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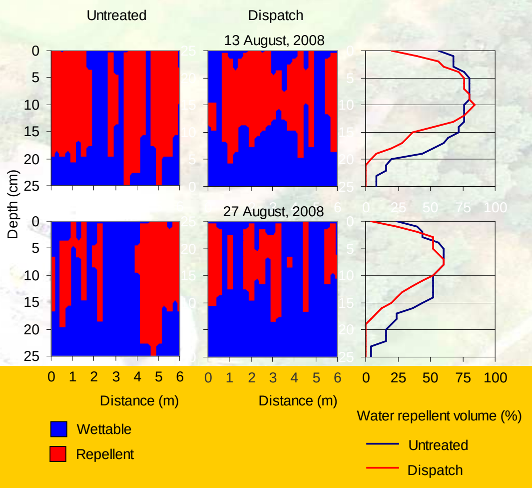

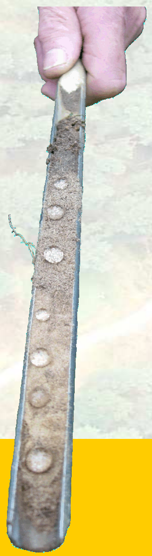

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Effects of surfactants on soil wetting and turf performance of fairways with a water repellent behavior

Héctor Aguilera, PhD student from the Instituto Geológica y Minero de España, Madrid, Spain was involved in the collection and interpretation of the data during his internship at Alterra.

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Abstract

Oostindie K., Dekker L.W., Aguilera H, Ritsema C.J., Wesseling J.G., Zeiliguer A. and Pintar M. 2009. *Effects of surfactants on soil wetting and turf performance of fairways with a water repellent behavior.* Wageningen, Alterra report 1819, 84 pp., 46 Figs., 1 Appendix, 46 References.

This study reports about the applications of soil surfactants to reduce the occurrence of water repellency and to improve the soil wetting of the fairways 5, 7, 11, and 18 of golf course De Pan, located at Bosch en Duin near Utrecht, The Netherlands. The sandy soil of the fairways exhibits a water repellent behavior resulting in a lot of localized dry spots 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 on soil cores taken to a depth of 25 cm with a small auger with a diameter of 1.5 cm.
Differences in grass performance, soil water content, and occurrence of water repellency between untreated and (in 2007) surfactant treated plots were still clearly present in June 2008. In March and April 2008 with Revolution treated ridges of fairway 11 had a better grass performance, higher soil water contents, and less water repellency than the untreated lower environments in May, June, and July. Low-rate treatments with Dispatch in a split fairway experiment on fairway 7 did not have clear effects on soil wetting and grass performance. Across fairway 5 one strip was treated with ACA 2766 and another strip with ACA 2766 + Dispatch. Higher soil water contents and a better grass performance were established in the ACA 2766 + Dispatch strip. The 3 plots on fairway 18 treated with Revolution and the 3 plots treated with ACA 2787 resulted in higher soil water contents, less water repellency and a better grass performance than the 3 untreated plots.

Keywords: actual water repellency, water drop penetration time (WDPT) test, Time Domain Reflectometry (TDR), critical soil water content

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Summary and Conclusions

The present studies have been performed on fairways 5, 7, 11, and 18 of golf course De Pan, located on inland dunes at Bosch en Duin near Utrecht in the Netherlands, between 21 May and 17 November, 2008. Soil water contents were measured in the upper 0-5 cm across the surfactant treated and untreated plots. Measurements were made at intervals of 10 cm or 25 cm over a length of 90 cm to 600 cm. At the same time soil cores were taken to determine the actual water repellency.

The sandy topsoil of fairway 18 exhibits extreme water repellency after a prolonged dry period. In 2007 the effects were studied of the surfactants Revolution, ACA 1936, RD 153718 and RD 153720 on the wetting of the soil and the turf performance (Oostindie et al., 2008d). The surfactants were applied 9 times to plots of 1.5 m by 1.5 m. The configurations of the untreated plots of the sites 1 and 2 were still clearly visible by the presence of a bad turf performance in comparison with the surfactant treated plots on 16 June, 2008. Also evidently lower soil water contents were established in the untreated plots in comparison with the nine month before for the last time with surfactants treated plots.

