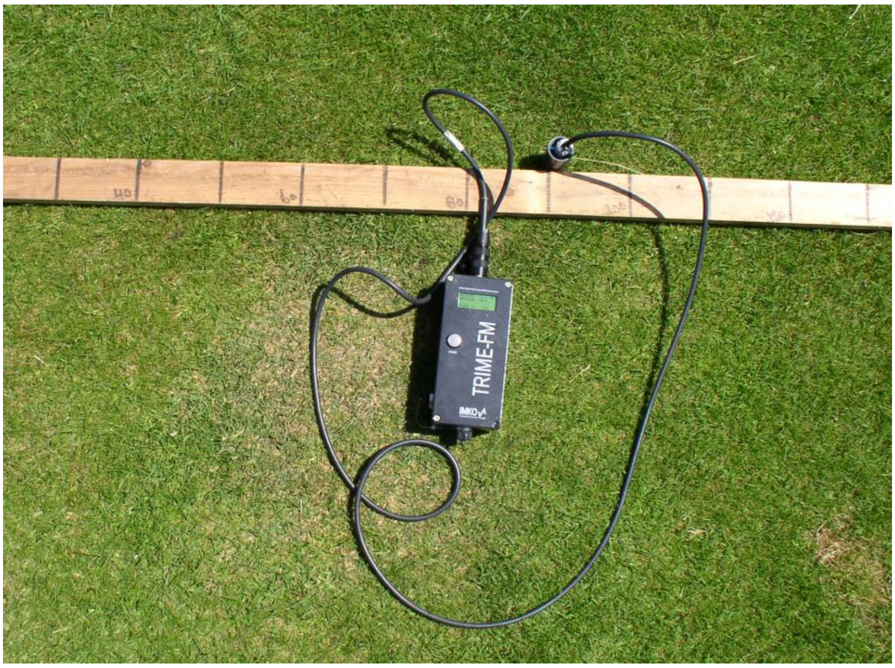

Figure 2.4 Portable TDR-device for measurement of the volumetric soil water content in the surface layer at depths of 0-5 cm.

2.5. Assessment of Actual Soil Water Repellency

On 4 September and 20 November, 2012 four soil cores were taken in the plots to a depth of 25 cm, using a small auger. The cores were sampled at distances of 40 cm across the eight plots. The actual water repellency was determined in the field by placing drops of water along the cores at intervals of 1 cm. The soil was considered water repellent if the infiltration of the drops exceeded 5 seconds and wettable if the drops disappeared within 5 seconds (Dekker et al., 2009). Depth and thickness of the actual water repellent soil of the cores were recorded.

2.6. Precipitation

Precipitation data was obtained from a nearby station. The total amount of precipitation between the dates of estimating the turf performance and measuring the soil water content of the surface layer are presented in Table 2.2.

The precipitation before the start of the experiment amounted to 34.2 mm for the month of February, whereas 22.5 mm precipitation fell between 1 March and 29 March. Figure 2.5 shows the daily precipitation from March to November, 2012.

Table 2.2 Precipitation (mm) between the dates of estimation turf performance, and measurement soil water content in the surface layer (0-5 cm) in the untreated and treated plots in 2012.

Dates of measurements	Precipitation	Dates of measurements	Precipitation
29 March – 27 April	73.3	9 July – 30 July	114.1
27 April – 29 May	85.9	30 July – 15 August	29.6
29 May – 3 July	94.1	15 August – 4 September	30.1
3 July – 9 July	13.3	4 September – 20 November	182.9

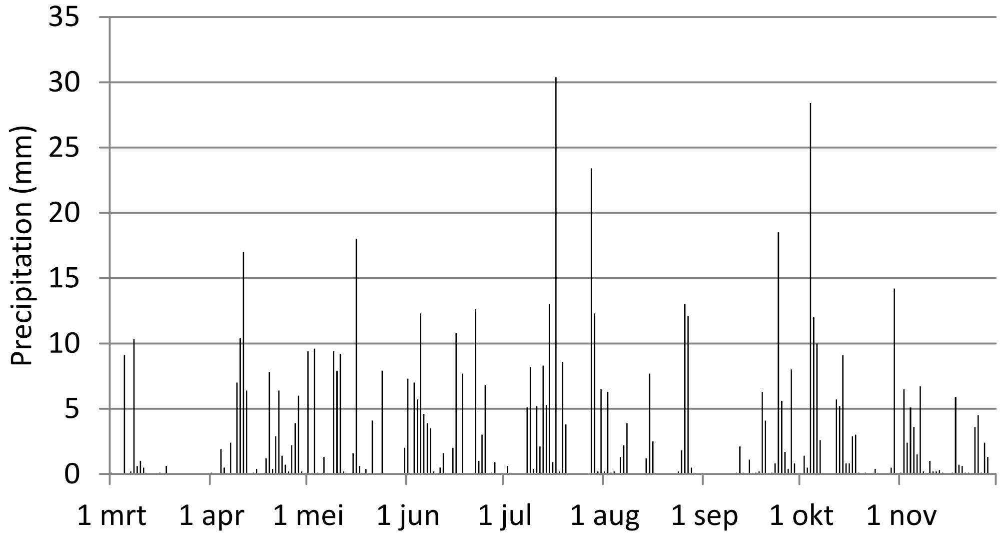

Figure 2.5 Daily precipitation from 1 March to 1 December, 2012.

2.7. Soil Column Sampling, Assessments, and Preparing Analyses

On the three sampling dates 29 March, 4 July, and 15 August two soil columns were collected with the cup-cutter in all eight plots. The soil columns were taken in the corner of the plots, where on that date the soil water contents were measured in the surface layer at depths of 0-5 cm, with the TDR-device (Fig. 2.2). One column was extracted from the square with the lowest (indicated with suffix D) soil water content of the 25 TDR measurements and the other column from the square with the highest (indicated with suffix W). The soil columns were taken to a depth of 18 cm and the holes were refilled with columns from a nursery (Fig. 2.6). The soil columns were split into two parts: a) the topsoil rich in organic matter and b) the subsoil poor in organic matter. The soil of the 32 soil samples was collected in plastic bags, which were tightly closed, transported to the laboratory, and weighed. The grass on the 16 topsoil samples was cut off with a pair of scissors, collected in aluminum boxes, and weighed.

The soil and grass samples were placed in a forced-air oven (70^{o}C) between 48 and 72 h. The samples were then weighed to obtain an oven-dried mass and the volumetric water content of the soil samples was calculated.

After drying, the soil samples were sieved with a mesh of 2 mm. The grass roots were separated from the soil and collected in aluminum boxes. The few grass roots present in the subsoil samples were added to those of the topsoil. The mineral particles >2 mm were weighed. The organic matter content was determined after oven-drying a portion of the soil samples <2 mm at 105^{0}C and thereafter at 450^{0}C, and by calculating the loss of organic matter as percentage of the soil dried at 105^{0}C.

The 16 grass and 16 root samples were milled into a fine particle size using a sample mill with a 1-mm mesh screen. The ground grass and root samples were analyzed for total N content by the chemical laboratory of Wageningen University.

The 16 topsoil and 16 subsoil samples were ground and submitted to the chemical laboratory of Wageningen University as well for analyzing total N content, N-(NO_3+NO_2), N-NH_4, and total soluble N content.

2.8. Fertilizer, Fairway Mowing, and Irrigation

The fairway was fertilized with "Sportsmaster", a quick working fertilizer, at a rate of 54 kg (24 kg N, 12 kg P, 18 kg K) per ha in May. Depending on the rate of the grass growth the fairway was mowed twice or three times a week during the months April to October, 2012. The fairway was irrigated two times in May after the fertilizer application. During the summer months the fairway was irrigated daily; however, only during dry periods, for about 20 min (3 mm) with permanent automatic sprinklers. On our request the sprinkler irrigation of fairway 10 was set on half the dose of the normally used application from 1 June on. This was arranged to prevent the occurrence of too wet a condition on the Revolution treated plots.

Figure 2.6 Taking the soil columns in the experimental plots with the cup-cutter to a depth of 18 cm, and refilling the holes with columns from a nursery.

3. Effects of Revolution Applications on Six Sampling Occasions

On six occasions the soil water content and grass performance were assessed in the center of the eight plots in 25 adjacent compartments, squares of 10 cm by 10 cm, in a grid of 50 cm x 50 cm. The occurrence of actual soil water repellency was measured on two occasions.

3.1. Effect on Water Content in the Surface Layer (0-5 cm)

Between the start of the experiment on 29 March and the second assessment date 73.3 mm of rain fell, 18 mm of which fell in the week before the field campaign on 27 April. Soil water contents at depths of 0-5 cm in the four untreated plots were relatively high and varied between 30 and 45 vol.% (Fig. 3.1). The soil water content of sixteen of the 25 measurements in the plots 2, 3, and 6, and of twenty-one from those in plot 7 varied between 35 and 40 vol.% (Fig. 3.2). The soil water contents in the surface layer of the four Revolution (one time) treated plots were very similar to those of the untreated plots and also varied between 30 and 45 vol.% (Fig. 3.3 and Fig. 3.4).

The rain amounted to 85.9 mm between 27 April and 29 May, and the sprinkler irrigation was used twice for watering in the applied fertilizer. Only 13 mm of rain fell in the 13 days before measuring the soil water contents on 29 May. The soil water contents in the surface layer of the four untreated plots were relatively low and varied between 10 and 25 vol.% (Fig. 3.1), with most water contents between 15 and 20 vol.% (Fig. 3.2). The soil water contents in the surface layer of the Revolution (two times) treated plots were slightly higher in three of the plots with values mainly between 15 and 25 vol.% (Fig. 3.3). The wetting of plot 5 was remarkably heterogeneous, with water contents divided over four moisture classes between 15 and 35 vol.% (Fig. 3.4).

In total 94.1 mm of rain was recorded between 29 May and 3 July, however only 1.6 mm fell in the 8 days before measuring the soil water contents on 3 July. The soil water contents were very low in the surface layer of the untreated plots 3 and 7, with values of mainly 10-15 vol.% (Fig. 3.1). However remarkably higher soil water contents of 20-25 vol.% were measured in plot 2. A large variation in soil water content, ranging from 10 to 30 vol.%, was assessed in the surface layer of plot 6 (see also Figs. 3.1 and 3.2). The soil water contents in the surface layer of the four Revolution (three times) treated plots were on 3 July clearly higher than on 29 May, and significantly higher than in the four untreated plots. The surface layer of plot 5 was on 27 April, as well as on 29 May and 3 July, the wettest of the four Revolution treated plots (Fig. 3.3).

Comparison of the 100 soil water content measurements in the four untreated and four Revolution treated plots, shows that they were more or less similar on 27 April. However, they were notably higher in the Revolution treated plots on 29 May and significantly higher on 3 July than those from the untreated plots (Fig. 3.5).

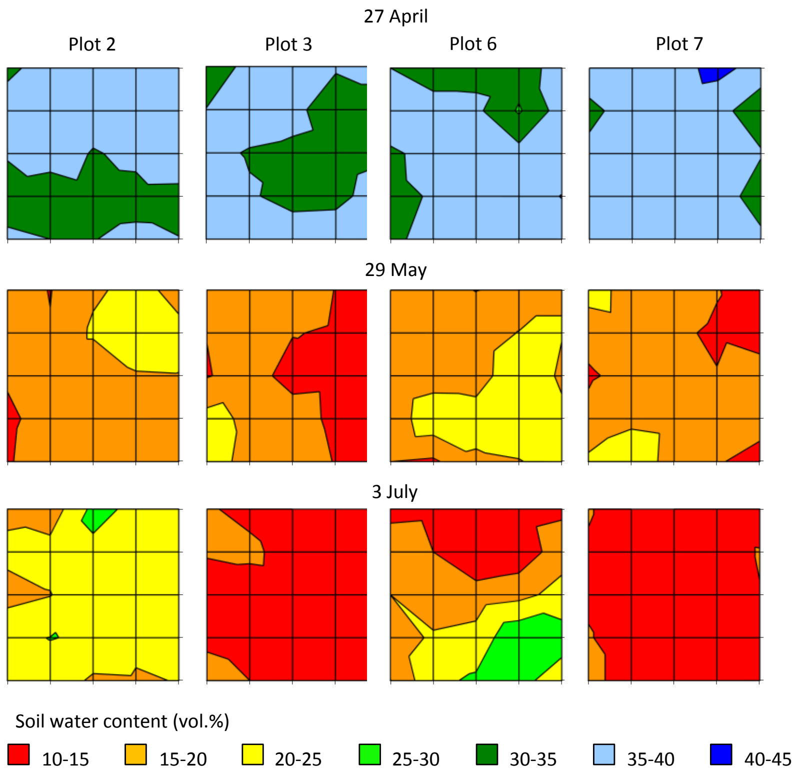

Figure 3.1 Top views (50 cm x 50 cm) with contours of the volumetric soil water content at 0-5 cm depth in the four untreated plots on 27 April, 29 May, and 3 July, 2012.

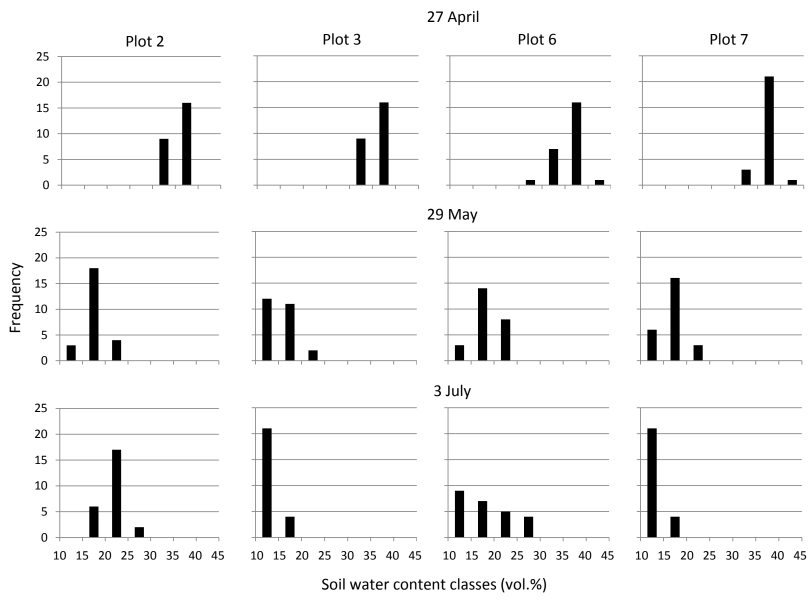

Figure 3.2 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in the four untreated plots on 27 April, 29 May, and 3 July, 2012 (n = 25).

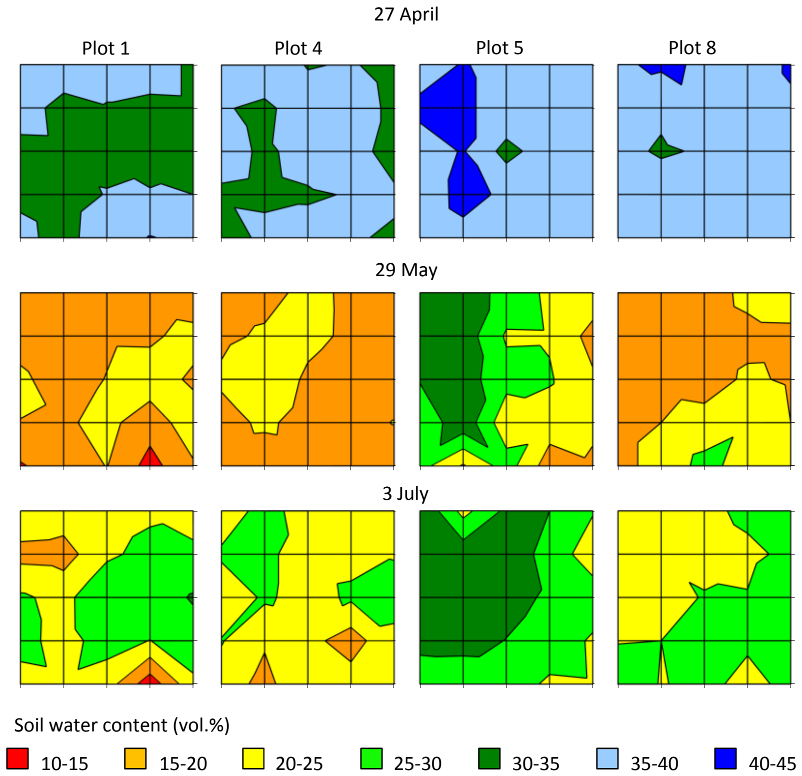

Figure 3.3 Top views (50 cm x 50 cm) with contours of the volumetric soil water content at 0-5 cm depth in the four Revolution treated plots on 27 April, 29 May, and 3 July, 2012.

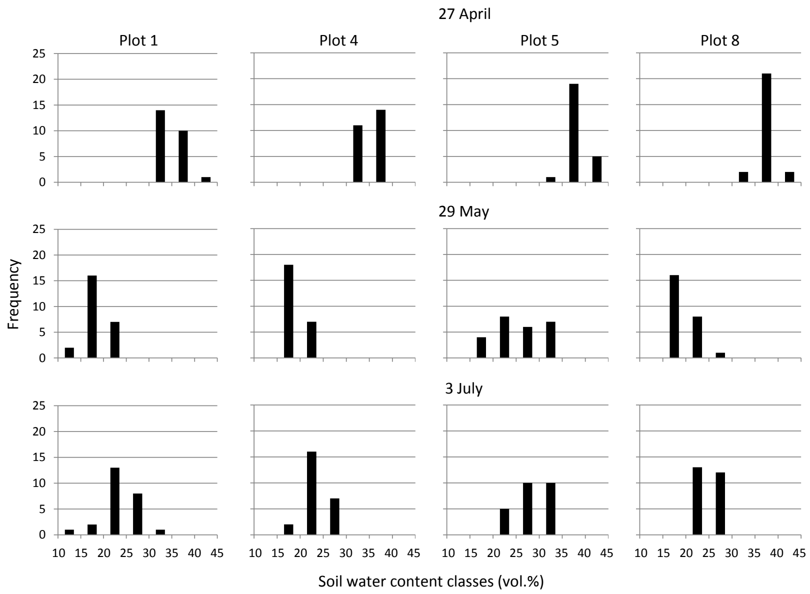

Figure 3.4 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in the four Revolution treated plots on 27 April, 29 May, and 3 July, 2012 (n = 25).

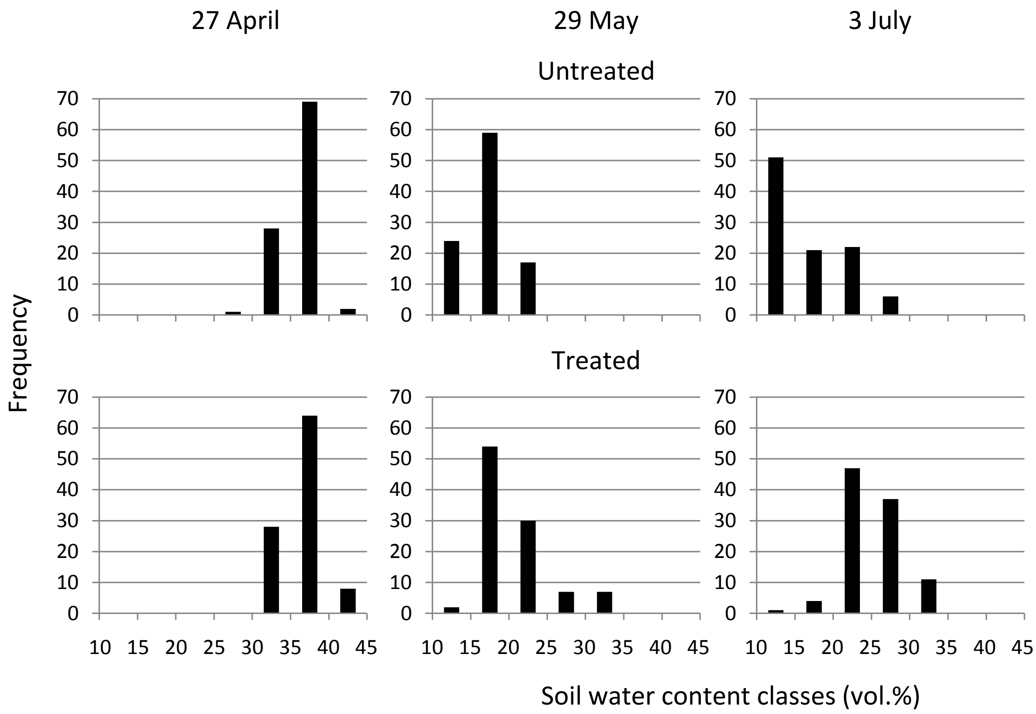

Figure 3.5 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in all untreated and Revolution treated plots on 27 April, 29 May, and 3 July, 2012 (n = 100).