The surfaces of the fairways of the golf course De Pan are undulating with the higher ridges being more susceptible to drought and turning in color in late spring and summer. However, the head greenkeeper treated some ridges of the fairways in March and April with Revolution. The treated ridges exhibited in May and June green grass, while a brown coloring was present at the lower lying surroundings. The water contents in the upper 5 cm of the soil were less than 5 vol.% at the untreated shoulders of the ridge on 18 June, while contents between 5 and 20 vol.% were measured at the Revolution treated higher part of the ridge. It is also remarkable that soil water repellency was present from the surface to depths of 15-25 cm in the untreated parts, while it only locally was present between 10 and 17 cm depth in the treated part of the ridge.

It is hypothesized that fairways can be protected to become water repellent by regular Dispatch applications, keeping the soil above its critical soil water content. In a split fairway experiment on fairway 7 we investigated if Dispatch could achieve this. One part of the fairway was not treated, the other part once every week during the period June until the end of August, 2008. The Dispatch was applied at a rate of 1 L/hectare. The low-rate treatments with Dispatch in June and July did not have clear effects on the height of the soil water contents in the upper 5 cm nor on the homogeneity of the wetting. Besides were no significant differences in the presence of water repellency between the Dispatch and untreated part of the fairway established in June, July and August, 2008.

Across fairway 5 one strip with a length of 45 m and a width of 6 m was treated with ACA 2766 in a concentration of 30 ml/100 m^2 in 4 L water and another strip with the same dimensions was treated with ACA 2766 in a concentration of 30 ml/100 m2 + 150 ml/100 m^2 Dispatch in 4 L water. Besides, an untreated strip was used as control. The surfactants were applied fortnightly between 2 July and 10 September, 2008. On 13 and 27 August varied the soil water contents in the upper 5 cm of the ACA 2766 + Dispatch strip between 10 and 25 vol.%, while in the

untreated and ACA 2766 strips many times less than 5 vol.% was measured. The higher soil water contents in the surface layer of the ACA 2766 + Dispatch strip resulted in a better grass performance.

To study the effects of surfactant applications on the wetting of the soil, three experimental sites were chosen on fairway 18. These sites were divided into three plots with an area of 1.5 m by 1.5 m. At each site one plot was randomly used as control and two plots were randomly treated with one of the surfactants Revolution and ACA 2787. The surfactants were applied 9 times between 21 May and 10 September, 2008. The better quality of the grass on the 3 Revolution and 3 ACA 2787 treated plots compared with the 3 untreated plots was present on 2 July

More than 80% green grass was established in all 100 compartments of the 6 surfactant treated plots on 10 September, 6 October, and 17 November, 2008. However, in the untreated plots contained 32-49% of the compartments only 50-80% green grass on 10 September and 6 October. A significant improvement of the grass quality in the untreated plots took finally place on 17 November, 2008.

The Revolution and ACA 2787 treated plots contained evidently higher mean soil water contents in the surface layer than the untreated plots after three applications till the end of the experiment. The mean soil water contents in the surfactant treated plots were 5-15 vol.% higher than in the untreated plots during the period studied. The standard deviations of the soil water content were decreasing for the surfactant treated plots and increasing for the untreated plots in the course of the experiment.

At the start of the experiment (21 May, 2008) contained the profiles of all nine plots a minor to major part of water repellent soil till a depth of 12 to 20 cm. Repellency started at the soil surface and besides were preferential flow paths present. The decrease of water repellency in time was more obvious in the treated than in the untreated plots. Besides, it is remarkable that water repellency in the surfactant treated plots often starts at more than 5 cm depth, whereas in the untreated plots repellency mostly starts within 5 cm. The repellent soil volume in the untreated plots was higher than in the surfactant treated plots between 18 June and 17 November, 2008. The water repellent soil volume in the ACA 2787 plots was on nearly all sampling occasions less than in the Revolution plots.

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). It results in ongoing management problems on sand-based turfgrass systems (Cisar *et al.,* 2000; Dekker *et al.,* 2004, 2008; Oostindie *et al.,* 2008a, 2009).

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, 2004; Oostindie *et al.,* 2005a, 2005b, 2006, 2007a, 2008b, 2008c).

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.*, 2005a, 2006, 2007b).

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, 2005b; Dekker *et al*., 2000, 2005a). Wetting agents that have a strong affinity for the surfaces of hydrophobic soil particles will adsorb to those surfaces and enhance infiltration and water distribution in the regions of the soil where they have been applied. 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 (Miller and Kostka, 1998; Kostka 2000; Karnok and Tucker, 2001b; Dekker *et al*., 2003). 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 or by minimizing the losses of water by surface runoff and leaching or drainage below the rootzone. Soil surfactants may have a role to play in this (Kostka et al., 2007a, b, 2008; Oostindie *et al.*, 2008a).