Between 3 July and 30 July the precipitation amounted to 127.4 mm, of which 36 mm fell in the three days before the sampling on 30 July. A large amount of rain fell between 7 and 19 July, followed by 7 days without any precipitation. The soil water contents in the surface layer of the untreated plots were, despite the high amount of rain in July, only slightly higher on 30 July than on 3 July (compare Fig. 3.6 with Fig. 3.1). Large differences in soil water content were present on 30 July in the untreated plots 2, 6, and 7, with values ranging between 10 and 35 vol.% (Fig. 3.7). Especially the locally higher soil water contents in the surface layer of plots 2 and 6 are not only indications of irregular wetting, but also of the development of preferential flow paths. The soil water contents in the surface layer of the four Revolution (four times) treated plots were significantly higher on 30 July than on 3 July (compare Fig. 3.8 with Fig. 3.3). On 30 July, the soil water contents in treated plots 1 and 4 varied between 25 and 40 vol.%, and in plots 5 and 8 between 30 and 40 vol.% (Fig. 3.9). The soil water contents in the surface layer of the four Revolution treated plots were exceptionally higher than those of the four untreated plots on 30 July.

The period between the samplings on 30 July and 4 September was relatively dry with a total of 59.7 mm rain. No precipitation at all was recorded on the eight days before the sampling on 4 September. The surface layer in the untreated plots 2, 3, and 7 was dry with soil water contents within the class 10-15 vol.% (Fig. 3.6). Wetting in plot 6 was particularly irregular, with soil water contents distributed over four soil water content classes (Fig. 3.7). This irregular wetting also indicates the presence of preferential flow paths. While still much higher than in the untreated plots, the soil water contents in the surface layer of the four Revolution (five times) treated plots were on 4 September significantly lower than on 30 July (Fig. 3.8). The soil water contents in the treated plots 4 and 8 mainly varied between 10 and 25 vol.%, and in plot 1 between 15 and 25 vol.%, whereas plot 5 was wetter, with water contents mainly between 25 and 35 vol.%.

Between 4 September and the last sampling on 20 November an amount of 182.9 mm rain was recorded. However, in the two weeks before the sampling of 20 November a total of only 9.3 mm fell. The soil water contents in the surface layer of the four untreated plots varied on 20 November between 25 and 45 vol.%. The surface layer of the Revolution (6 times) treated plots was in three of the four plots evidently wetter and more homogeneous than in the four untreated plots (compare Fig. 3.6 with Fig. 3.8).

Comparison of the 100 soil water contents, measured in the surface layer of the four untreated and four Revolution treated plots, shows that the contents were clearly higher in the Revolution treated plots on 30 July, 4 September, and 20 November (Fig. 3.10).

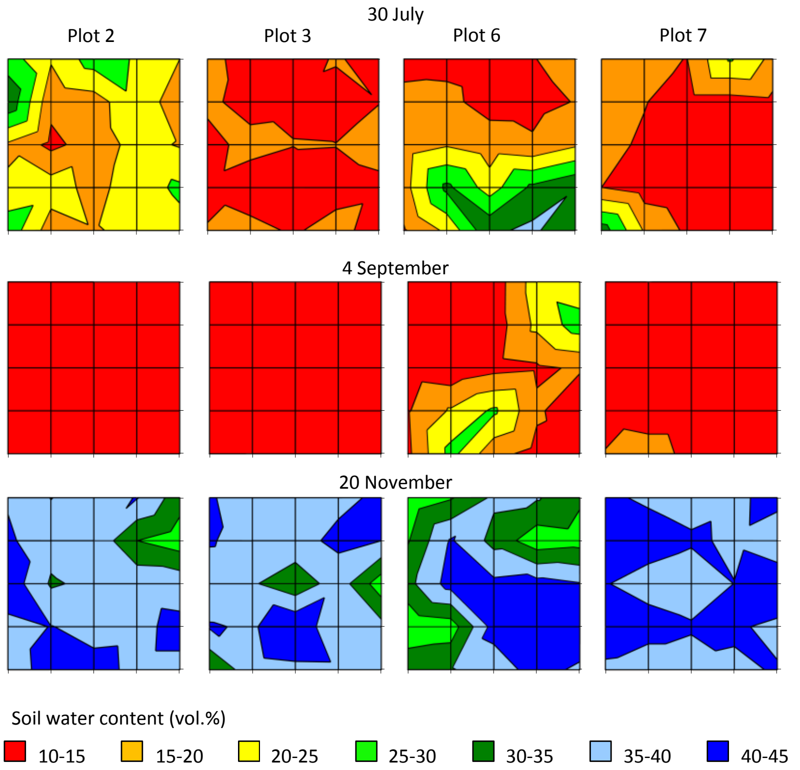

Figure 3.6 Top views (50 cm x 50 cm) with contours of the volumetric soil water content at 0-5 cm depth in the four untreated plots on 30 July, 4 September, and 20 November, 2012.

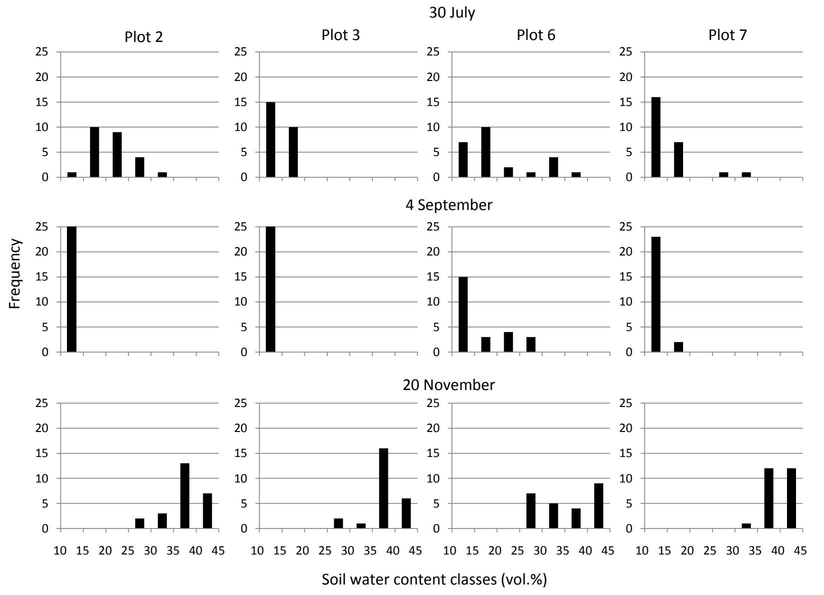

Figure 3.7 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in the four untreated plots on 30 July, 4 September, and 20 November, 2012 (n = 25).

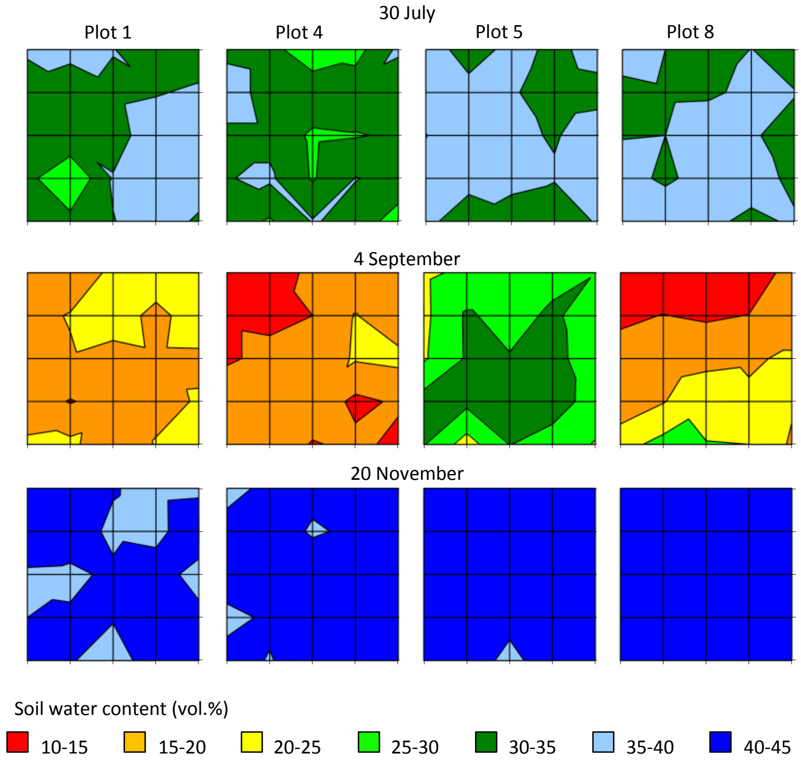

Figure 3.8 Top views (50 cm x 50 cm) with contours of the volumetric soil water content at 0-5 cm depth in the four Revolution treated plots on 30 July, 4 September, and 20 November, 2012.

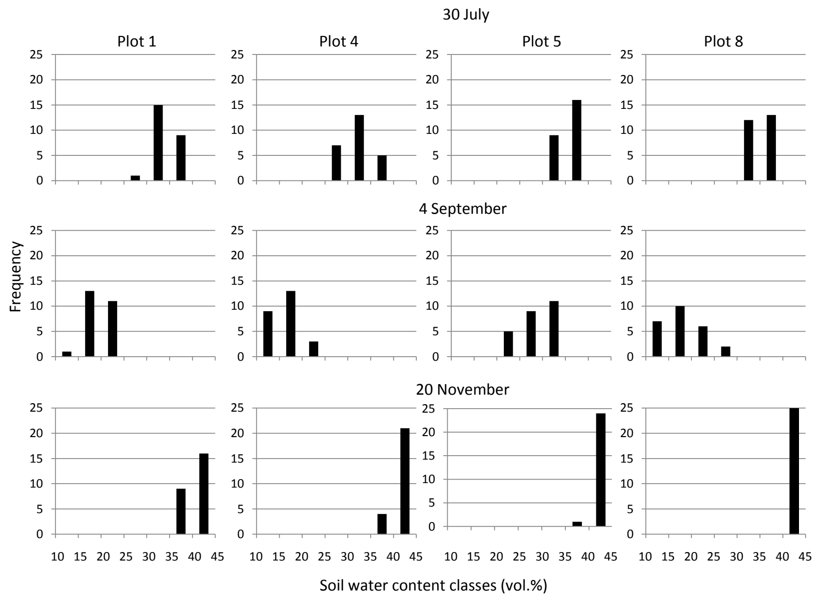

Figure 3.9 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in the four Revolution treated plots on 30 July, 4 September, and 20 November, 2012 (n = 25).

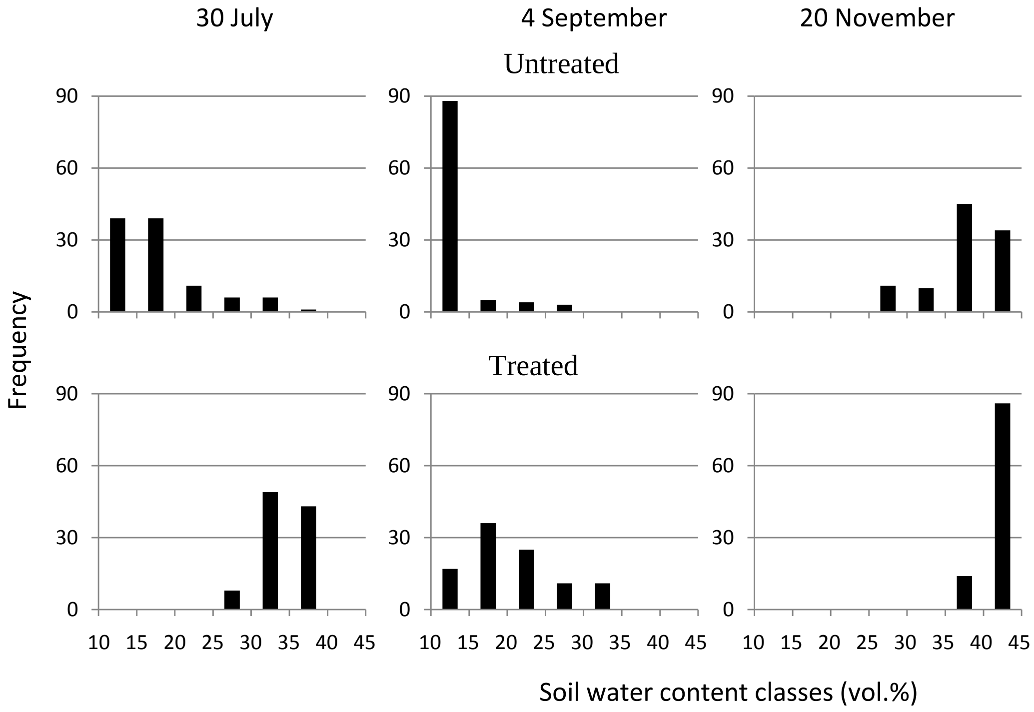

Figure 3.10 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in all untreated and Revolution treated plots on 27 April, 29 May, 3 July, 30 July, 4 September, and 20 November, 2012 (n=100).

3.2. Effect on Turf Performance

On 27 April 2012 no evident differences in the grass performance between the untreated and Revolution (one time) treated plots could be established. All 10 cm by 10 cm compartments of all plots contained more than 80% green grass (upper diagrams on the left side of Fig. 3.11). A decrease in grass growth was observed for seven of the eight plots on 29 May, as shown in the middle upper diagrams of Figure 3.11. On the Revolution (two times) treated plots 1, 5, and 8 the grass growth was relatively good, however less on the treated plot 4. In contrast the grass quality was less on the untreated plots 2, 6, and 7, whereas the grass quality was relatively good on plot 3. This is noteworthy because the surface layer of this plot had the lowest soil water contents of all eight plots on that date.

On 3 July the grass performance on the untreated plots 3 and 7 was poor, with only 50-80% green grass on the major part of the surface and less than 50 % locally. These two plots had the driest surface layers on this date with soil water contents mostly in the 10-15 vol.% class. The other two untreated plots had a wetter surface layer, and a major part of the plots exhibited a percentage of green grass of more than 80. The Revolution (three times) treated plots 1, 5, and 8 had higher soil water contents in the surface layer, and contained consistently more than 80% green grass. Only plot 4 had a very small area that exhibited 50-80% green grass (Fig. 3.11, upper right-hand side).

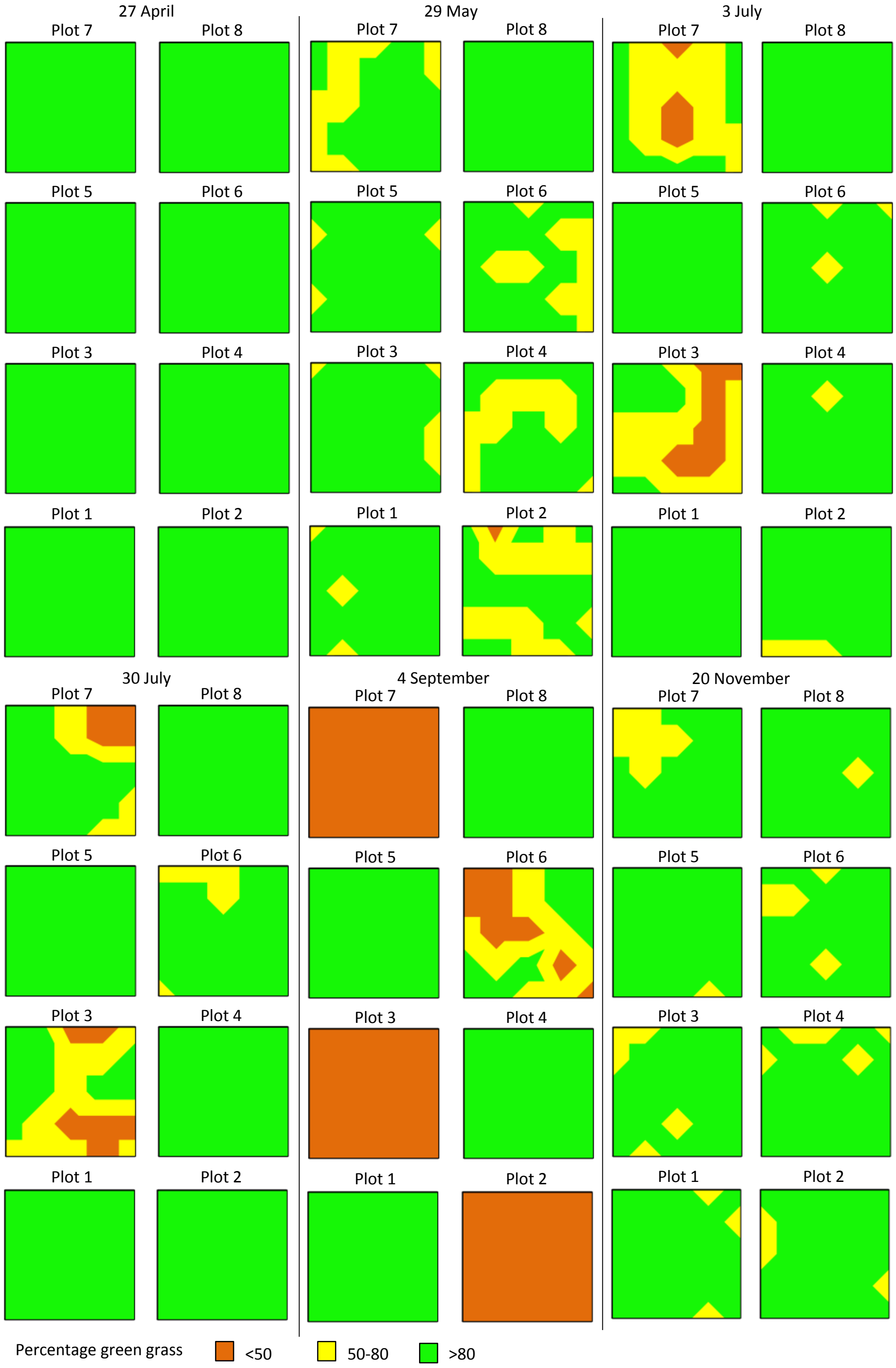

Figure 3.11 Contour plots (50 cm x 50 cm) of the turf performance on the treated (1, 4, 5, 8) and untreated (2 ,3, 6, 7) plots on 27 April, 29 May, 3 July, 30 July, 4 September, and 20 November, 2012.

Significant differences in grass growth were established between the untreated plots and the Revolution (four times) treated plots on 30 July. All four treated plots had soil water contents in the surface layer of more than 25 vol.% and exhibited more than 80% green grass. In the untreated plots 3, 6, and 7, low water contents of 10-15 vol.% were measured locally in the surface layer and the percentage green grass was locally less than 50. The surface layer of plot 2 was slightly wetter, and exhibited a green grass percentage of more than 80.

The grass quality on the Revolution (five times) treated plots was dramatically better than on the untreated plots on 4 September. All four treated plots exhibited a percentage of green grass greater than 80, while on the untreated plots 2, 3, and 7 less than 50% green grass was established, as shown in Fig. 3.11. These three plots also had the driest surface layer on 4 September with soil water contents of 10-15 vol.%, as shown in Fig. 3.6. The great differences in grass performance between the treated plots 1 and 4 and the untreated plots 2 and 3 is clearly illustrated by the photo made on 4 September (Fig. 3.12). The irregular green and brown grass patterns, just near the experimental site, were also fascinating on the foggy morning of 4 September (Fig. 3.13).

The grass quality of the untreated plots improved increasingly between 4 September and 20 November, due to the wetting of the surface layer. During the same period, the grass quality of the Revolution treated plots, decreased slightly (Fig. 3.11).

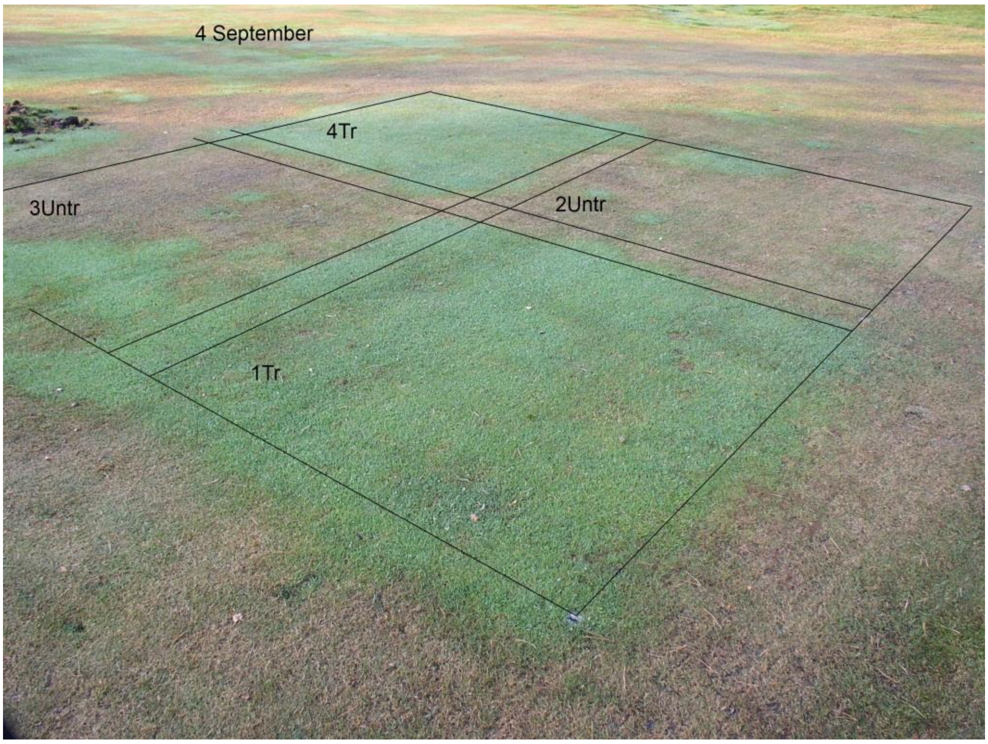

Figure 3.12 Photo with two untreated and two Revolution treated plots on 4 September, 2012.