An important test of the effectiveness of a soil surfactant must include the assessment of the uniformity of distribution of the water in the soil, as well as the increase in water content. The objective of our study was to investigate the effectiveness of surfactants for amelioration of water repellent fairways.

In chapter 2 we give a description of the soil and the methods used to assess soil water content and to determine the presence of actual soil water repellency. In chapter 3 we show the influence of surfactants applied on plots of the sites 1 and 2 of fairway 18 in 2007 (Oostindie *et al.*, 2008d) on the wetting of the soil and grass performance on 16 June 2008. In chapter 4 we describe the effects of Revolution applied on ridges of fairway 11 by the head greenkeeper Mark Lampe. Chapter 5 gives an overview of the effects of applications of a surfactant at a low rate to a part of fairway 7. The effects of two surfactants applied in 2008 on fairway 5 are described in chapter 6 and the results of applications of two surfactants on fairway 18 are represented in chapter 7.

2. Soil and Measurements

2.1. The Soil Profile

The present studies have been performed on fairways 5, 7, 11, and 18 of golf course De Pan, located on inland dunes at Bosch en Duin near Utrecht in the Netherlands, between 21 May and 17 November, 2008. The soil of the fairways consists of fine non-calcareous sand with less than 3% clay to a depth of more than 2 m. An organic matter content of 5-12 w.% was established in the surface layer at depths of 0-2.5 cm and of 3.5-7 w.% at depths of 2.5-5 cm. At depths of 7-12 cm an organic matter content was detected of 2-5 w.%. It further decreased to 2-3 w.% at depths of 20-25 cm. Below this depth the organic matter content was found to be less than 1 w.%.

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

Beginning on 21 May, 2008 soil water contents were measured with the portable TDR-device (Fig. 2.1) in the upper 0-5 cm across the surfactant treated and untreated plots. Measurements were made at intervals of 10 cm or 25 cm over a length of 90 cm to 600 cm.

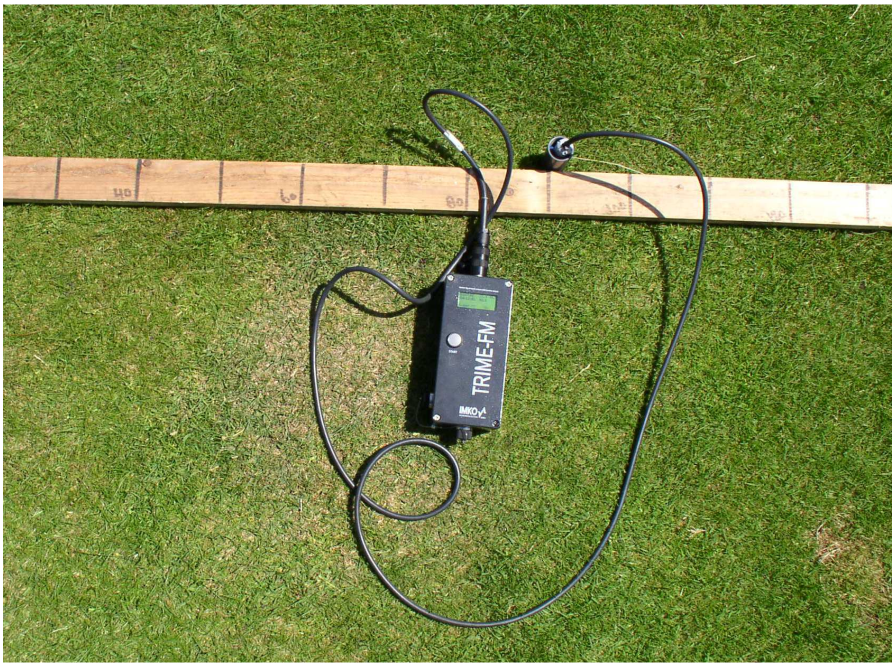


Figure 2.1 Portable TDR-device for measurement of soil water content.

2.3. Assessment of Actual Soil Water Repellency

At the same time of the soil water content measurements soil cores were taken at these points, using a small auger, and the actual water repellency was determined in the field by placing drops of water on the cores with intervals of 1 cm (Fig. 2.2). Depth and thickness of the actual water repellent soil were recorded.

Figure 2.2 Determination of the occurrence, depth and thickness of a water repellent layer in the field, by using a small core sampler.