Figure 3.13 Grass performance adjacent to the experimental site on fairway 10 on 4 September, 2012 after a foggy morning.

3.3. Effect on Development and Elimination Actual Soil Water Repellency

On 4 September and 20 November, 2012 four soil cores were taken from both the untreated and Revolution (five times) treated plots to a depth of 25 cm, using a small auger (Fig. 3.14). The cores were sampled at distances of 40 cm across the eight plots. The actual water repellency was determined in the field by placing drops of water along the cores at intervals of 1 cm. The soil was considered water repellent if the infiltration of the drops exceeded 5 seconds, and wettable if the drops disappeared within 5 seconds. Depth and thickness of the actual water repellent soil of the cores were recorded.

Actual soil water repellency was found in all four untreated plots to, often, a depth of more than 20 cm on 4 September. Only one soil core taken in plot 7 was completely wettable, suggesting the presence of a preferential flow path (Fig. 3.15). In five cores taken in the Revolution treated plots 1 and 4, small soil parts with lengths of 2 to 5 cm were water repellent, whereas the other eleven cores were completely wettable. The soil cores taken in the treated plots on 20 November were all completely wettable. In eleven of the sixteen soil cores, taken in the untreated plots, water repellent areas were present. In some areas the persistence of actual water repellency, as checked in the laboratory directly after the field campaign, exceeded 6 h.

Figure 3.14 Determination of the occurrence, depth and thickness of a water repellent layer in the field, by using a small core sampler.

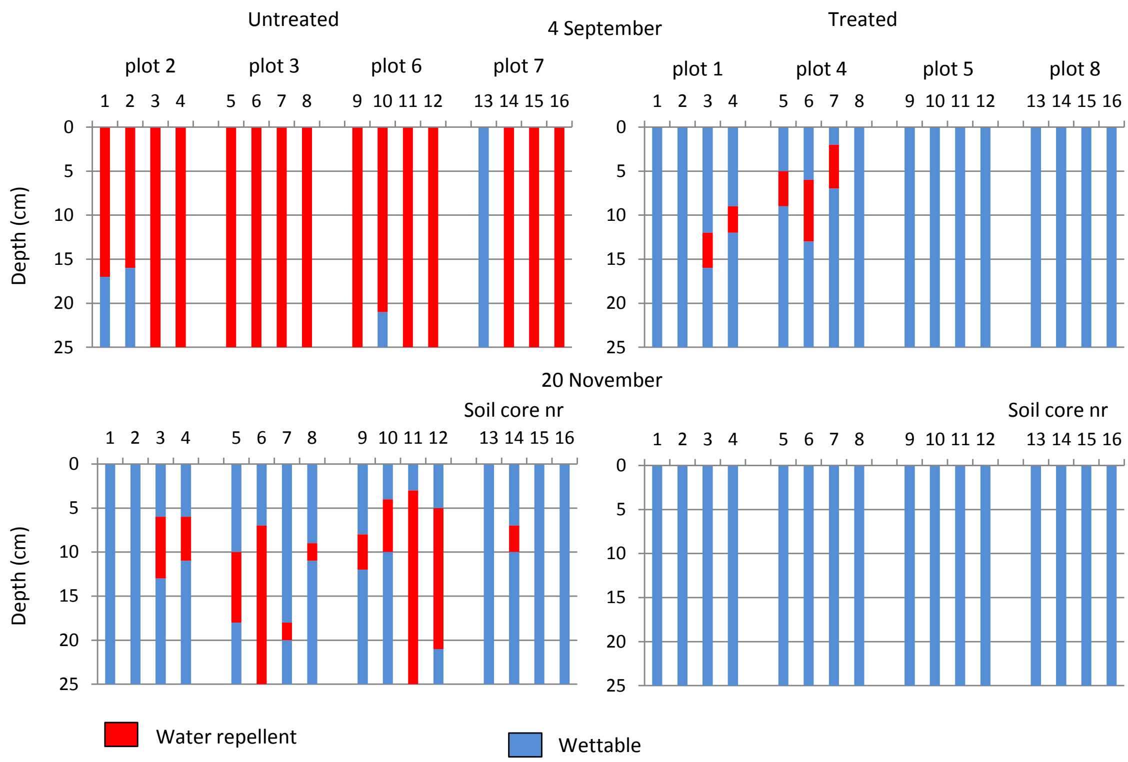

Figure 3.15 Occurrence of actual water repellency assessed with the soil core sampler at depths of 0-25 cm, four times at intervals of 40 cm, in the four untreated and four Revolution treated plots on 4 September and on 20 November, 2012.

4. Results of Samplings on 29 March, 9 July, and 15 August

On three occasions the soil water content and grass performance were assessed in one of the corners of the eight plots in 25 adjacent compartments, squares of 10 cm by 10 cm, in a grid of 50 cm x 50 cm. In each plot two soil columns were collected to a depth of 18 cm with a cup-cutter. One column was taken in the compartment with the lowest and a second column in the compartment with the highest water content of the twenty five TDR measurements in the surface layer (0-5 cm).

4.1. Water Content in the Surface Layer (0-5 cm)

Before the start of the experiment it was relatively dry. Only 0.7 mm of rain was recorded between 11 March and 29 March. In the period before that, from 1 February to 11 March, it rained frequently with a total of 55.5 mm precipitation. The volumetric soil water contents at depths of 0-5 cm differed between the four plots to be used as controls on 29 March (Fig. 4.1). Water contents of mainly 20-30% were assessed in plot 2, of mainly 25-35% in plot 6, of mainly 30-40% in plot 3, whereas large differences in water contents from between 15 and 40% were measured in plot 7 (Fig. 4.2). The soil water contents in the surface layer of plots 4 and 5, to be used for Revolution application, varied between 25 and 35 %, whereas in plot 1 they varied between 25 and 40%, and 15 and 40% in plot 8 (Fig. 4.3 and Fig. 4.4).

Large variations in soil water content were measured in the surface layer of the four untreated plots on 9 July (Fig. 4.1). Water contents divided over six classes, between 15 and 45 vol.%, were measured in the plots 2, 6, and 7 (Fig. 4.2). The soil water contents were quite different from those measured six days earlier on the sampling occasion of 3 July. At that time, soil water contents in plots 3 and 7 were mainly between 10-15 vol.% (see Fig. 3.1). The rapid changes in soil water contents were due to precipitation of 13.3 mm on 7 and 8 July, and to some sprinkler irrigation in the previous days. The differences in the level and variability of the soil water contents of the surface layer between the Revolution (four times) treated and untreated plots were exceptional on 9 July (compare Fig. 4.3 with Fig. 4.1). Most of the soil water contents measured in the treated plots ranged between 35 and 40 vol.% (Fig. 4.4). We conclude that a more or less homogeneous wetting was developed on the Revolution treated plots, whereas an irregular wetting with the development of preferential flow paths took place in the untreated plots, due to the presence of actual water repellency in the soil profiles.

Huge differences in levels and variability of soil water content were also measured in the central part of the untreated and Revolution (four times) treated plots on 30 July (compare Fig. 3.6 with Fig. 3.8).

Between the soil core samplings on 9 July and 15 August there was a total of 143.7 mm rainfall, this means an average of 4 mm per day. Despite this amount of rain, the soil water contents in the untreated plots declined to mainly 10-20 vol.%. (Fig. 4.1). The variability was also low, with the exception of plot 7 (Fig. 4.2). The relatively dry period between 2 and 13 August with only 7.7 mm rain, thus far below the potential evaporation, will be the reason for the relatively dry surface layer. The surface layer of the Revolution (five times) treated plots was dryer on 15 August than on 9 July, but still notably wetter than the surface layer of the untreated plots (compare Fig. 4.3 with Fig. 4.1).

Comparison of the 100 soil water contents, measured in the surface layer of the four untreated and four Revolution treated plots, shows that the contents were notably higher in the Revolution treated plots on 9 July and 15 August, after respectively four and five applications (Fig. 4.5).

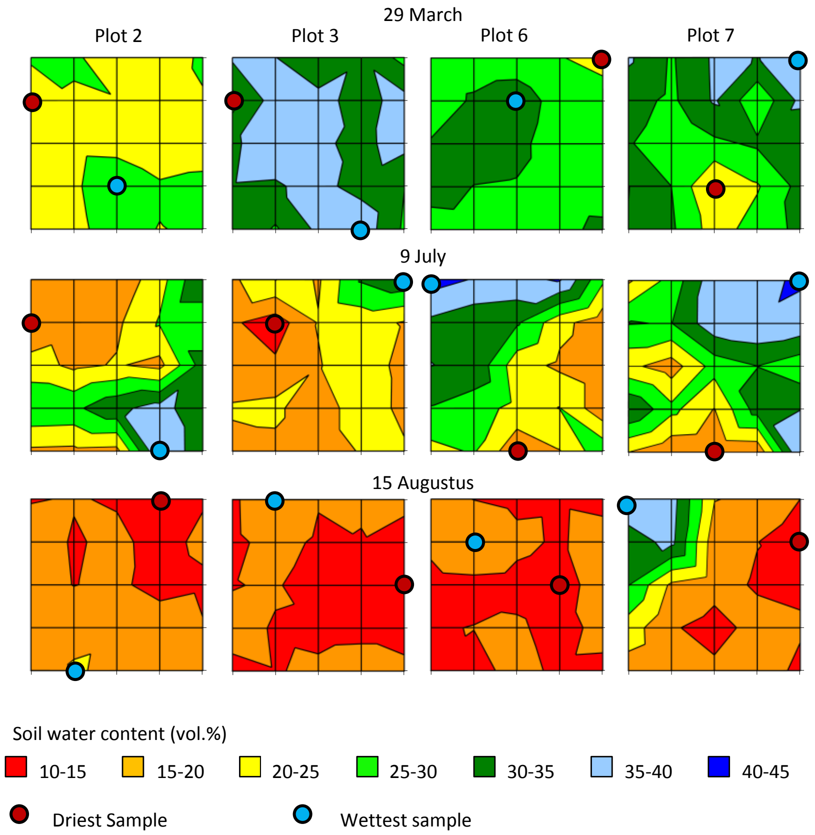

Figure 4.1 Top views (50 cm x 50 cm) with contours of the volumetric soil water content at 0-5 cm depth in the four untreated plots on 29 March, 9 July, and 15 August, 2012.

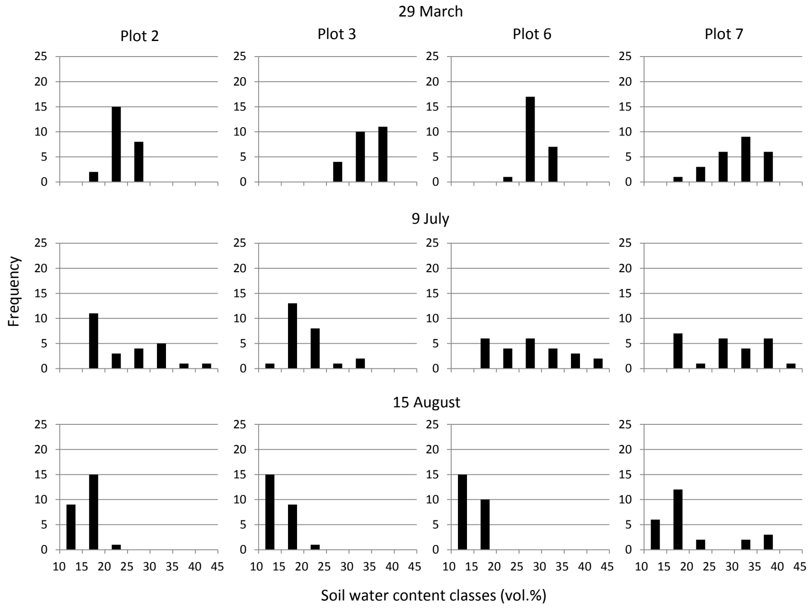

Figure 4.2 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in the four untreated plots on 29 March, 9 July, and 15 August, 2012 (n=25).

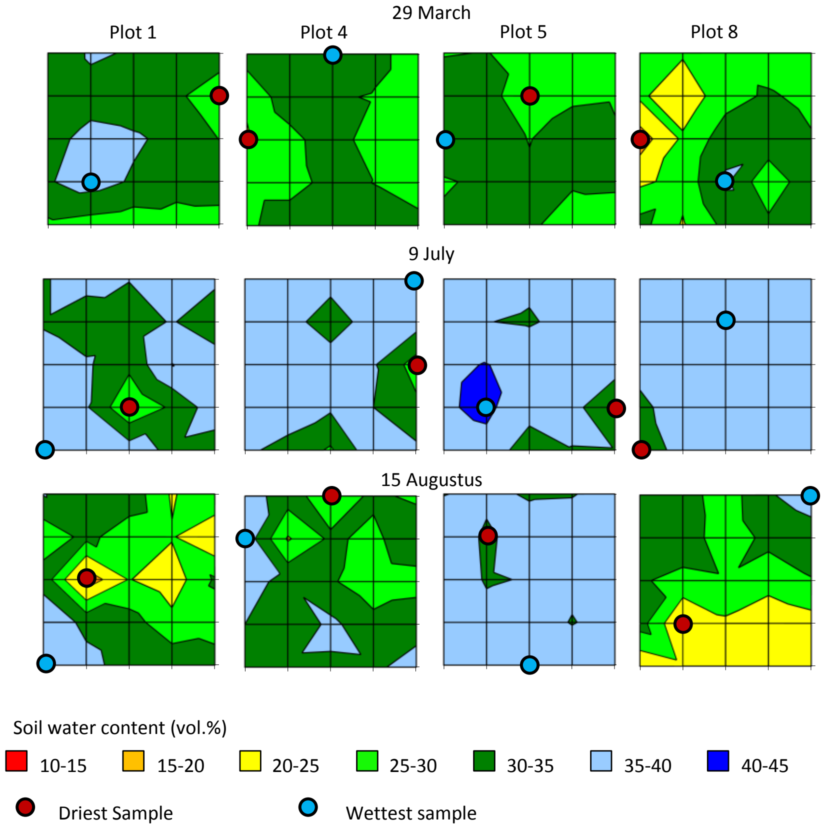

Figure 4.3 Top views (50 cm x 50 cm) with contours of the volumetric soil water content at 0-5 cm depth in the four Revolution treated plots on 29 March, 9 July, and 15 August, 2012.

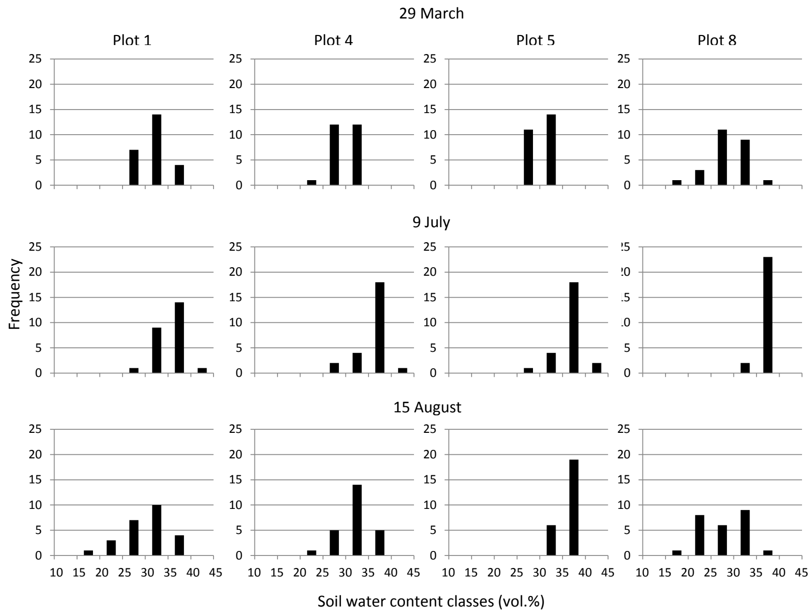

Figure 4.4 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in the four Revolution treated plots on 29 March, 9 July, and 15 August, 2012.

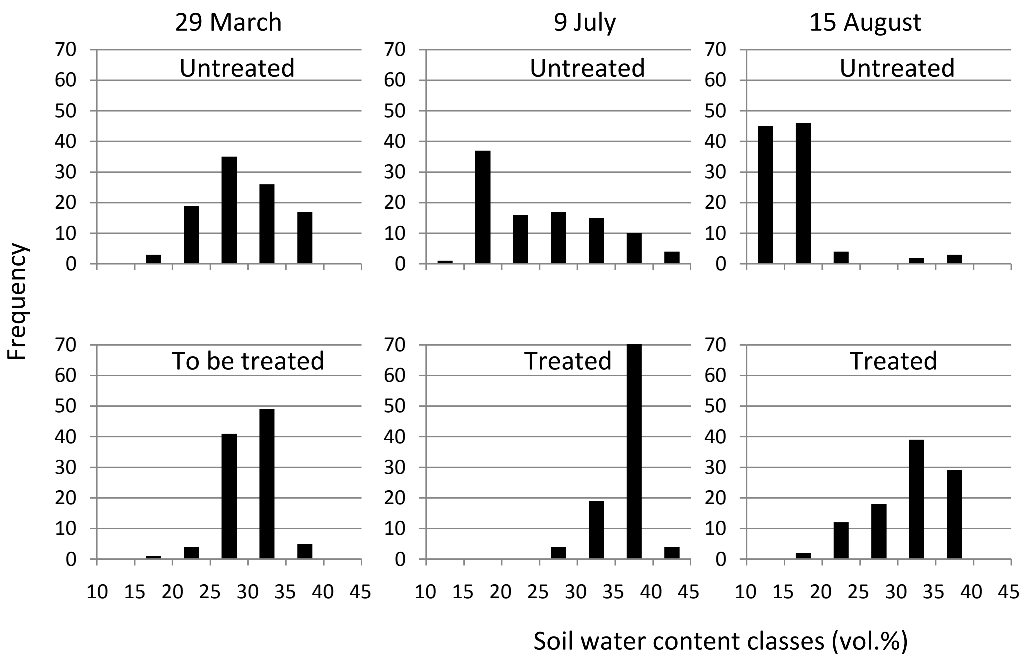

Figure 4.5 Frequency distribution of volumetric soil water content classes at 0-5 cm depth in all untreated and Revolution treated plots on 29 March, 9 July, and 15 August, 2012 (n=100).

4.2. Turf Performance on the Three Sampling Dates

The major part of the eight plots exhibited more than 80% green grass at the start of the experiment on 29 March. Only small spots with 50-80% green grass occurred locally (Fig. 4.6). On 9 July, all four Revolution (four times) treated plots still exhibited >80% green grass, while on three untreated plots significant areas of 50-80% green grass were present. The soil water contents in the surface layer of the untreated plots were also lower and more variable than in the treated plots. Also on 15 August > 80% green grass was present in the four Revolution treated plots, while in the untreated plots less than 80% green grass was present in areas (Fig. 4.6).

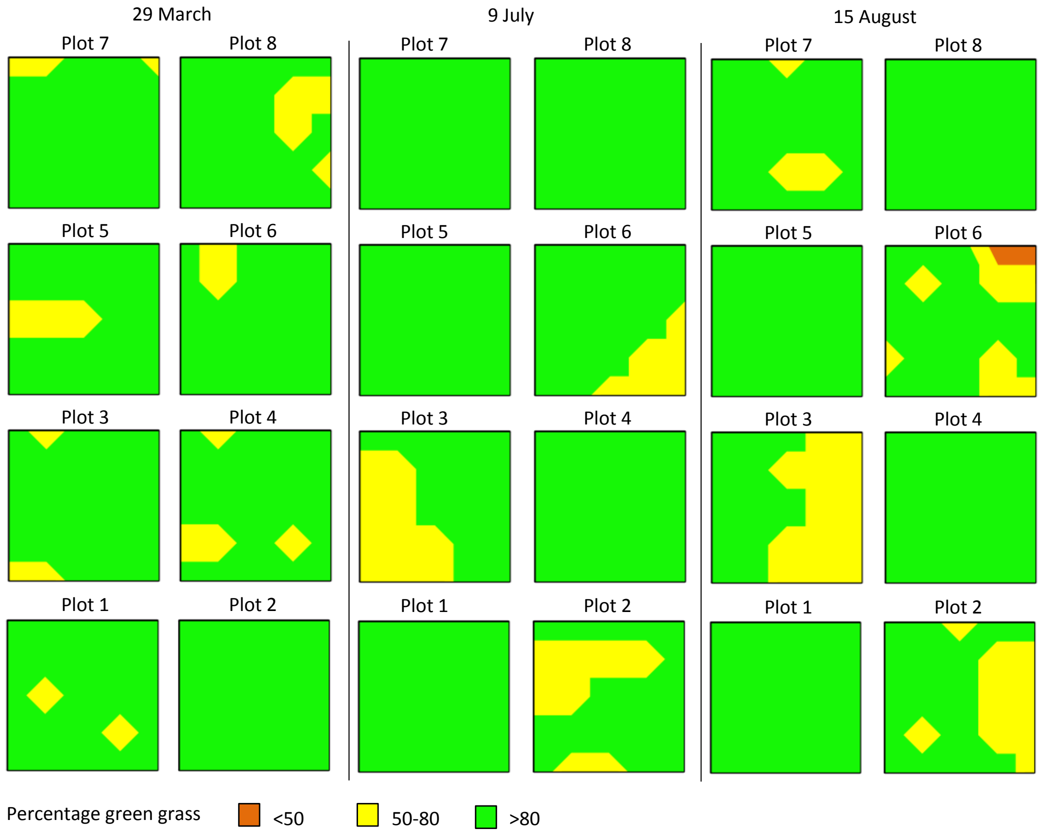

Figure 4.6 Contour plots (50 cm x 50 cm) of the turf performance on the treated (1, 4, 5, 8) and untreated (2, 3, 6, 7) plots on 29 March, 9 July, and 15 August, 2012.

4.3. Organic Matter Content in Topsoil and Subsoil

The thickness of the two parts, topsoil and subsoil, sampled by cutting the columns, differed from place to place, due to differences in depth of the organic matter (Table 4.1). The mean thickness of the topsoil sampled in the four untreated plots varied between 5.8 and 7.4 cm and in the four treated plots between 6.8 and 7.1 cm. The minimum thickness in the untreated plots ranged between 4.0 and 6.0 cm and in the treated plots between 5.5 and 6.0 cm. The maximum thickness varied in the four untreated and four treated plots, respectively, between 7.0 and 10.0 cm and 8.0 and 10 cm. The mean thickness of all subsoil samples in the untreated plots was 11.4 cm and in the treated plots 11.1 cm.

The mean organic matter content in the topsoil of the four untreated plots was 8.2% and in the four treated plots 8.3%. A variation of 5.9 to 10.7% was measured for samples from the untreated and of 6.3 to 10.8% for samples from the treated plots (Table 4.1). The mean organic matter content in the subsoil of the four untreated plots was 1.8% and in the four treated plots 1.6%. A variation of 1.0 to 2.8% was measured for samples from the untreated and of 0.8 to 2.8% for samples from the treated plots (Table 4.1). Generally 5-30 gram of the soil samples consisted of soil > 2 mm, except in plots 7 and 8, where 150 to 250 gram of the subsoil samples was > 2 mm due to the presence of gravel.

Table 4.1 Mean, minimum and maximum length of soil column samples and mean, lowest and highest organic matter content in the topsoil and subsoil of the untreated (control) and treated plots from all three sampling dates.

Plot	Soil column length (cm)			Organic matter content (%)		
	Mean	Min.	Max.	Mean	lowest	highest
Untreated plot 2						
Topsoil	5.8	4.0	7.5	9.0	7.3	10.7
Subsoil	12.2	10.5	14.0	1.5	1.2	1.9
Untreated plot 3						
Topsoil	7.0	5.0	10.0	8.1	6.6	10.1
Subsoil	11.0	8.0	13.0	2.2	1.6	2.7
Untreated plot 6						
Topsoil	6.2	6.0	7.0	8.2	5.9	9.2
Subsoil	11.8	11.0	12.5	1.6	1.0	2.8
Untreated plot 7						
Topsoil	7.4	6.0	9.0	7.5	6.0	8.9
Subsoil	10.6	9.0	12.0	1.9	1.2	2.5
Treated plot 1						
Topsoil	6.8	5.5	10.0	8.5	6.3	10.8
Subsoil	11.2	8.0	12.5	1.5	1.1	1.8
Treated plot 4						
Topsoil	6.8	6.0	9.0	8.3	6.7	9.4
Subsoil	11.2	9.0	12.0	1.4	0.8	1.7
Treated plot 5						
Topsoil	7.0	6.0	8.5	8.4	6.9	9.4
Subsoil	11.0	9.5	12.0	1.6	1.2	2.3
Treated plot 8						
Topsoil	7.1	6.0	8.0	8.0	6.5	9.1
Subsoil	10.9	10.0	12.0	2.0	1.0	2.8

4.4. Soil Water Contents in Topsoil and Subsoil

The variation and level of the volumetric soil water contents in topsoil and subsoil samples of the untreated and to be treated plots were more or less identical at the start of the experiment on 29 March, 2012 (Fig. 4.7). The topsoil samples in the four to be treated plots (1, 4, 5, 8), indicated with the suffix W, had indeed higher soil water contents than those with the suffix D. However, the topsoil samples 2W and 3W from the untreated plot contained slightly less water than the samples 2D and 3D. The subsoil samples 4W, 2W, and 3W also contained less water than their counterparts 4D, 2D, and 3D. This means that the soil water contents, measured with the TDR-device in the surface layer at depths of 0-5 cm, not always predicted the places of the most-wet and less-wet soil columns.

The mean volumetric soil water content of the topsoil samples from the Revolution (four times) treated plots on 9 July was 33.5 vol.%, while for the untreated plots it was 26.3 vol.%. This means that the topsoil samples of the treated plots on average contained 27% more water than those of the untreated plots. Worthy of mention is the heterogeneity of the wetting of the topsoil in the four untreated plots in comparison with the four treated plots (Fig. 4.7). Quite noticeable was the difference in water content between the most-wet samples of the untreated plots, with an average of about 38 vol.% , in comparison with the less wet samples with an average of about 15 vol.%. This means that the wet samples (indicated with W) contained 153% more water than their counterparts (indicated with D) in the untreated plots. The great differences in soil water content of the topsoil samples in the untreated plots is assumed to be caused by the presence of water repellency in the soil, which presumably was not present in the treated plots.

Also worthy of note is the heterogeneity of the wetting of the subsoil in the four untreated plots in comparison with the four treated plots on 9 July (Fig. 4.7). Whereas the soil water content in the subsoil samples from the Revolution treated plots ranged from 6 to 11 vol.%, the range for the untreated plots was from 2.5 to 17.5 vol.%. Both extremes were measured for samples from plot 6. This means that in the untreated plot 6 some parts of the subsoil contained 600% more water than other parts. We feel sure that this is due to the presence of localized water repellent spots. The soil water contents of the wet subsoil samples in the untreated plots 3, 6, and 7 were higher than those of the four treated plots. The topsoil samples of the columns 3W, 6W, and 7W contained also relatively high soil water contents. We assume that lateral water flow had taken place through the topsoil and that preferential flow paths had been formed.

On 15 August the soil water content of the topsoil samples from the treated plots varied between 17 and 35 vol.%, while in seven of the topsoil samples from the untreated plots the water content was between 8 and 17 vol.%. The high water content of the wet topsoil and wet subsoil samples of untreated plot 7 indicates the presence of preferential flow. The low water contents measured in the 2D, 3D, and 6D subsoil samples indicate the presence of soil water repellency in the untreated plots.

Table 4.2 shows that the mean volumetric soil water contents of the eight topsoil samples from the untreated and to be treated plots were nearly the same on 29 March, respectively, 29.2 and 29.9%. On 9 July and 15 August, the mean soil water contents of the topsoil samples of the Revolution treated plots were noticeably higher than those from the untreated plots. The heterogeneity of the soil water content in the untreated topsoil samples was clearly greater than in the Revolution treated plots on both dates, as indicated by the higher standard deviations and coefficients of variation (Table 4.2).

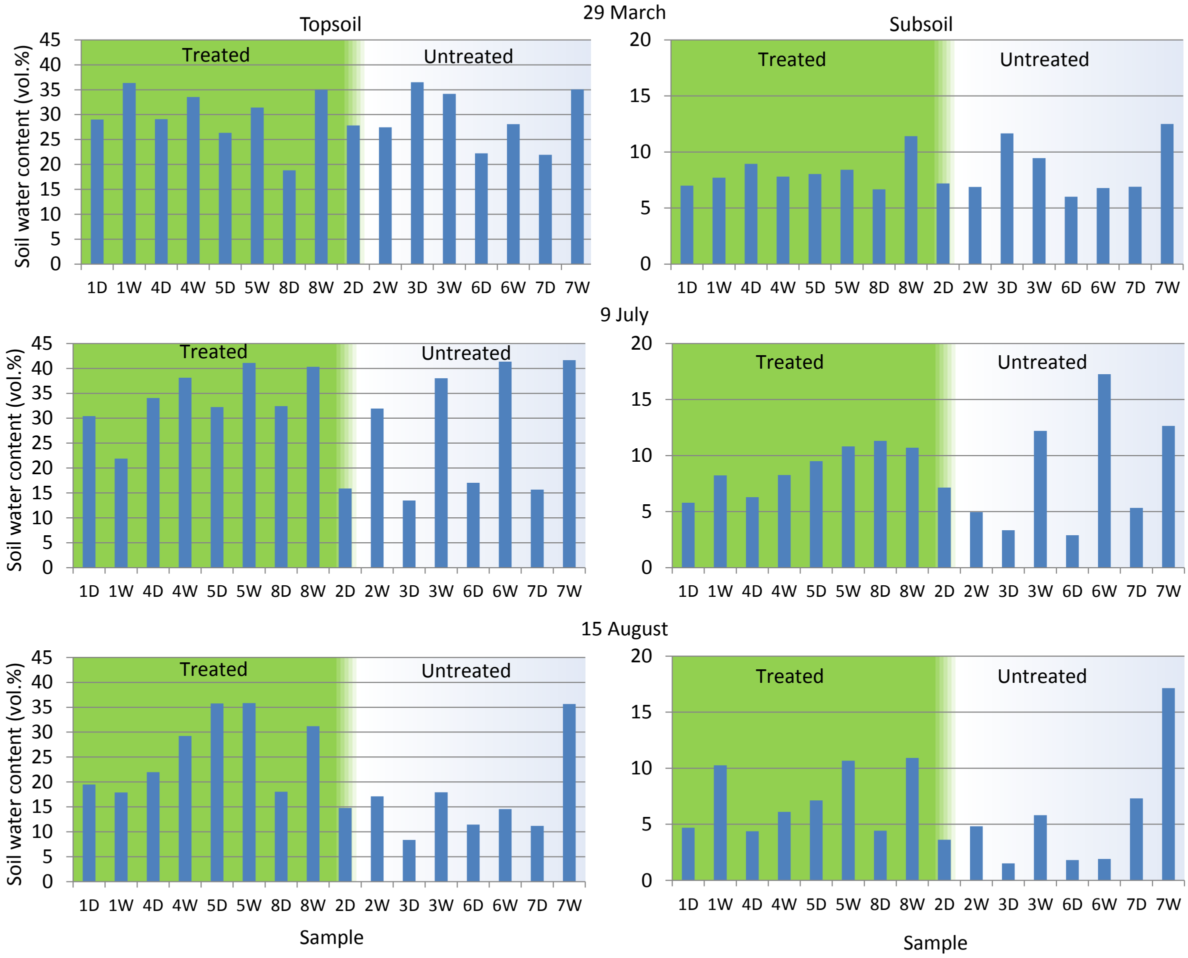

Figure 4.7 Volumetric water content of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

Table 4.2 Mean water content (vol.%) in topsoil samples from the columns taken in untreated and Revolution treated plots on 29 March, 9 July, and 15 August. Besides the standard deviation (vol.%) and coefficient of variation (%) are presented (n = 8).

Date	Untreated			(To be) Treated		
	Mean (vol.%)	SD (vol.%)	CV (%)	Mean (vol.%)	SD (vol.%)	CV (%)
29 March	29.2	5.6	19.2	29.9	5.6	18.7
9 July	26.9	12.5	46.6	33.8	6.2	18.4
15 August	16.4	8.4	51.3	26.2	7.7	29.5

4.5. Total Nitrogen in Grass Leaves and Roots

At the start of the experiment, 29 March, the total nitrogen concentration in the grass leaves of the four to be treated plots varied between 8 and 22.5 g/kg and in the four control plots between 12 and 25.5 g/kg (Fig. 4.8). As shown in Fig. 4.7 on this date the topsoil samples 2W and 3W were actually drier than the topsoil samples 2D and 3D. For plots 4, 5, 6 and 7, where the W topsoil samples were in fact wetter than the D counterparts, the nitrogen concentration in the grass leaves was higher in the wetter sample than in the less-wet sample. However, for plots 1 and 4 where the W sample was indeed wetter than the D sample, and plots 2 and 3 where, as mentioned it was the other way around, the total nitrogen concentration in the grass leaves was higher in the drier samples than in the wetter samples.

On 9 July, the total nitrogen concentration in the grass leaves of the four Revolution (four times) treated plots varied between 8 and 26.5 g/kg and of the four untreated plots between 11 and 25.5 g/kg (Fig. 4.8). As shown in Fig. 4.7 the topsoil sample 1W was in reality less wet than the topsoil sample 1D. Again on this date we found that in some cases nitrogen concentration in the grass leaves was higher in the wetter topsoil samples, and in other cases higher in the less wet samples.

On the August sampling date, the total nitrogen concentration in the grass leaves of the four Revolution (five times) treated plots varied between 4 and 30 g/kg and between 8 and 17.5 g/kg for the untreated plots (Fig. 4.8). Fig. 4.7 shows that on this date as well topsoil sample 1W was in reality less wet than the topsoil sample 1D. Taking this into account we again found that the total nitrogen concentration was sometimes higher in the wetter samples and sometimes higher in the drier samples.

We conclude that there were no differences in the total nitrogen concentration of the grass leaves related to the relatively wetter or drier topsoil samples. It is interesting to note that the range of total nitrogen concentrations found in the grass leaves increased for the Revolution treated plots and declined for the untreated plots – particularly by the August sampling date.

The total nitrogen concentration in the grass roots was less variable, and ranged on the three sampling dates between 12.5 and 23.5 g/kg. No evident differences in total nitrogen concentration of the roots were established between samples from the untreated plots in comparison with those from the Revolution treated plots. Also no evident differences were found between the concentration of total nitrogen in the roots from wetter topsoil samples compared with less-wet topsoil samples.

We conclude that the application of Revolution had no significant influence upon the total nitrogen concentration in the leaves or roots of the grass cover of the fairway on a direct g/kg basis. Secondly we conclude that there was no direct correlation between the soil water content of the topsoil and the total nitrogen concentration in leaves or roots of the grass vegetation.

Figure 4.9 supports our conclusions. In addition, this figure shows that the means of the total nitrogen concentration in the respective four leaf samples on all three dates are found within the range 13-21 g/kg, and in the respective four root samples within the range 15-18 g/kg.

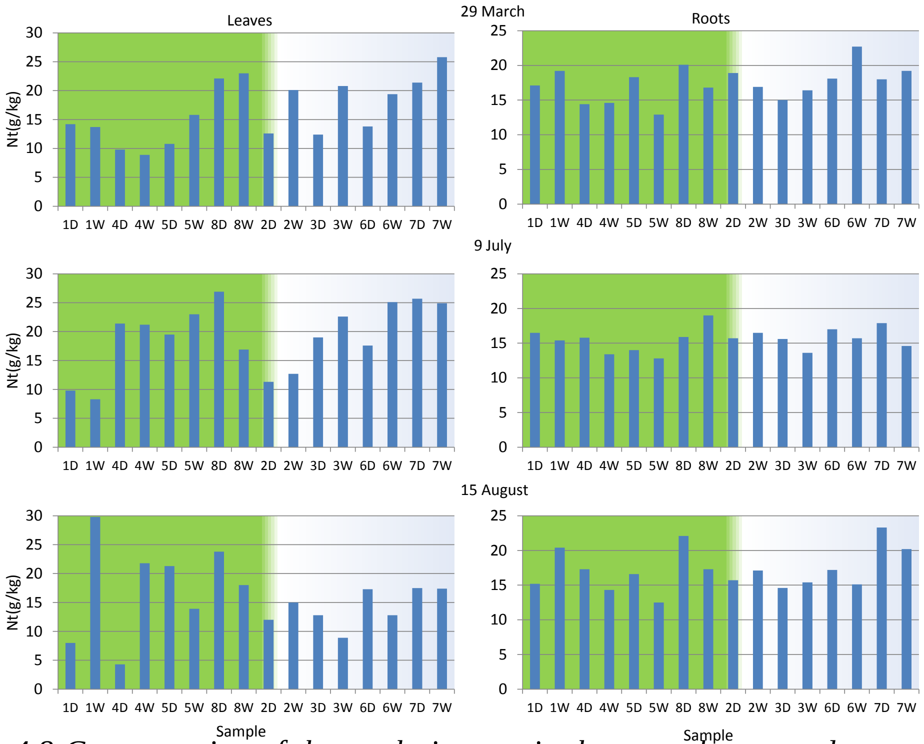

Figure 4.8 Concentration of the total nitrogen in the grass leaves and roots of the four treated (green background) and four untreated plots on the three sampling dates. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

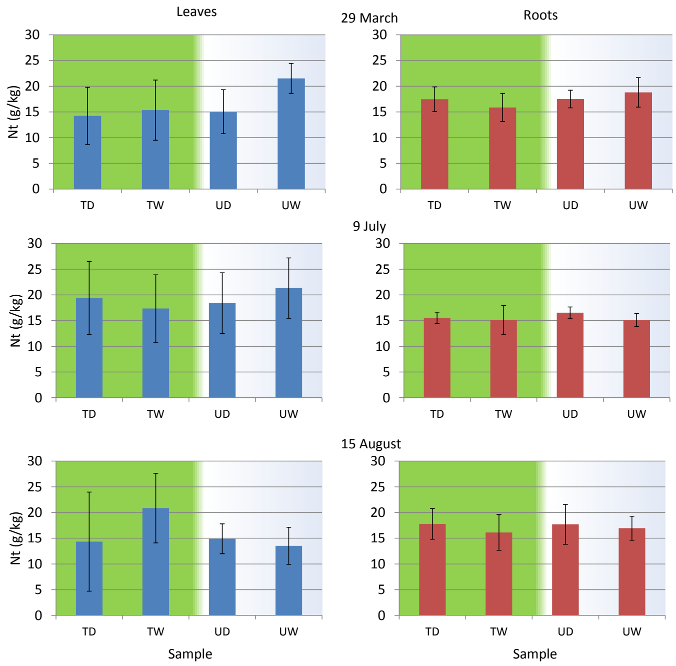

Figure 4.9 Mean concentrations of total nitrogen in the grass leaves and roots of the four treated (green background) and four untreated plots on the three sampling dates. TD and UD represent the origin from the soil columns taken on the places with the lowest and TW and UW with the highest water content measured by TDR. The standard deviation is indicated in the bars (n = 4).

The total amounts of grass tissue which could be cut from the topsoil samples of the untreated and to be treated plots on 29 March were quite similar. The mean amount of total nitrogen in the grass leaves of the topsoil samples from the untreated and to be treated plots was in both cases 39.6 mg (Table 4.3). This means, that after calculation with the surface area of the column, the grass leaves contained 43.2 kg total nitrogen per ha.

On 9 July the mean amount of total nitrogen in the grass leaves from the untreated plots was 56.1 mg and from the Revolution treated plots 71.5 mg. Converting this to kg per ha indicates that on this date the grass leaves from the untreated plots contained 61 kg/ha and from the Revolution treated plots 77.9 kg/ha. Thus, the grass leaves of the Revolution treated plots contained 27.7% more total nitrogen in comparison with the untreated plots.

On 15 August the mean amount of total nitrogen in the grass leaves from the untreated and treated plots was respectively, 49.5 and 55.0 mg, equivalent to 54 and 60 kg/ha. This means that on this date the grass leaves of the Revolution treated plots contained 11% more total nitrogen than those of the control plots.

Table 4.3 Mean total nitrogen (mg) in grass leaves from the soil columns sampled in untreated and Revolution treated plots on 29 March, 9 July, and 15 August. Besides the standard deviation and coefficient of variation are presented (n = 8).

Date	Untreated			(To be) Treated		
	Mean (mg)	SD (mg)	CV (%)	Mean (mg)	SD (mg)	CV (%)
29 March	39.6	4.6	11.7	39.6	8.6	21.8
9 July	56.1	10.6	18.9	71.5	19.4	27.1
15 August	49.5	10.7	21.7	55.0	19.7	35.8

4.6. Total Nitrogen in Topsoil and Subsoil

The total nitrogen concentration of the topsoil samples varied on 29 March between 2.1 and 3.5 g/kg. No evident differences were established between the samples from the untreated and to be treated plots (Fig. 4.10).

On 9 July the concentration of the topsoil samples from the (four times) Revolution treated plots varied between 2.1 and 3.8 g/kg and from the untreated plots between 2.7 and 4.2 g/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots.

The nitrogen concentrations were a bit lower on 15 August in comparison with the two previous dates. The concentration of the topsoil samples from the (five times) Revolution treated plots varied from 1.9 to 3.2 g/kg and from the untreated plots from 1.8 to 3.1 g/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots.

No evident differences between the nitrogen concentrations in the topsoil samples from the columns taken on the places with the highest (W) and lowest (D) volumetric soil water content (measured with TDR) could be established on any of the three dates.

The total nitrogen concentration of the subsoil samples varied on 29 March between 0.4 and 0.9 g/kg. No evident differences were established between the samples from the untreated and to be treated plots (Fig. 4.10).

On 9 July the concentration of the subsoil samples from the (four times) Revolution treated plots varied between 0.3 and 0.7 g/kg and from the untreated plots between 0.4 and 0.6 g/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots.