3. Long-term Effects of Surfactants Applied on Fairway 18 in 2007

3.1. Effects of Treatments in 2007

The sandy topsoil of fairway 18 exhibits extreme water repellency after a prolonged dry period. In 2007 the effects were studied of the surfactants Revolution, ACA 1936, RD 153718 and RD 153720 (Aquatrols, Paulsboro, New Jersey, USA) on the wetting of the soil and the turf performance (Oostindie et al., 2008d). The surfactants were applied 9 times to plots of 1.5 m by 1.5 m between 6 June and 18 September, 2007 at a rate of 1.85 ml/m^2 in a water volume of 70 ml/m^2, using a backpack sprayer. On the same dates an identical amount of water (70 ml/m^2 equal to 0.07 mm) was applied to untreated control plots.

The effects of the surfactants on grass growth and soil wetting were evident. There was a large difference in grass performance between the untreated plots and the surfactant treated plots of sites 1 and 2 between 25 July and 20 November, 2007. The mean soil water contents in the surface layer of the surfactant treated plots of site 1 and 2 were very similar and always higher than those of the untreated plots. The water repellent soil volume decreased the most during the experiment in the profiles of the surfactant treated plots.

3.2. Effects of Surfactants 9 Months After Applications

The configurations of the untreated plots of the sites 1 and 2 were still clearly visible by the presence of a bad turf performance in comparison with the surfactant treated plots on 16 June, 2008, as illustrated by Figure 3.1.

We mapped the turf performance of the 10 plots of both sites by using an iron grid of 1 m by 1 m consisting of 10 cm by 10 cm cutting faces (see Fig. 3.2). In any of these compartments the percentage of green grass was estimated by using the following classes: >80%, 50-80%, and <50% green grass. In the untreated plots we established in 45 of the 100 compartments in site 1 and in 30 compartments of site 2 less than 50% green grass and in only 5, respectively 17 compartments >80% green grass, as illustrated by Figure 3.3. The most compartments with >80% green grass were present in the ACA 1936, RD 153718 and RD 153720 plots of site 1. The Revolution plot of site 2 was a little bit striking, with less than half of the compartments containing >80% green grass.

We measured also the soil water contents with the portable TDR-device (see Fig. 2.1, chapter 2) in the upper 0-5 cm across the surfactant treated and untreated plots of both sites. Measurements were made at intervals of 10 cm over a length of 90 cm. The soil water contents in the untreated plots were very low with contents not exceeding 5 vol.% in site 2 and 9 vol.% in site 1 (Figure 3.4). Mean higher soil water contents, although varying strongly over short distances, were measured in the 8 surfactant treated plots, as illustrated in Figure 3.4.

At the points of the soil water content measurements we took also soil cores, using a small core sampler, to determine the water repellency in the field by placing drops of water on the cores with intervals of 1 cm (see Fig. 2.2, chapter 2). Depth and thickness of the water repellent soil were recorded. Figure 3.5 shows that water repellency recurred completely in the untreated plots, whereas a thin surface layer and some preferential flow paths were wettable in the surfactant treated plots.