The nitrogen concentrations were a bit lower on 15 August in comparison with the two previous dates. The concentration of the subsoil samples from the (five times) Revolution treated plots varied from 0.2 to 0.8 g/kg and from the untreated plots from 0.2 to 0.7 g/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots.

The volumetric soil water content of the subsoil samples 1W, 5W, 8W, and 7W was respectively 10, 10.5, 11, and 17% on 15 August (see Fig. 4.7), whereas all other subsoil samples contained between 2 and 7 vol.% water. It is worth noting that the total nitrogen in these four subsoil samples was respectively, 0.5, 0.7, 0.8, and 0.7, whereas with the exception of one sample, the other samples had concentrations between 0.2 and 0.5 g/kg. This may be an indication that nitrogen was transported from the topsoil to the subsoil layer.

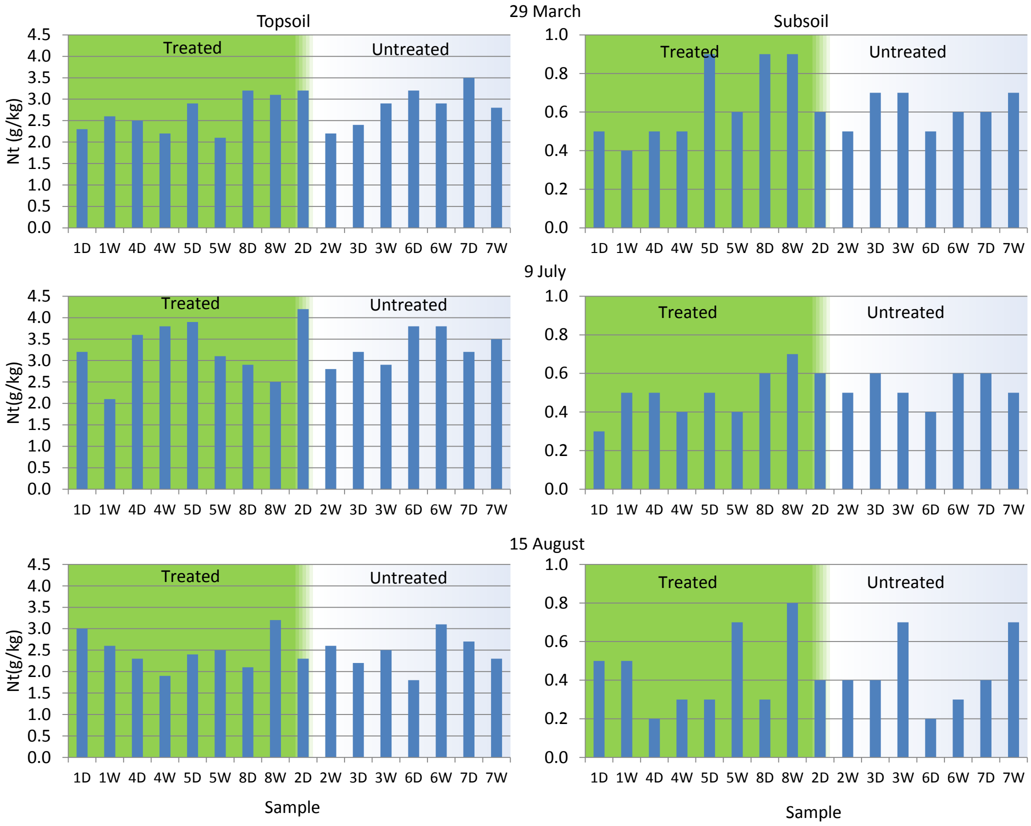

Figure 4.10 Concentrations of total nitrogen of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

4.7 Concentrations N-(NO_3+NO_2) in Topsoil and Subsoil

The concentration N-(NO_3+NO_2) of the topsoil samples varied on 29 March between 6 and 16 mg/kg. No evident differences were established between the samples from the untreated and to be treated plots (Fig. 4.11).

On 9 July the concentration of the topsoil samples from the (four times) Revolution treated plots varied between 2.5 and 7.5 mg/kg and between 1.5 and 9 mg/kg in the untreated plots. The concentrations were notably lower than on 29 March. A lower mean nitrogen concentration was established for the samples from the untreated plots (4.1 mg/kg) in comparison with the mean concentration (5.3 mg/kg) of the Revolution treated plots (Table 4.4), a difference of 29%. As shown in Fig. 4.11 slightly higher concentrations were found for seven of the eight samples from the wettest columns (suffix W) in comparison with the dryer samples (suffix D).

The 15 August samples show that the nitrogen concentrations of the topsoil had been decreased again. The concentration of the samples from the (five times) Revolution treated plots varied from 1.8 to 5.8 mg/kg and from the untreated plots from 1.7 to 4.2 mg/kg. Again a mean higher N-(NO_3+NO_2) concentration, in this case of 3.4: 2.2 (Table 4.4), or 54.5% higher concentration, occurred for the topsoil samples from the Revolution treated plots compared with the untreated plots.

Table 4.4 Mean concentration N-(NO_3+NO_2) (mg/kg) in topsoil samples from the soil columns taken in untreated and surfactant treated plots on 29 March, 9 July, and 15 August. Besides the standard deviation (mg/kg) and coefficient of variation (%) are presented (n = 8).

Date	Untreated			(To be) Treated		
	Mean (mg/kg)	SD (mg/kg)	CV (%)	Mean (mg/kg)	SD (mg/kg)	CV (%)
29 March	9.6	2.3	24.0	10.6	3.5	33.4
9 July	4.1	2.5	61.6	5.3	1.5	28.6
15 August	2.2	1.1	51.2	3.4	1.4	42.2

No evident differences between the nitrogen concentrations in the topsoil samples from the columns taken on the places with the highest (W) and lowest (D) volumetric soil water content (measured with TDR) could be established on 15 August.

The concentration N-(NO_3+NO_2) of the subsoil samples varied on 29 March between 1.1 and 4.5 mg/kg and no differences between the samples from the untreated and to be treated plots were found (Fig. 4.11).

On 9 July the concentration of the subsoil samples from the (four times) Revolution treated plots and the untreated plots varied between 0.1 and 1.1 mg/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots. The concentrations were clearly lower than on 29 March.

The nitrogen concentrations were also low on 15 August. The concentration of the subsoil samples from the (five times) Revolution treated plots varied from 0.1 to 1.6 mg/kg and from the untreated plots from 0.2 to 0.8 mg/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots.

The volumetric soil water content of the subsoil samples 1W, 8W, and 7W was respectively 10, 11, and 17% on 15 August (see Fig. 4.7), whereas all other subsoil samples contained between 2 and 10.5 vol.% water. It is worth noting that the total nitrogen in these three subsoil samples was respectively, 0.5, 0.8, and 0.7, whereas most other samples had concentrations between 0.2 and 0.5 g/kg. The concentration N-(NO_3+NO_2) of these three samples are relatively high in comparison with all other subsoil samples on 15 August. This may strengthen the indication that nitrogen was transported from the topsoil via preferential flow to the subsoil layer.

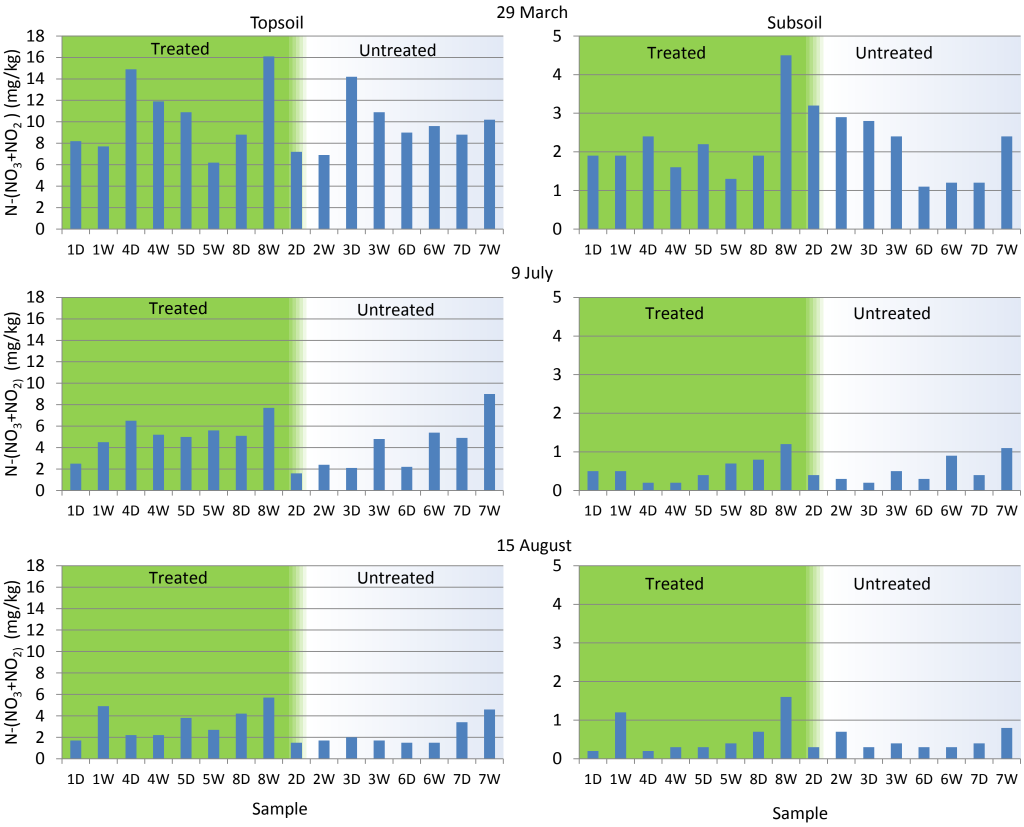

Figure 4.11 Concentrations of N-(NO_3+NO_2) of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

4.8 Concentrations N-NH_4 in Topsoil and Subsoil

The concentration N-(NH_4) of the topsoil samples varied on 29 March between 5.8 and 14 mg/kg. No evident differences were established between the samples from the untreated and to be treated plots (Fig. 4.12). However, the mean concentration was 18,3% higher in the topsoil samples from the (to be) treated plots (Table 4.5)

On 9 July the concentration of the topsoil samples from the (four times) Revolution treated plots varied between 4.8 and 7.4 mg/kg and between 4.8 and 11.5 mg/kg in the untreated plots. The mean concentration was much lower than on 29 March. Again slight differences in N-NH_4 concentration occurred between the samples from the treated and untreated plots. In this case the mean concentration in the samples from the treated plots was 8.5% lower.

The 15 August samples show that the N-NH_4 concentrations of the topsoil had been decreased again a bit in the untreated plots. The concentration in the samples from the (five times) Revolution treated plots varied from 5.8 to 8.6 mg/kg and from the untreated plots from 4.0 to 7.0 mg/kg. In this case a slightly higher mean concentration (27.8%) occurred in N-NH_4 concentration in the samples from the treated in comparison with samples from the untreated plots (Table 4.5).

No evident differences between the N-NH_4 concentrations in the topsoil samples from the columns taken on the places with the highest (W) and lowest (D) volumetric soil water content (measured with TDR) could be established on all three sampling dates (Fig. 4.12).

The concentration of N-(NH_4) in the subsoil samples varied on 29 March between 0.6 and 5.4 mg/kg, with 13 of the sixteen samples having a concentration of 0.6-1.5 mg/kg. No differences between the samples from the untreated and to be treated plots were found (Fig. 4.12).

In July, the concentration of the subsoil samples from the (four times) Revolution treated plots and from the untreated plots varied between 0.6 and 1.3 mg/kg. Again no evident differences in nitrogen concentration occurred between the samples from the treated and untreated plots. The N-(NH_4) concentrations were more uniform than on 29 March.

The N-(NH_4) concentrations were also uniform on 15 August, and higher than on 9 July. The concentration of the subsoil samples from the (five times) Revolution treated plots and also from the untreated plots varied from 0.7 to 2.5 mg/kg. Again no evident differences in N-(NH_4) concentration occurred between the samples from the treated and untreated plots.

Also no evident differences between the N-NH_4 concentrations in the subsoil samples from the columns taken on the places with the highest (W) and lowest (D) volumetric soil water content (measured with TDR) could be established on the three sampling dates (Fig. 4.12).

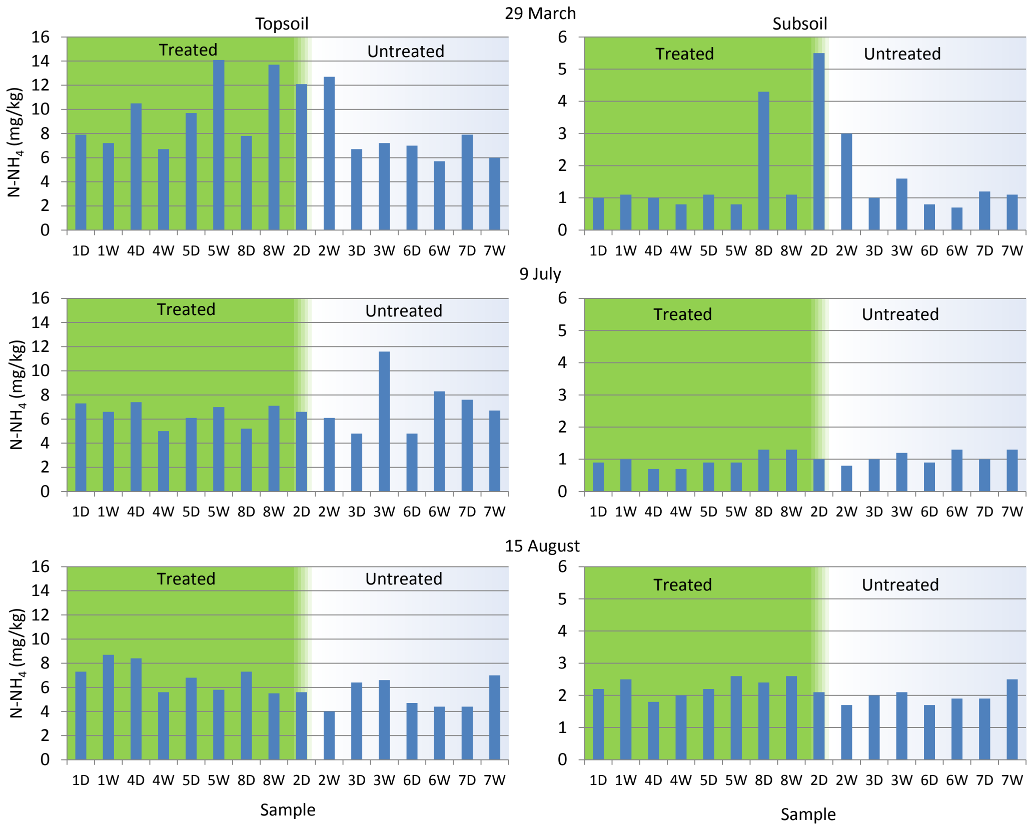

Figure 4.12 Concentrations of N-NH$_4$ of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

Table 4.5 Mean concentration of N-NH$_4$ (mg/kg) in topsoil samples from the soil columns taken in untreated and surfactant treated plots on 29 March, 9 July, and 15 August. Besides the standard deviation (mg/kg) and coefficient of variation (%) are presented (n = 8).

Date	Untreated			(To be) Treated		
	Mean (mg/kg)	SD (mg/kg)	CV (%)	Mean (mg/kg)	SD (mg/kg)	CV (%)
29 March	8.2	2.7	33.2	9.7	2.9	29.7
9 July	7.1	2.2	31.2	6.5	0.9	14.5
15 August	5.4	1.2	21.6	6.9	1.2	17.8

4.9 Concentrations of Total Soluble Nitrogen in Topsoil and Subsoil

The concentration of total soluble nitrogen (Nts) of the topsoil samples varied on 29 March between 30 and 55 mg/kg. No evident differences were established between the samples from the untreated and to be treated plots (Fig. 4.13).

On 9 July the concentration of the topsoil samples from the (four times) Revolution treated plots varied between 26 and 45 mg/kg and between 24 and 61 mg/kg in the untreated plots. The mean concentration of the total soluble nitrogen was a bit lower than on 29 March. Again no evident differences in Nts concentration occurred between the samples from the treated and untreated plots.

The 15 August samples show that the Nts concentrations of the topsoil had again decreased a bit. The concentration of the samples from the (five times) Revolution treated plots varied from 25 to 38 mg/kg and from the untreated plots from 19 to 28 mg/kg. A mean slightly higher (25%) Nts concentration occurred in the samples from the treated plots on 15 August (Table 4.6).

Here too, no evident differences between the total soluble nitrogen concentrations in the topsoil samples from the columns taken on the places with the highest (W) and lowest (D) volumetric soil water content (measured with TDR) could be established on all three sampling dates (Fig. 4.13).

The concentration of total soluble nitrogen of the subsoil samples varied on 29 March between 5 and 13 mg/kg. No evident differences between the samples from the untreated and to be treated plots were found (Fig. 4.13).

On 9 July the concentration of the subsoil samples from the (four times) Revolution treated plots and untreated plots varied between 4 and 9 mg/kg. Again no evident differences in Nts concentration were measured between the samples from the treated and untreated plots. The mean concentrations of the total soluble nitrogen in treated and untreated plots were slightly lower than on 29 March.

The Nts concentrations on 15 August were more or less comparable with those on 9 July. The concentration of the subsoil samples from the (five times) Revolution treated plots and untreated plots varied from 5 to 10 mg/kg. Again no evident differences in total soluble nitrogen concentration occurred between the samples from the treated and untreated plots.

Also no evident differences between the Nts concentrations in the subsoil samples from the columns taken on the places with the highest (W) and lowest (D) volumetric soil water content (measured with TDR) could be established on the three sampling dates (Fig. 4.13).

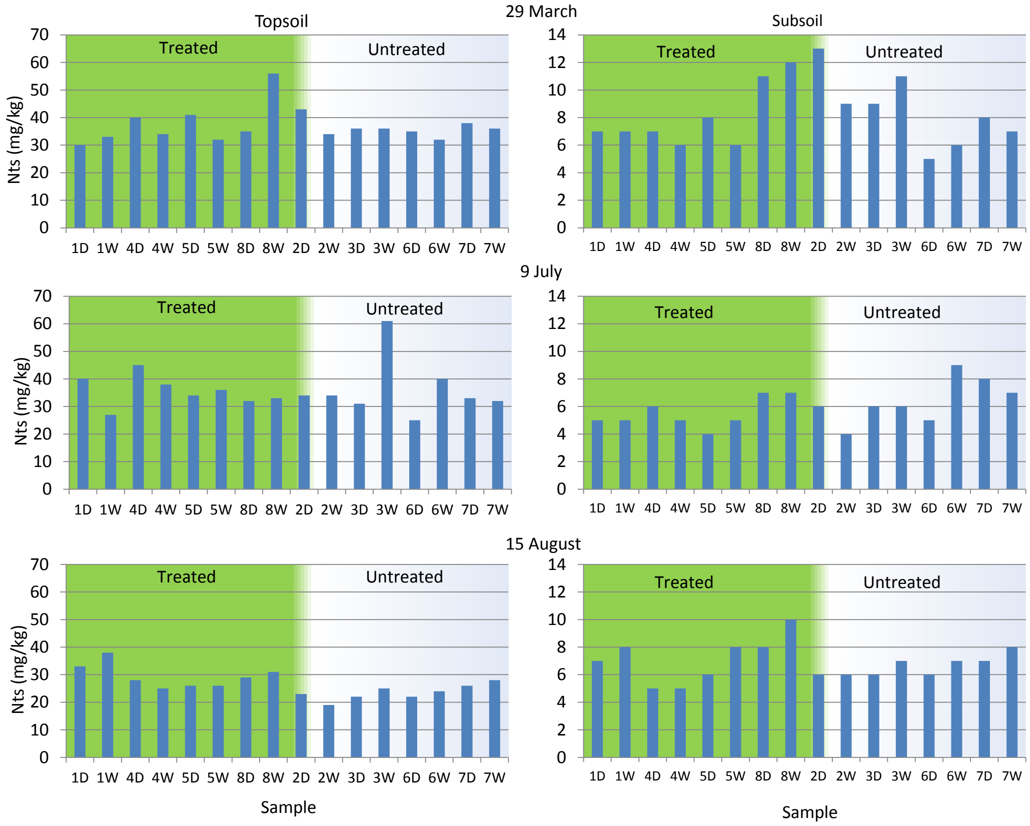

Figure 4.13 Concentrations of total soluble nitrogen of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

Table 4.6 Mean total soluble nitrogen (mg/kg) in topsoil samples from the soil columns taken in the untreated and surfactant treated plots on 29 March, 9 July, and 15 August. Besides the standard deviation (mg/kg and coefficient of variation (%) are presented (n = 8).

Date	Untreated			(To be) Treated		
	Mean (mg/kg)	SD (mg/kg)	CV (%)	Mean (mg/kg)	SD (mg/kg)	CV (%)
29 March	36.3	3.2	8.9	37.6	8.3	22.1
9 July	36.3	10.8	29.8	35.6	5.5	15.4
15 August	23.6	2.8	11.7	29.5	4.4	14.8

4.10 Boxplots with Concentrations Total Nitrogen, N-(NO_3+NO_2), N-NH_4, and Total Soluble Nitrogen in Topsoil and Subsoil

Box-and-Whisker plots, also called box-plots, have been used to show the differences in concentrations of total nitrogen, N-(NO_3+NO_2), N-NH_4, and total soluble nitrogen (Nts) from samples of topsoil and subsoil, collected on 29 March, 9 July, and 15 August (Fig. 4.14 and Fig. 4.15). A distinction has been made in: 1) the four samples with the lowest volumetric soil water content from the untreated plots (UD); 2) the four samples with the highest water content of the untreated plots (UW); 3) the four samples with the lowest water content of the treated plots (TD); and 4) the four samples with the highest water content of the treated plots (TW). The lowest and highest volumetric soil water contents were based on the 25 TDR measurements on the respective sampling dates.

The four values of the respective nitrogen analysis were put in numerical order. The lower part of the grey box shows the first quartile (Q1), which in our case is the mean of the two lowest values. The upper part of the grey box shows the third quartile (Q3), which in our case is the mean of the two highest values. The second quartile (Q2), or the median value, is in our case the mean of the second and third value of the numerical order, and is indicated which the horizontal line in the grey box. Also the lowest and the highest measured value are indicated with the vertical lines, respectively above and below the grey box.

According to the boxplots of the concentration of total nitrogen in the topsoil samples, there were no significant differences assessed between the four untreated samples with the lowest water contents (UD), with the four untreated samples with the highest water contents (UW), with the four treated samples with the lowest water contents (TD), and with the four treated samples with the highest water contents (TW), and between each other, on any of the three sampling dates (Fig. 4.14). Also no significant differences were established between the concentrations of N-NH4, N-(NO_3+NO_2), and total soluble nitrogen between untreated (UD and UW) and treated (TD and TW) topsoil samples on the three sampling dates.

Figure 4.15 shows that also no significant differences were established between the concentrations of total nitrogen, N-NH_4, N-(NO_3+NO_2), and total soluble nitrogen between untreated (UD and UW) and treated (TD and TW) subsoil samples on the three sampling dates.

To conclude, no significant differences in nitrogen analyses were assessed for topsoil and subsoil samples from untreated and treated plots, and for samples with lower and higher water content, on any of the three sampling dates.

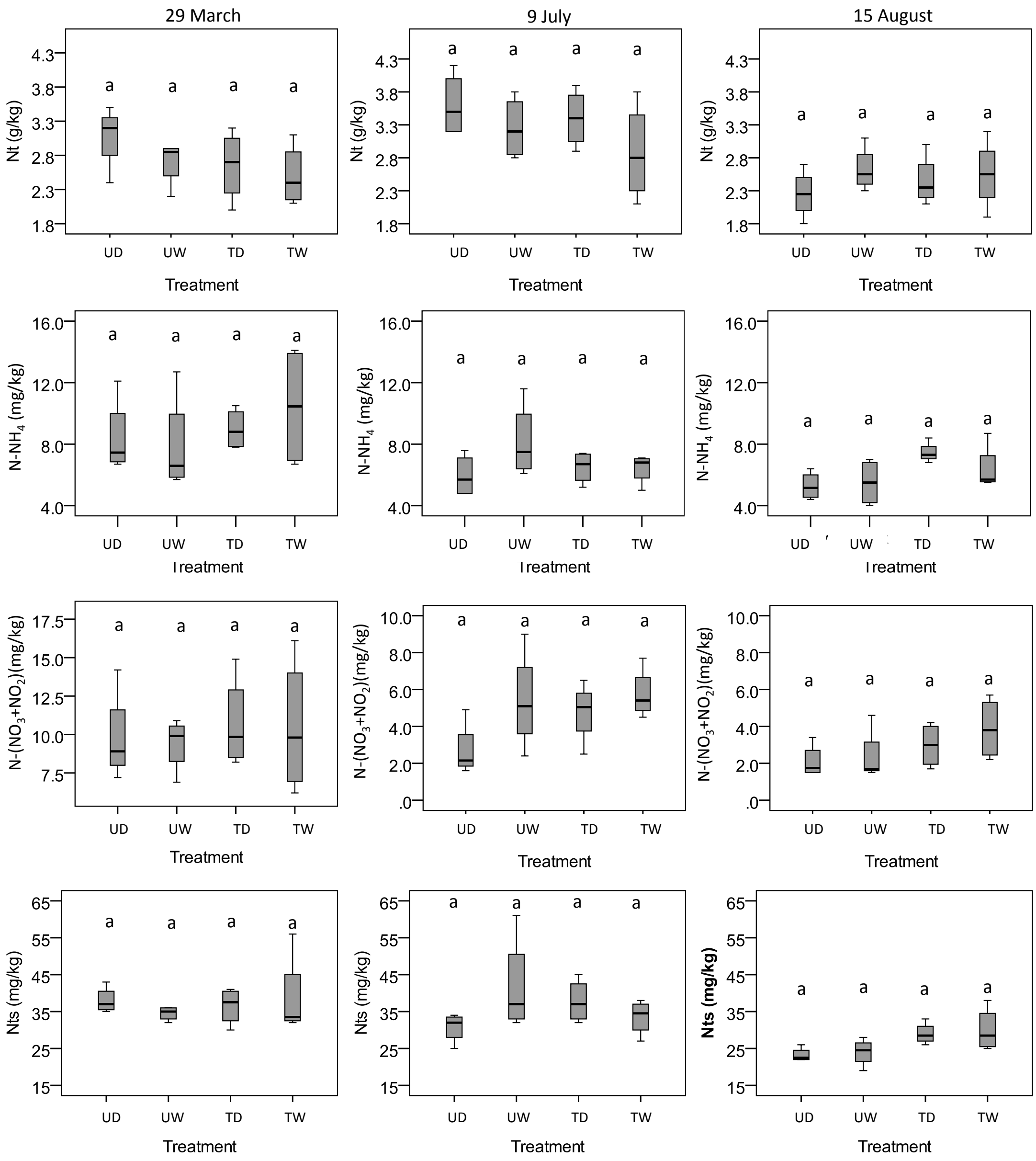

Figure 4.14 Box-and-Whisker plots of concentrations of total nitrogen, N-NH$_4$, N-(NO$_3$+NO$_2$), and total soluble nitrogen of samples from the topsoil of the untreated (U) and Revolution treated (T) plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil samples with the lowest and suffix W with the highest water content measured by TDR.

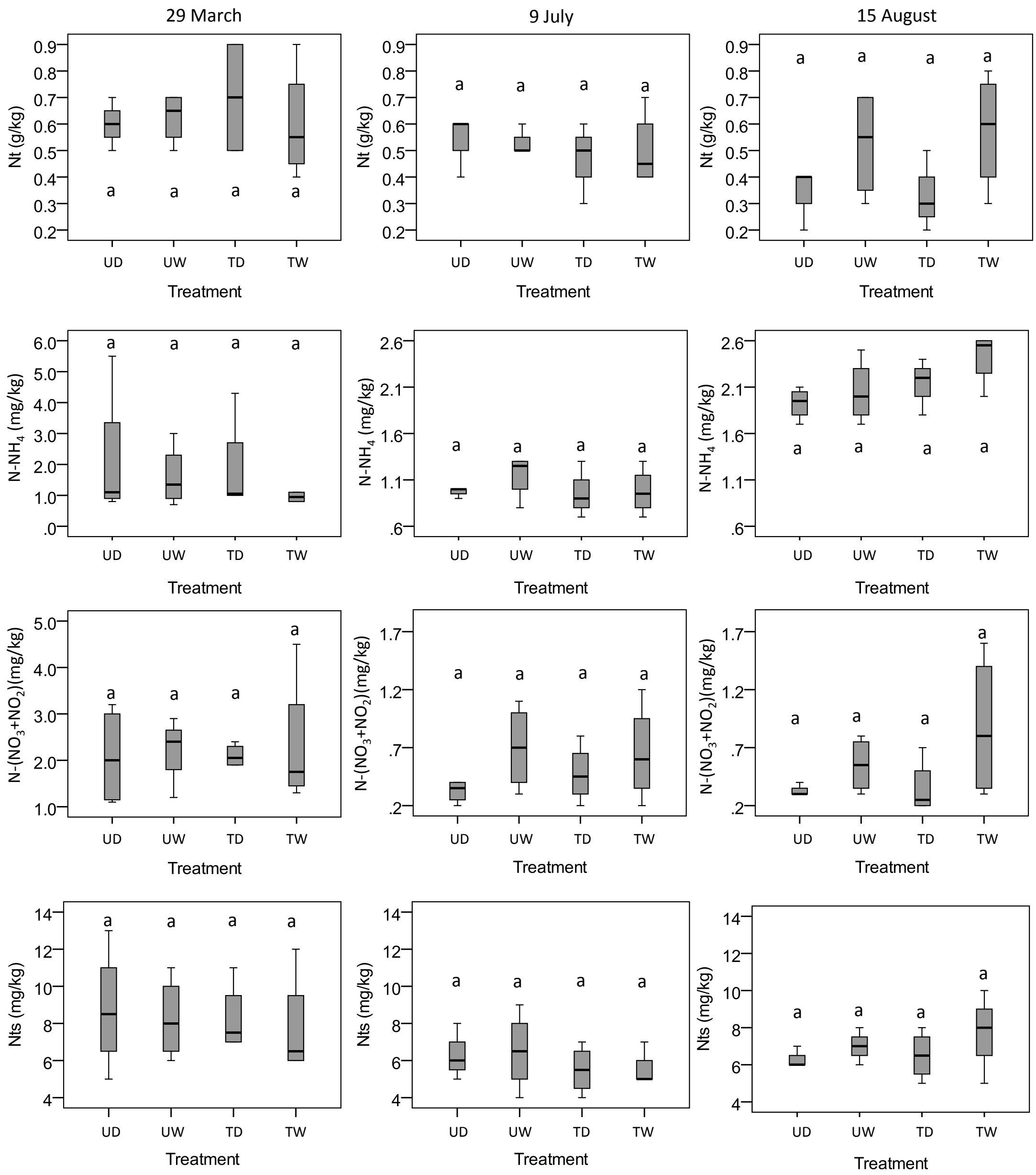

Figure 4.15 Box-and-Whisker plots of concentrations of total nitrogen, N-NH_4, N-(NO_3+NO_2), and total soluble nitrogen of samples from the subsoil of the untreated (U) and Revolution treated (T) plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil samples with the lowest and suffix W with the highest water content measured by TDR.

4.11 Total Nitrogen, N-(NO_3 + NO_2), N-NH_4, and Total Soluble Nitrogen Expressed in Standard Volume (0.05 m^3) in Topsoil and Subsoil

The concentration of the total nitrogen in the topsoil and subsoil samples from the untreated and (to be) treated plots was used to calculate the quantity of total nitrogen in a standard volume of 0.05 m x 1 m x 1 m = 0.05 m^3.

The nitrogen content in the standard volume of the topsoil samples varied between 140 and 195 gram on 29 March, between 80 and 235 gram on 9 July, and between 125 and 220 gram on 15 August (Fig 4.16). No evident differences in mean quantities were found between the samples from the untreated and treated plots, or between the mean quantities on the three sampling days.

The nitrogen content in the standard volume of the subsoil samples varied between 29 and 60 gram on 29 March, between 24 and 53 gram on 9 July, and between 14 and 61 gram on 15 August (Fig. 4.16). No evident differences in mean quantities were found between the samples from the untreated and treated plots. A slight decrease in the mean quantities of total nitrogen in the subsoil samples is visible in the period 29 March to 15 August (Fig. 4.16).

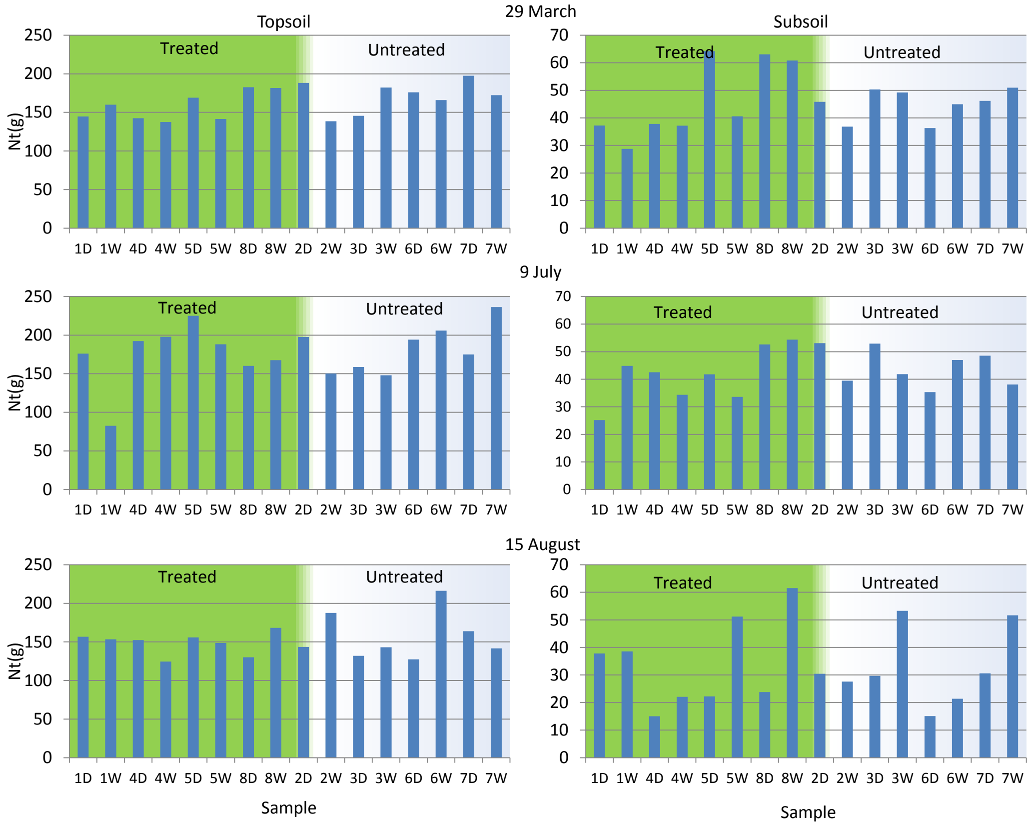

Figure 4.16 Total nitrogen expressed in standard volume (0.05 m^3) of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

Also the concentration of N-(NO_2+NO_3) in the topsoil and subsoil samples from the untreated and (to be) treated plots was used to calculate the quantity of total nitrogen in a standard volume of 0.05 m x 1 m x 1 m = 0.05 m^3.

The N-(NO_2+NO_3) content in the standard volume of the topsoil samples varied between 400 and 950 milligram on 29 March, between 75 and 600 milligram on 9 July, and between 75 and 300 milligram on 15 August (Fig 4.17). Slightly lower mean quantities were found for the samples from the untreated plots compared with the treated plots on 9 July and 15 August.
A decrease in the mean quantities of N-(NO_2+NO_3) in the topsoil samples is visible in the period 29 March to 15 August (Fig. 4.17).

The N-(NO_2+NO_3) content in the standard volume of the subsoil samples varied from 75 to 300 milligram on 29 March, from 20 to 95 milligram on 9 July, and from 10 and 125 milligram on 15 August (Fig. 4.17). No evident differences in mean quantities were found between the samples from the untreated and treated plots. Also an evident decrease in the mean quantities of N-(NO_2+NO_3) in the subsoil samples occurred in the period 29 March to 15 August (Fig. 4.17).

On 29 March a slight relationship was established of the N-(NO_3+NO_2) content of the topsoil, expressed in a standard volume of 0.05 m3, with the volumetric soil water content of the topsoil samples, with a correlation coefficient r = 0.49. For the subsoil samples existed also a slight relationship between both parameters, with a correlation coefficient r = 0.54 (Fig. 4.18).

On 9 July a stronger relationship was established between the N-(NO_3+NO_2) content of the samples and the volumetric soil water content. A correlation coefficient of r = 0.70 was assessed for the topsoil and of r = 0.73 for the subsoil samples.

On 15 August slightly relationships again occurred with correlation coefficients of r = 0.50 for the topsoil samples, and r = 0.57 for the subsoil samples respectively.

Figure 4.19 presents the relationship of the amounts of N-(NO_3+NO_2), expressed in a standard volume of 0.05 m3, from the subsoil with the topsoil samples from the same columns. Correlation coefficients of r = 0.49, r = 0.87, and r = 0.73 were found for samples from the untreated plots from respectively 29 March, 9 July, and 15 August. Correlation coefficients of r = 0.51, and r = 0.82 were found for samples from the Revolution treated plots from respectively 9 July, and 15 August.

To conclude: higher soil water contents in topsoil and subsoil tend to contain higher N-(NO_3+NO_2) contents. And relatively higher contents of N-(NO_3+NO_2) in the topsoil tend to have also higher contents of N-(NO_3+NO_2) in the subsoil.

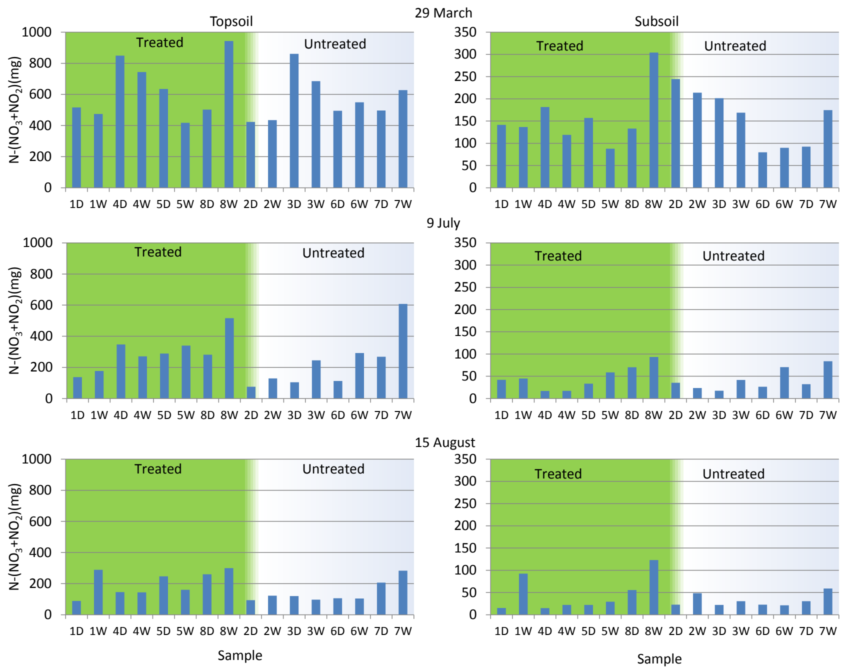

Figure 4.17 N-(NO_3+NO_2) expressed in standard volume (0.05 m^3), of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

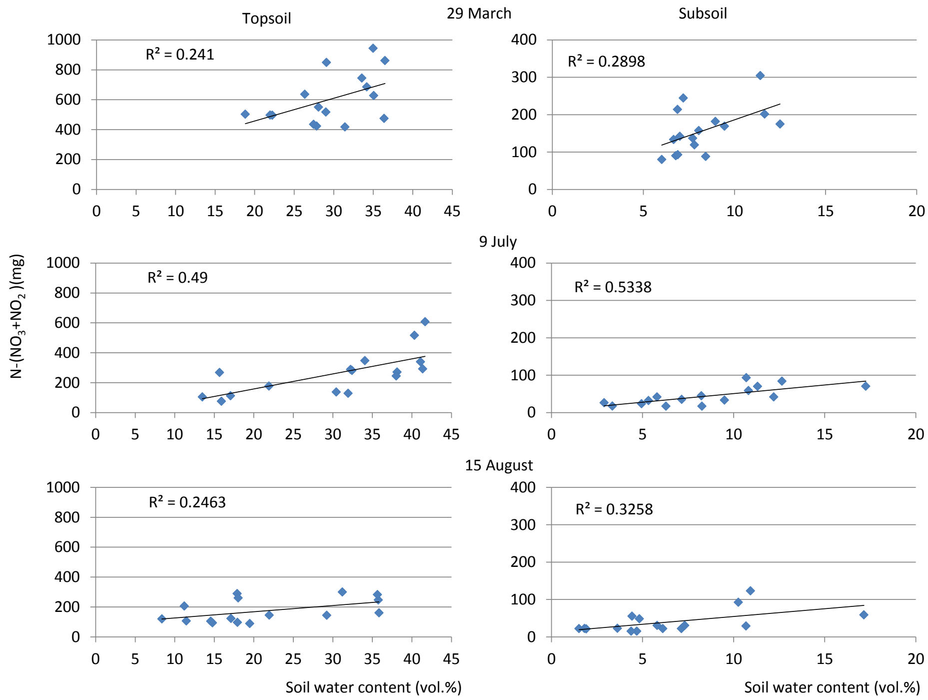

Fig. 4.18 Relationship between N-(NO_3+NO_2) expressed in standard volume (0.05 m^3), of samples from topsoil and subsoil with soil water content of the treated and untreated plots on 29 March, 9 July, and 15 August.