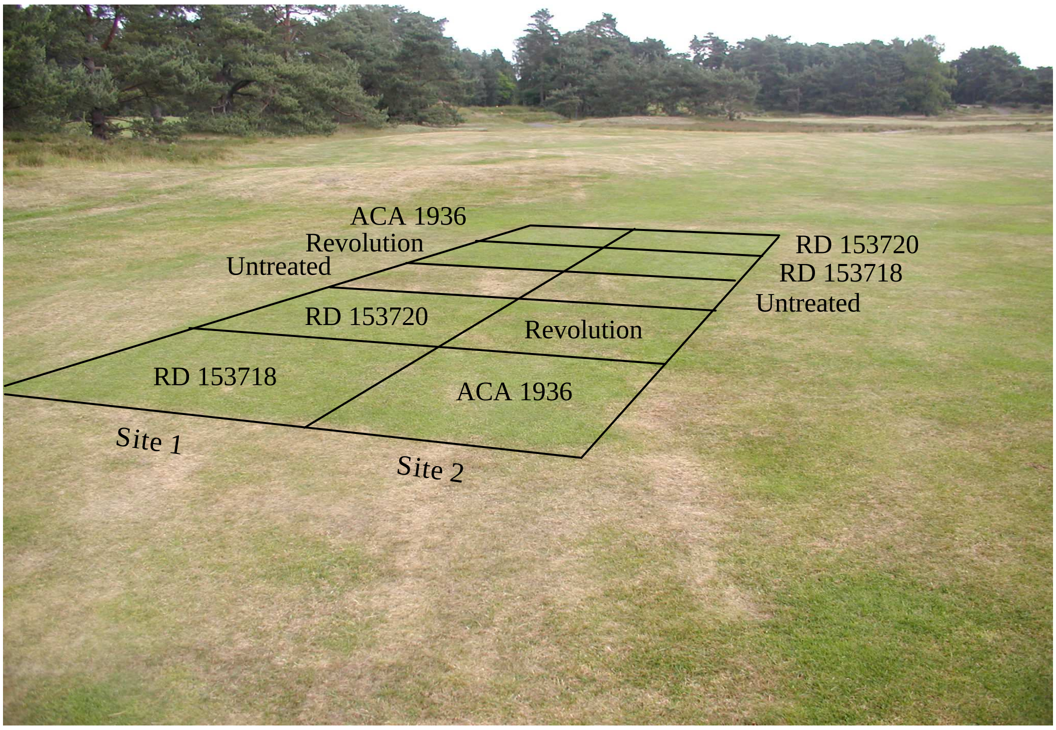


Figure 3.1 The influence of surfactant applications on site 1 and site 2 of fairway 18 in 2007 are still visible in the grass performance on 16 June, 2008.

Figure 3.2 Estimation of the percentage of green grass in adjacent compartments, squares of 10 cm by 10 cm, by using an iron grid of 1 m by 1 m.

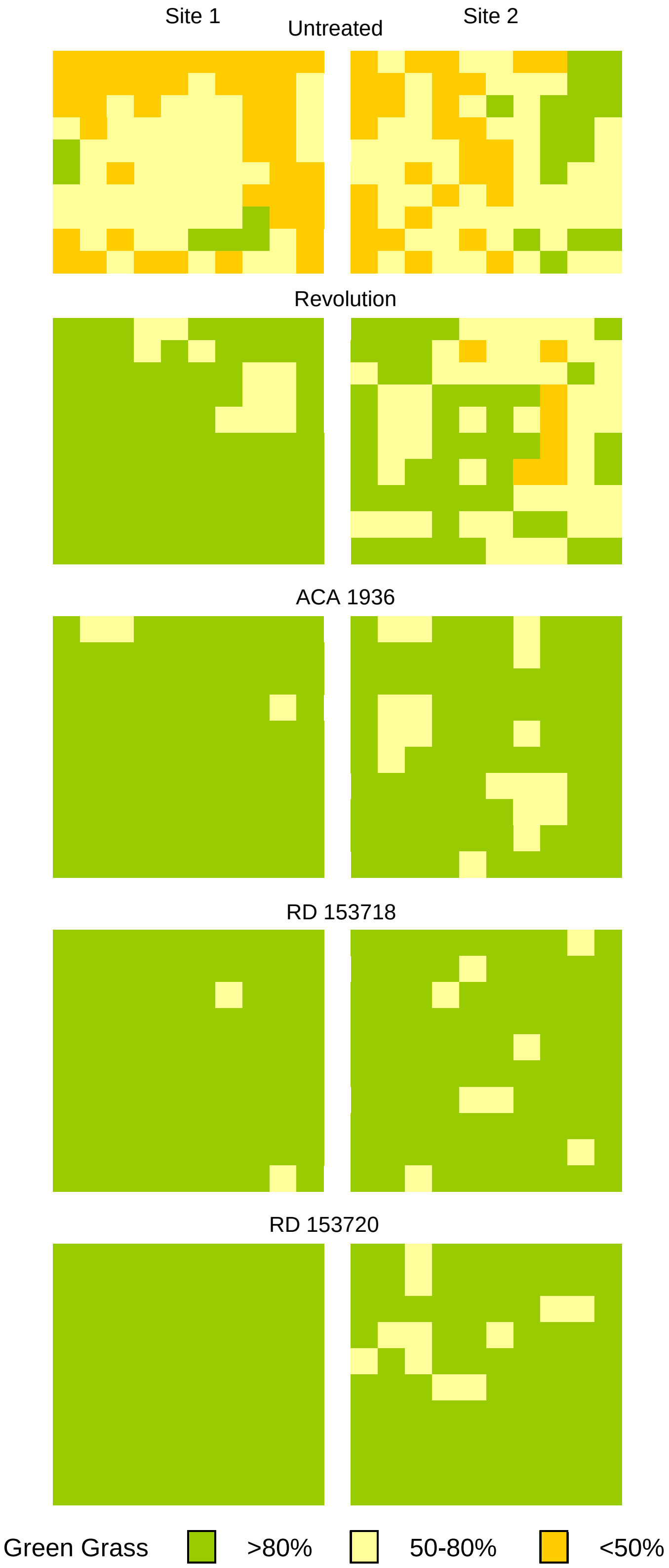


Figure 3.3 Turf performance on the untreated and (in 2007) surfactant treated plots of site 1 and 2 on 16 June, 2008.