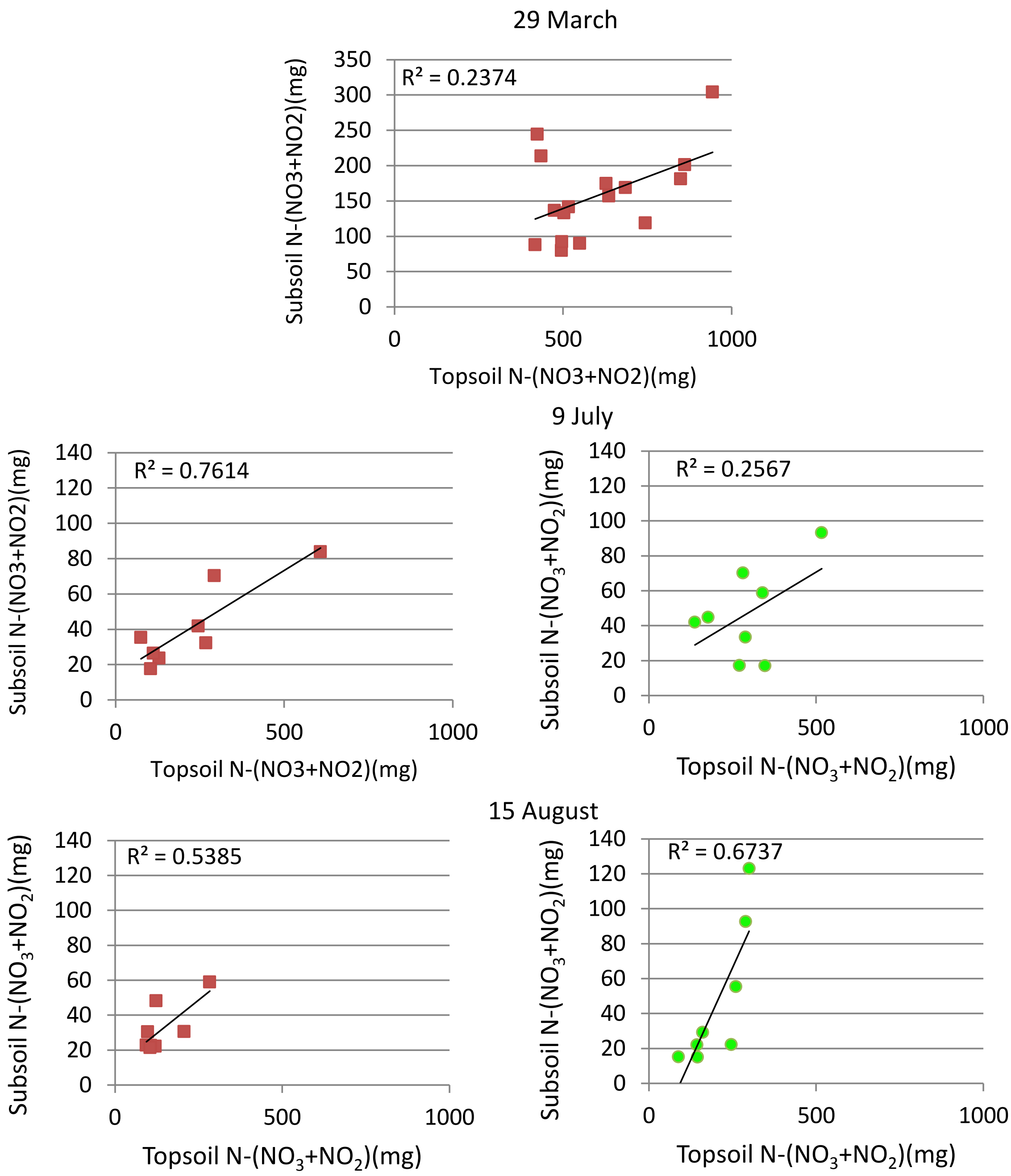

Fig. 4.19 Relationship between the amount of N-(NO_3+NO_2) in subsoil with topsoil samples from the same column, expressed in a standard volume of 0.05 m^3, on 29 March, 9 July, and 15 August. The samples of the Revolution treated plots are indicated with a green colour.

Also the concentration of N-NH_4 in the topsoil and subsoil samples from the untreated and (to be) treated plots used to calculate the quantity of total nitrogen in a standard volume of 0.05 m x 1 m x 1 m = 0.05 m^3.

The N-NH_4 content in the standard volume of the topsoil samples varied between 350 and 950 milligram on 29 March, between 220 and 600 milligram on 9 July, and between 240 and 580 milligram on 15 August (Fig 4.20). No evident differences in mean quantities were found between the samples from the untreated and treated plots. A decrease in the mean quantities of N-NH_4 is visible between 29 March and 9 July (Fig. 4.20).

The N-NH_4 content in the standard volume of the subsoil samples varied from 50 to 420 milligram on 29 March, from 55 to 110 milligram on 9 July, and from 110 to 200 milligram on 15 August (Fig. 4.20). No evident differences in mean quantities were found between the samples from the untreated and treated plots. A slight increase in the mean quantities N-NH_4 is visible between 9 July and 15 August (Fig. 4.20).

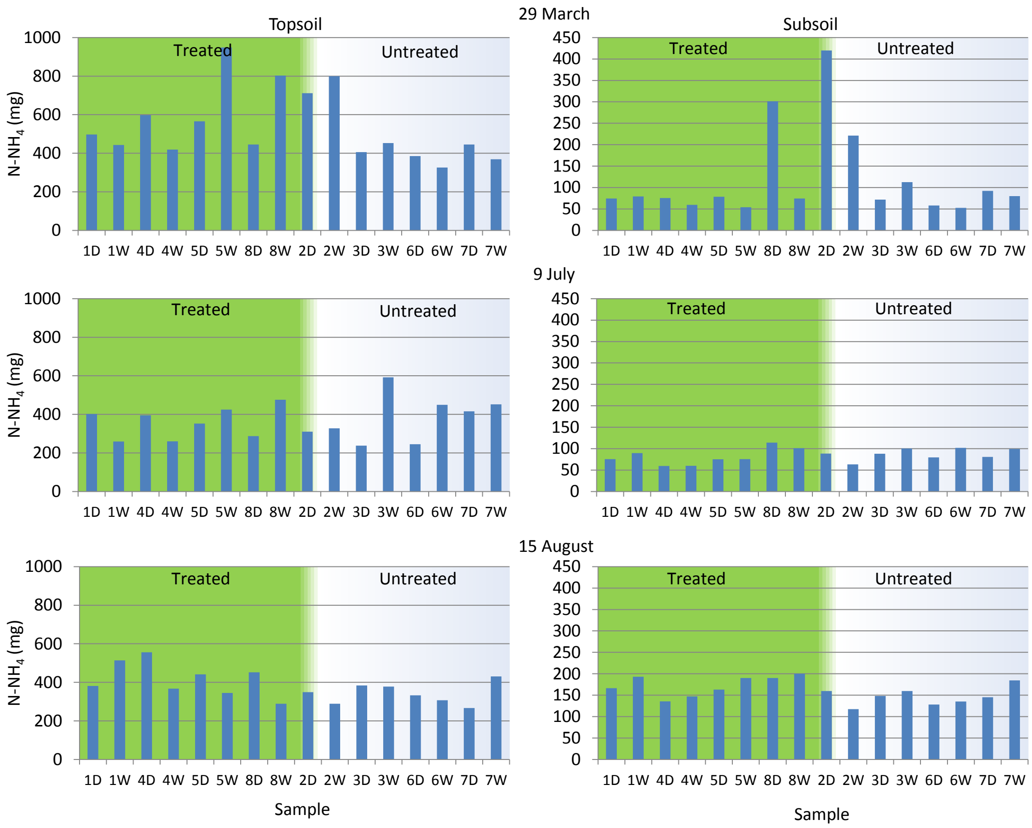

Figure 4.20 N-NH_4 expressed in standard volume (0.05 m^3), of samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

Also the concentration of total soluble nitrogen (Nts) in the topsoil and subsoil samples from the untreated and (to be) treated plots was used to calculate the quantity of total nitrogen in a standard volume of 0.05 m x 1 m x 1 m = 0.05 m^3.

The Nts content in the standard volume of the topsoil samples varied between 1800 and 3250 milligram on 29 March, between 1000 and 3100 milligram on 9 July, and between 1300 and 2200 milligram on 15 August (Fig 4.21). No evident differences in mean quantities were found between the samples from the untreated and treated plots. A decrease in the mean quantities of Nts is visible between 29 March and 15 August (Fig. 4.21).

The Nts content in the standard volume of the subsoil samples varied from 360 to 1000 milligram on 29 March, from 300 to 700 milligram on 9 July, and from 380 to 780 milligram on 15 August (Fig. 4.21). No evident differences in mean quantities were found between the samples from the untreated and treated plots. A slight decrease in the mean quantities Nts is visible between 29 March and 9 July (Fig. 4.21).

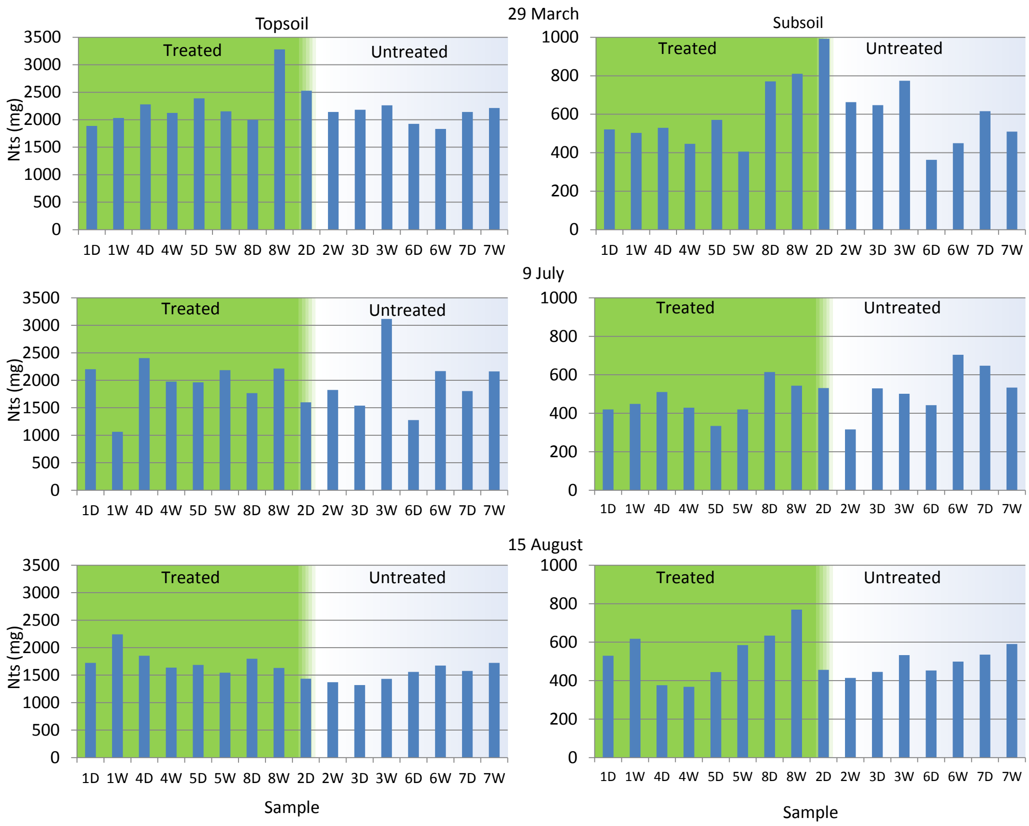

Figure 4.21 Total soluble nitrogen, expressed in standard volume (0.05 m^3), of soil samples from topsoil and subsoil of the treated and untreated plots on 29 March, 9 July, and 15 August, 2012. Suffix D indicates the origin from the soil sample with the lowest and suffix W with the highest water content measured by TDR.

4.12 Relationship between Soil Water Content of Subsoil with Topsoil

Higher soil water contents in the subsoil samples are often related with higher soil water contents in the topsoil as illustrated in Figure 4.22. The correlation coefficient for all untreated samples was r = 0.82. For 9 July and 15 August the correlation coefficient for the untreated plots was even r = 0.85.

It is worthy of note that the correlation coefficient of the samples from the Revolution treated plots from 9 July and 15 August were less with r = 0.52.

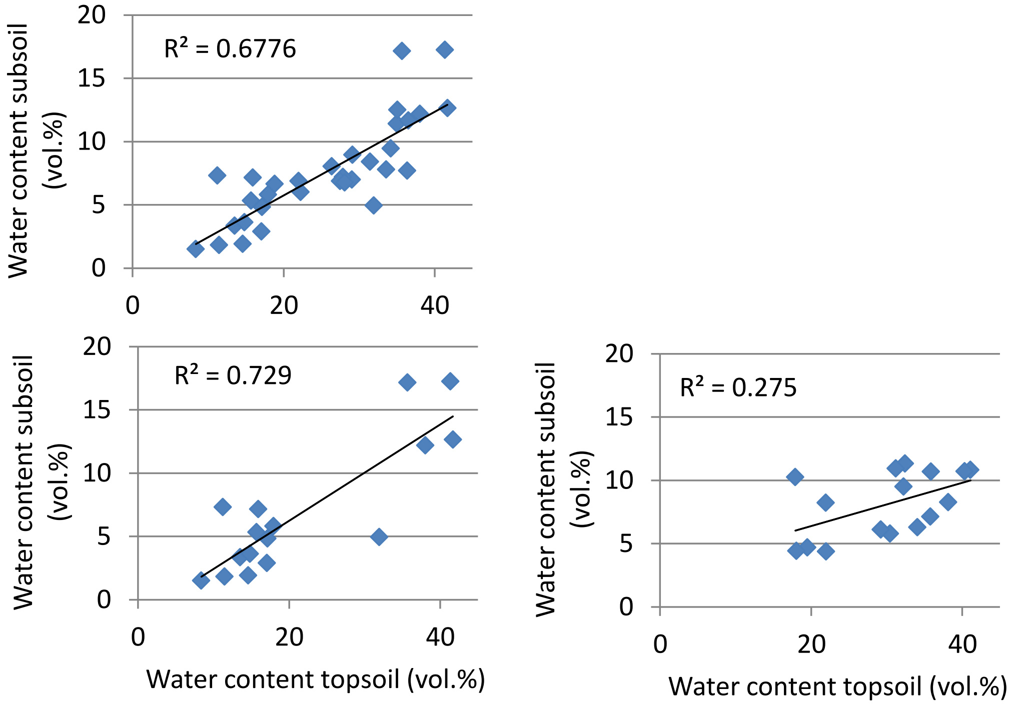

Figure 4.22 Relationship between volumetric soil water content in the subsoil samples with those of the topsoil. All samples of the untreated plots and the control plots of 29 March are presented in the upper left diagram. The samples of the untreated plots from 9 July and 15 August are presented in the left-hand lower diagram, and those of the Revolution treated plots in the right-hand diagram.

4.13 Influence of Revolution on Decomposition/Mineralization of Organic Matter

All microbial activities are influenced by environmental conditions. Of these, temperature and moisture content play the most important role, but also other factors, e.g. oxygen availability and soil texture, influence the rates of conversion (De Willigen et al., 2008).

Fig. 4.24 shows the relative decomposition rate in dependence of the soil water content in the topsoil at depths of 0-5 cm. The optimal decomposition rate (1) occurs at volumetric soil water contents in the range 25-35 vol.%. The relative decomposition rate decreases at soil water contents lower than 25 vol.%, due to lack of enough water. It also decreases at soil water contents higher than 35 vol.%, as a consequence of decreasing oxygen contents, thus by lack of aeration.

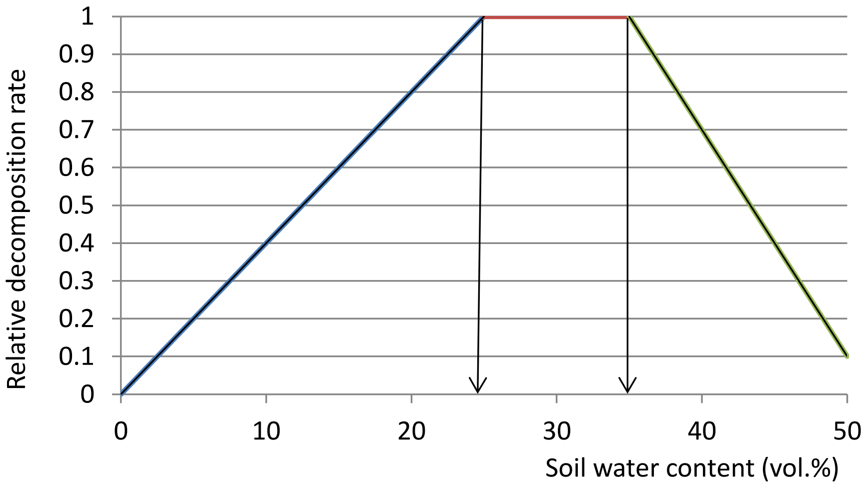

Figure 4.24 Relationship between the relative decomposition rate and soil water content of the topsoil at depths of 0-5 cm.

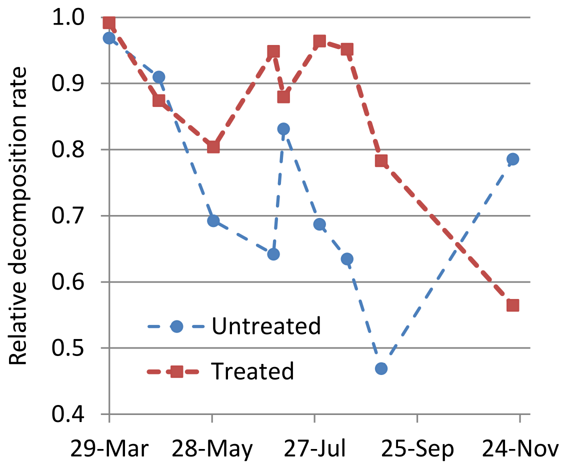

Figure 4.25 Mean relative decomposition rate of the topsoil at depths of 0-5 cm in the untreated and Revolution treated plots on the nine sampling dates.

Fig. 4.25 shows the mean relative decomposition rate calculated from the soil water contents at depths of 0-5 cm in the untreated and Revolution treated plots on the nine sampling occasions. The diagram shows that from 20 May to 15 August the mean relative decomposition rate is notably higher in the Revolution treated plots.

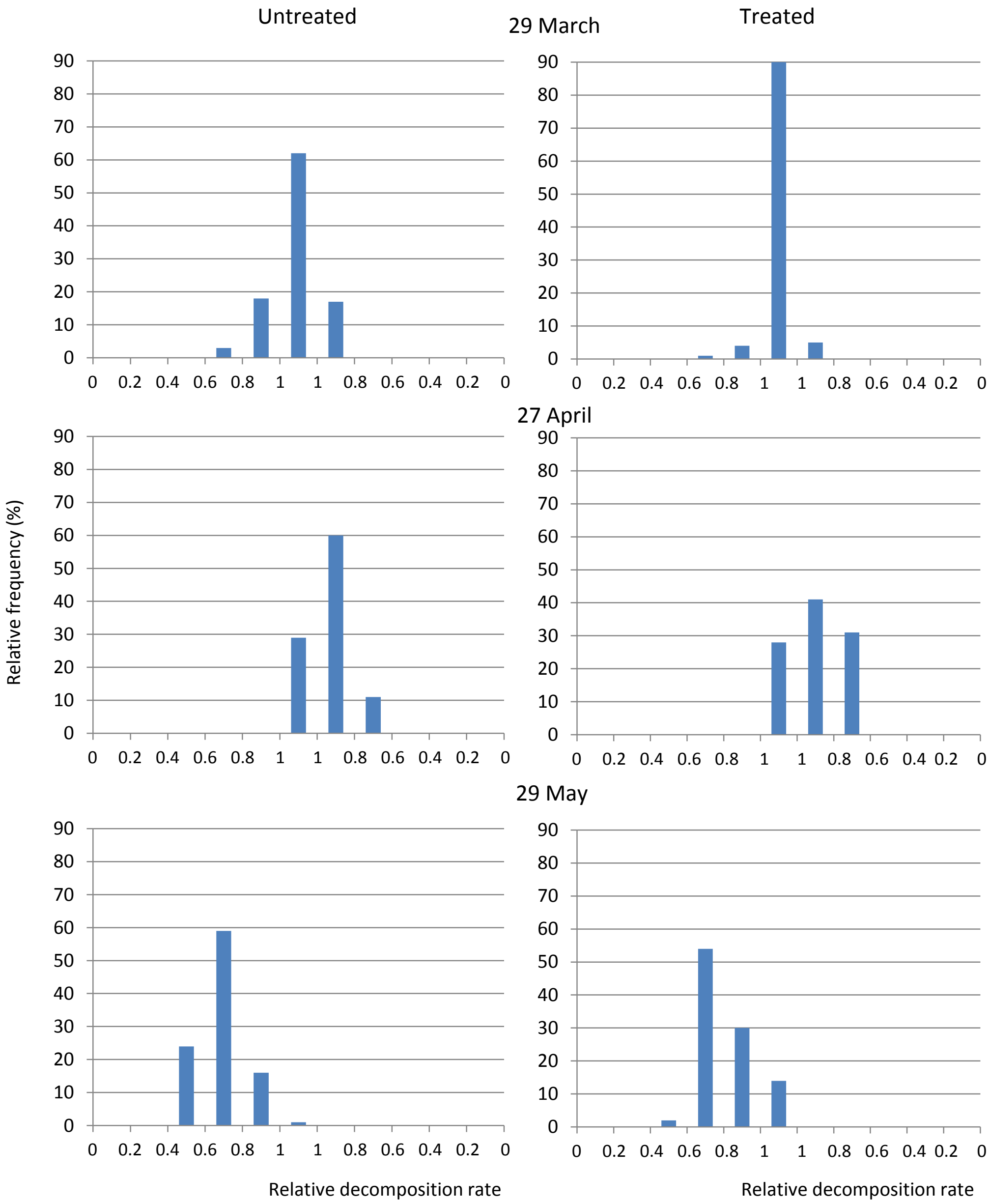

Figure 4.26 Relative frequency distributions of the relative decomposition rate classes, calculated from the soil water contents, measured with the TDR-device at depths of 0-5 cm in the untreated and Revolution treated plots on 29 March, 27 April, and 20 May, 2012 (n= 100).

Fig. 4.26 shows that the relative rate of decomposition is slightly higher in the Revolution treated plots on 29 May in comparison with the untreated plots. The decomposition rate between 3 July and 30 July was significantly higher in the treated plots (Fig. 4.27). This was also the case on 15 August and 4 September. However on 20 November the untreated plots had relatively higher rates (Fig.4.28).

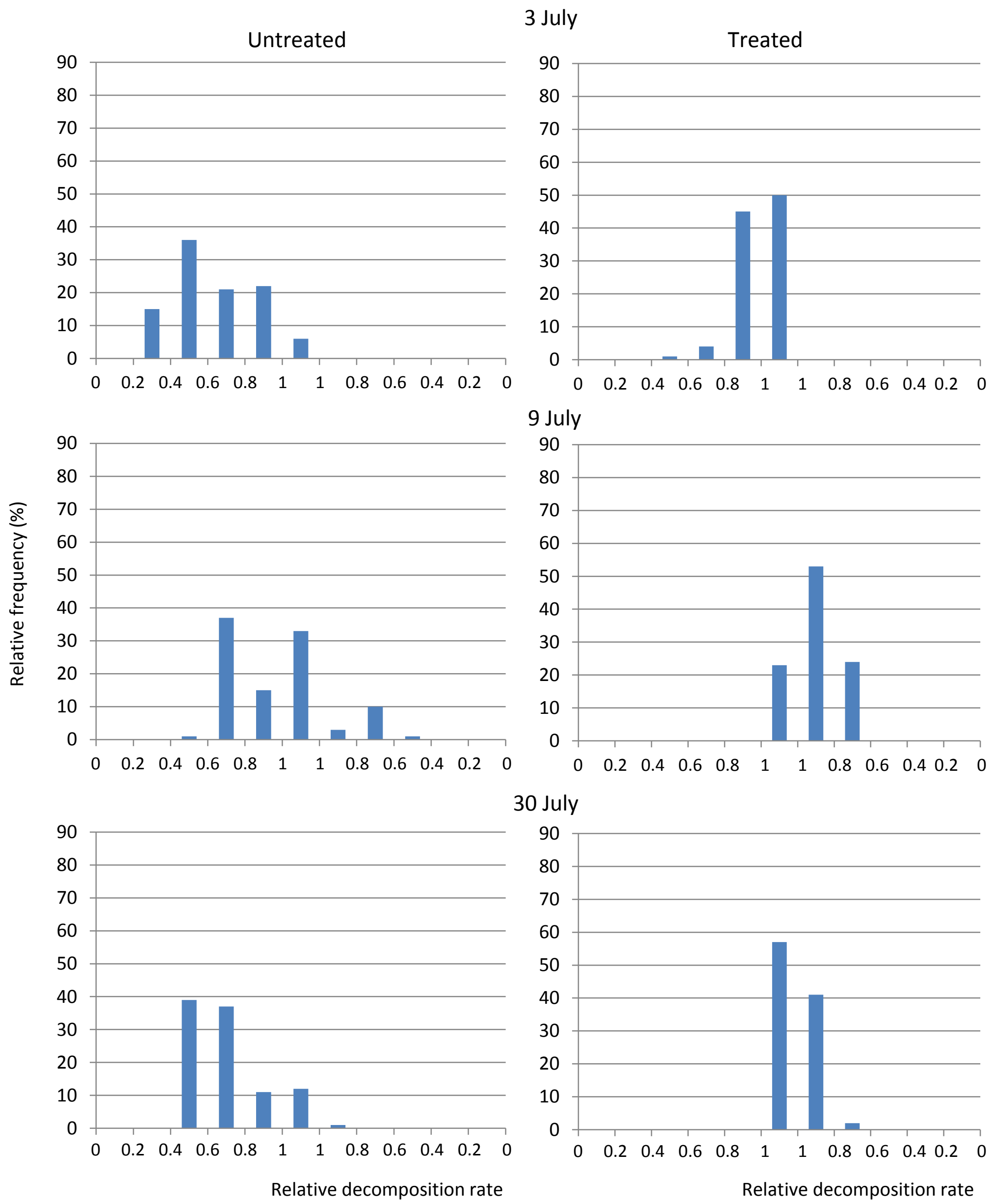

Figure 4.27 Relative frequency distributions of the relative decomposition rate classes, calculated from the soil water contents, measured with the TDR-device at depths of 0-5 cm in the untreated and Revolution treated plots on 3 July, 9 July, and 30 July, 2012 (n = 100).

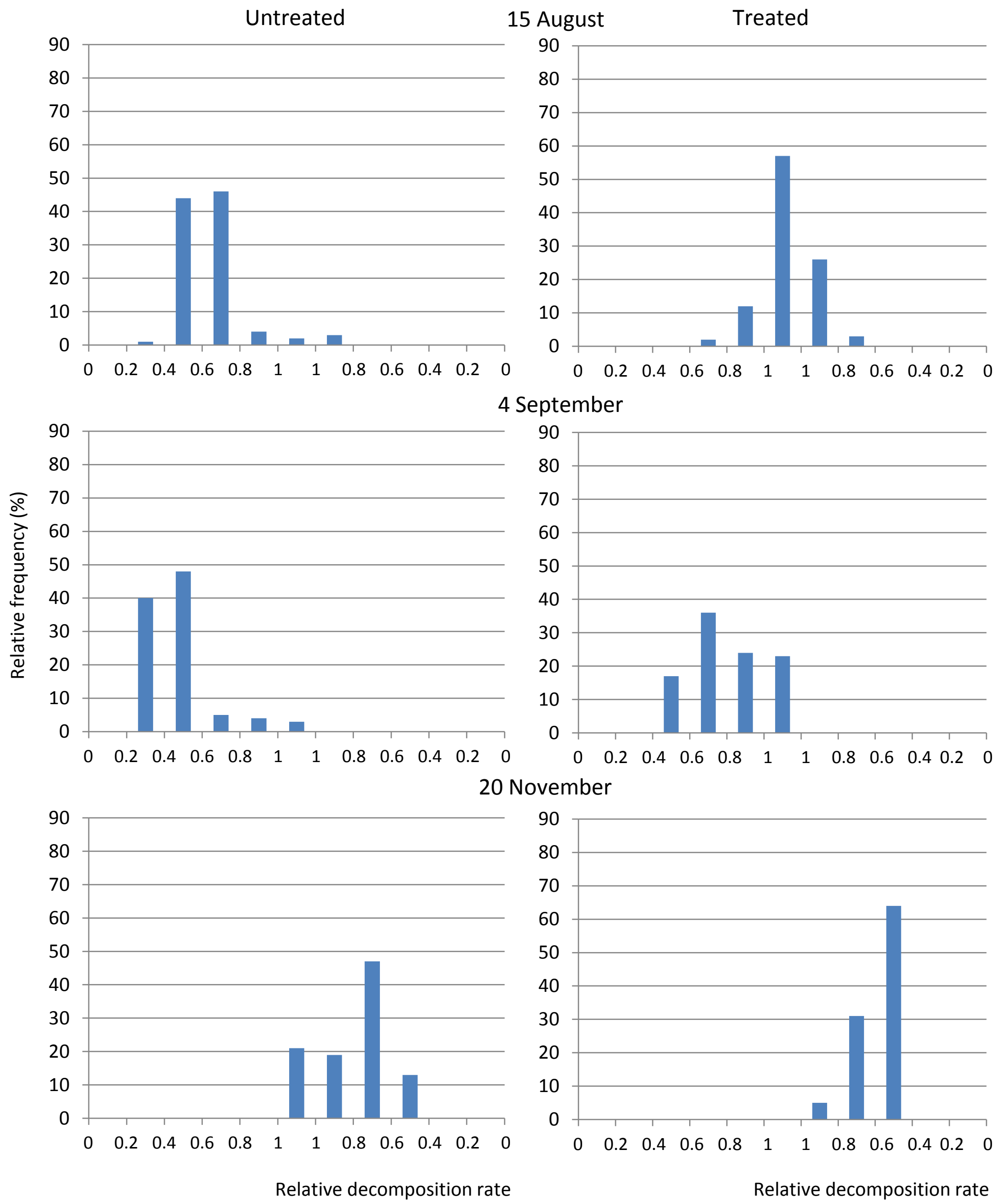

Figure 4.28 Relative frequency distributions of the relative decomposition rate classes, calculated from the soil water contents, measured with the TDR-device at depths of 0-5 cm in the untreated and Revolution treated plots on 15 August, 4 September, and 20 November, 2012 (n=100).

Figs 4.29, 4.30, and 4.31 show the contour plots on all 9 sampling occasions with the relative decomposition rate. The decomposition rate in most of the treated plots is notably higher than in the untreated plots.

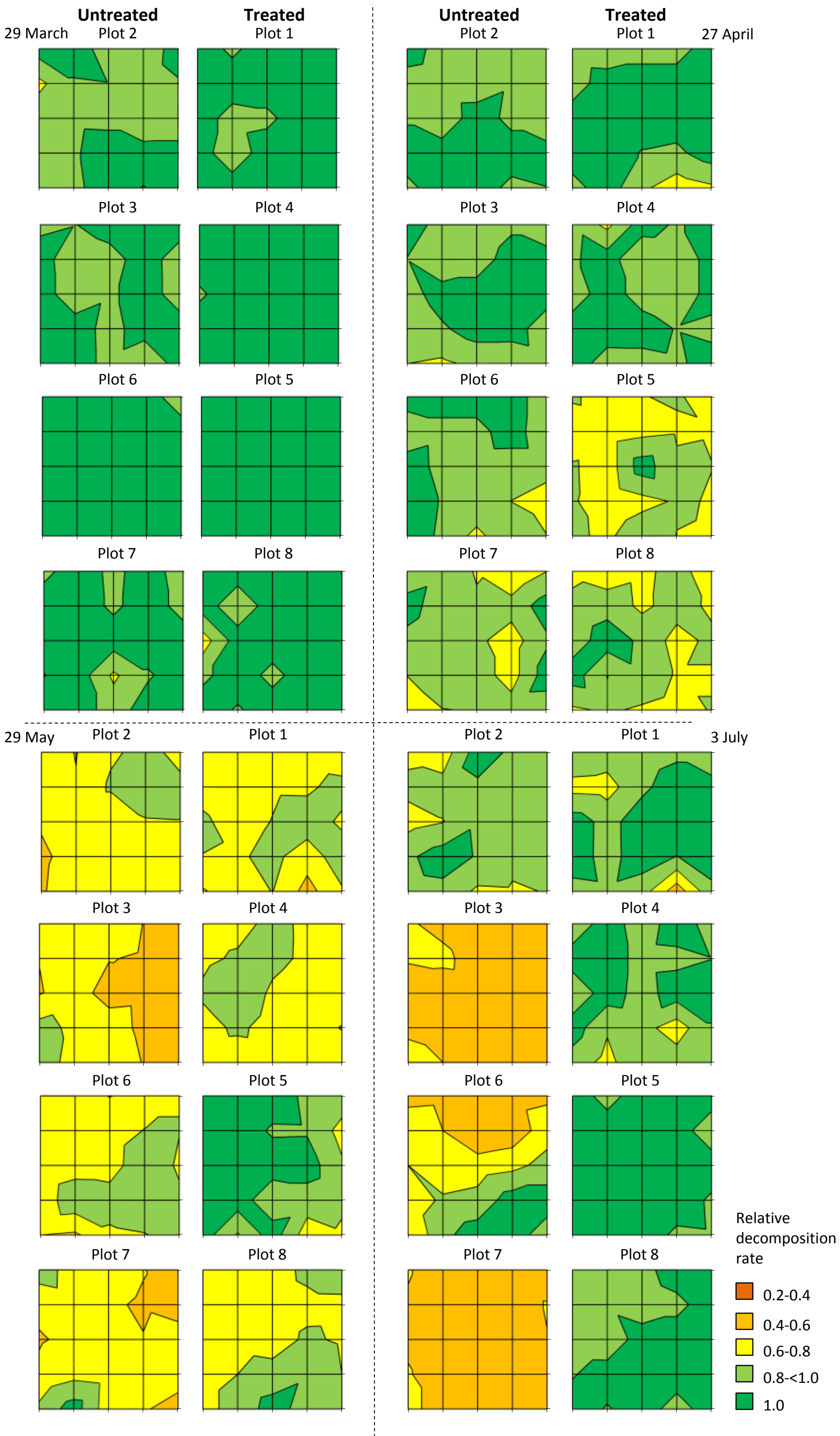

Figure 4.29 Contour plots of the relative decomposition rate classes at depths of 0-5 cm in the untreated and Revolution (to be) treated plots on 29 March, 27 April, and 29 May, and 3 July, 2012.

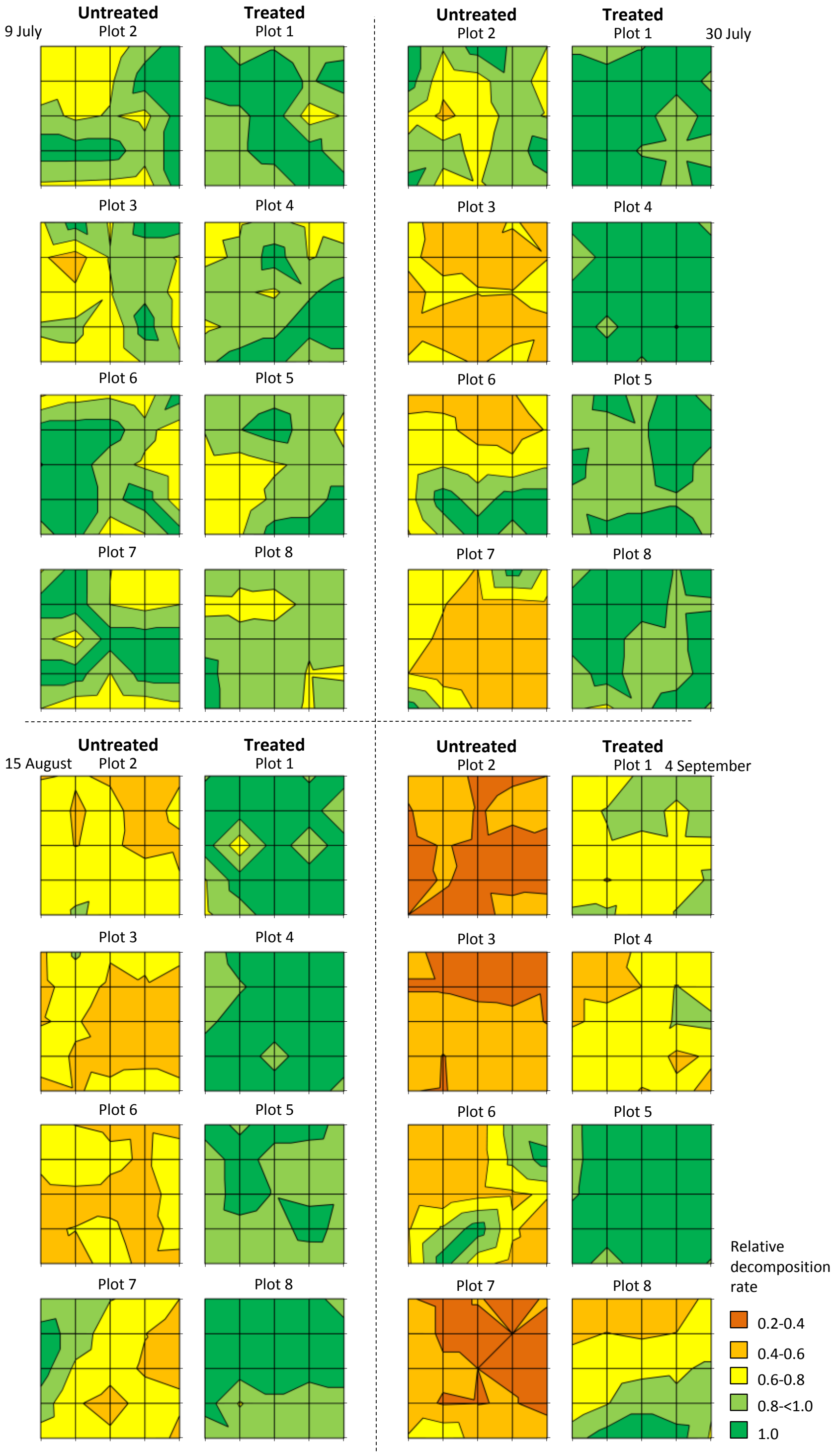

Figure 4.30 Contour plots of the relative decomposition rate classes at depths of 0-5 cm in the untreated and Revolution treated plots on 9 July, 30 July, and 15 August, and 4 September, 2012.

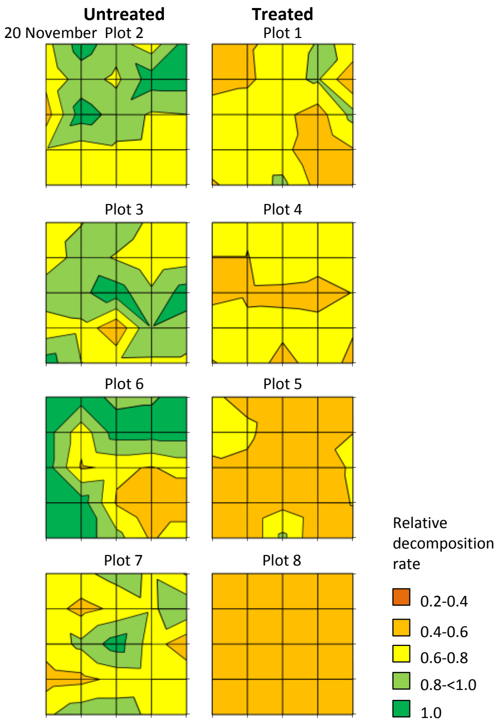

Figure 4.31 Contour plots of the relative decomposition rate classes at depths of 0-5 cm in the untreated and Revolution treated plots on 20 November, 2012.

5. Conclusions

Comparison of the 100 soil water contents, measured in the surface layer of the four untreated and four Revolution treated plots, shows that they were more or less similar on 27 April, however the contents were notably higher in the Revolution treated plots on all seven sampling dates between 29 May and 20 November.

The grass performance was significantly better on the Revolution treated plots in comparison with the untreated plots on the four sampling dates in July and August. The grass quality on the Revolution treated plots was extremely better on 4 September.

The application of Revolution, and also the soil water content of the topsoil, had no evident influence upon the total nitrogen concentration in the leaves and roots of the grass vegetation on a g/kg basis. The mean nitrogen concentration ranged in the leave samples, from the untreated and treated plots, on all three dates between 13 and 21 g/kg, and in the root samples between 15 and 18 g/kg. However the mean amounts of total nitrogen in the grass leaves from the Revolution treated plots were respectively, 27.7% and 11% higher than in those from the untreated plots on 9 July and 15 August. The higher amounts are due to the larger amount of plant tissue, present on the columns taken from the treated plots.

The organic matter content of the topsoil, which is important for the nitrogen cycle, was relatively high, with mean contents of 8.2% in the untreated and 8.3% in the treated plots.

No significant differences in nitrogen analyses (Nt., $N\text{-}NH_4$, $N\text{-}(NO_3+NO_2)$ and total soluble nitrogen) were assessed for topsoil and subsoil samples from untreated and treated plots, and for samples with lower and higher water content, on all three sampling dates.

The great differences in soil water content of the topsoil samples in the untreated plots is assumed to be caused by the locally presence of water repellent soil, which presumably was only scarcely present in the treated plots. Also the greater heterogeneity of the wetting of the subsoil in the untreated plots in comparison with the treated plots, for example on 9 July, is assumed to be the consequence of the occurrence of soil water repellency.

Higher water contents in topsoil and subsoil tend to result in higher $N\text{-}(NO_3+NO_2)$ contents, which is assumed to be due to lateral water flow in the surface layer and the development of preferential flow paths into the subsoil.

Relatively high $N\text{-}(NO_3+NO_2)$ contents in the topsoil tend to have also relatively high $N\text{-}(NO_3+NO_2)$ contents in the subsoil.

On the Revolution treated plots the greenkeepers mowed and removed many more clippings (including nitrogen) than on the untreated plots. This as a consequence of the better grass performance during the growing season, especially in July, August, and September.

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