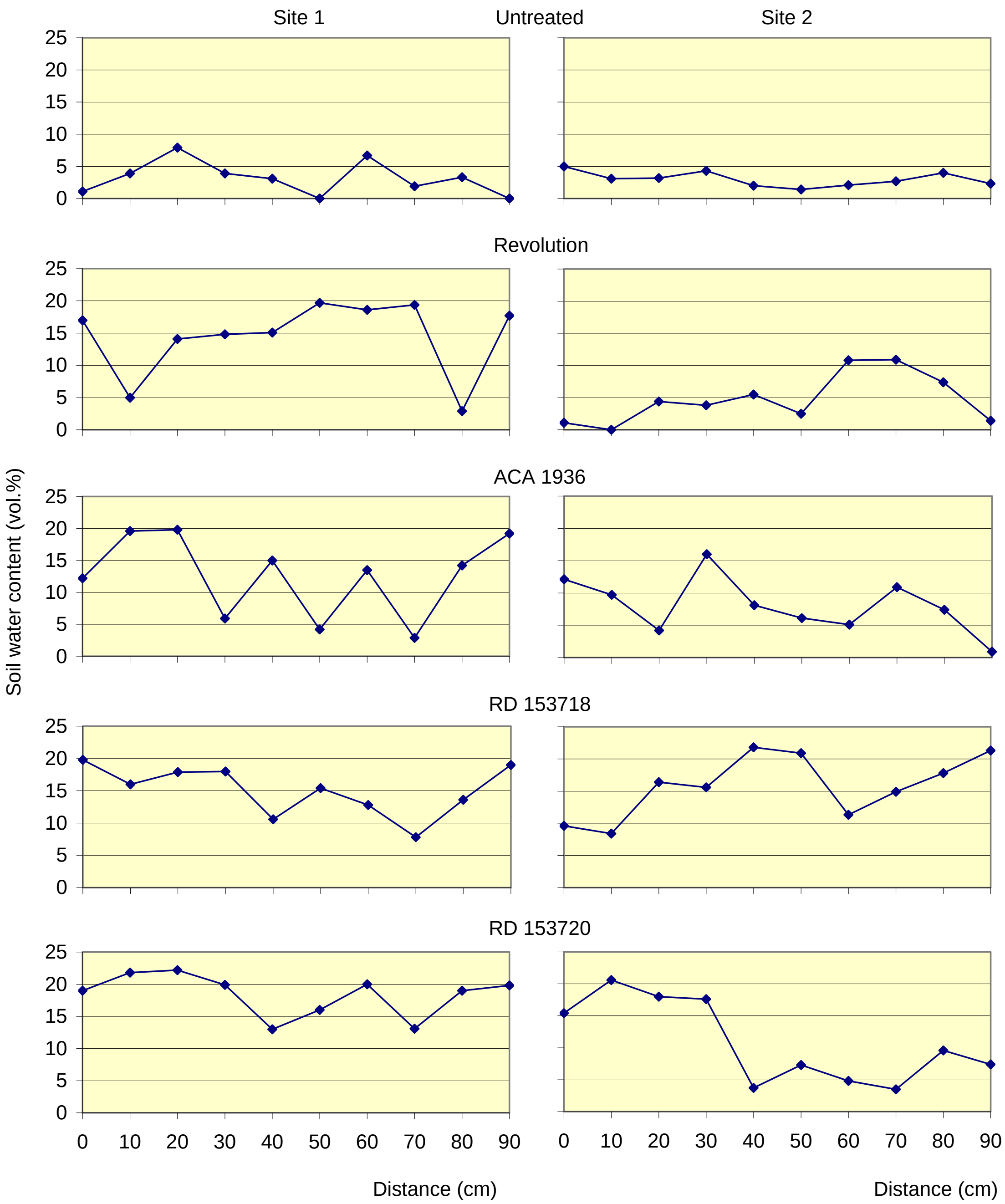


Figure 3.4 Volumetric soil water content in the surface layer of the untreated and surfactant treated plots of the 2007 experiment, measured on 16 June, 2008.

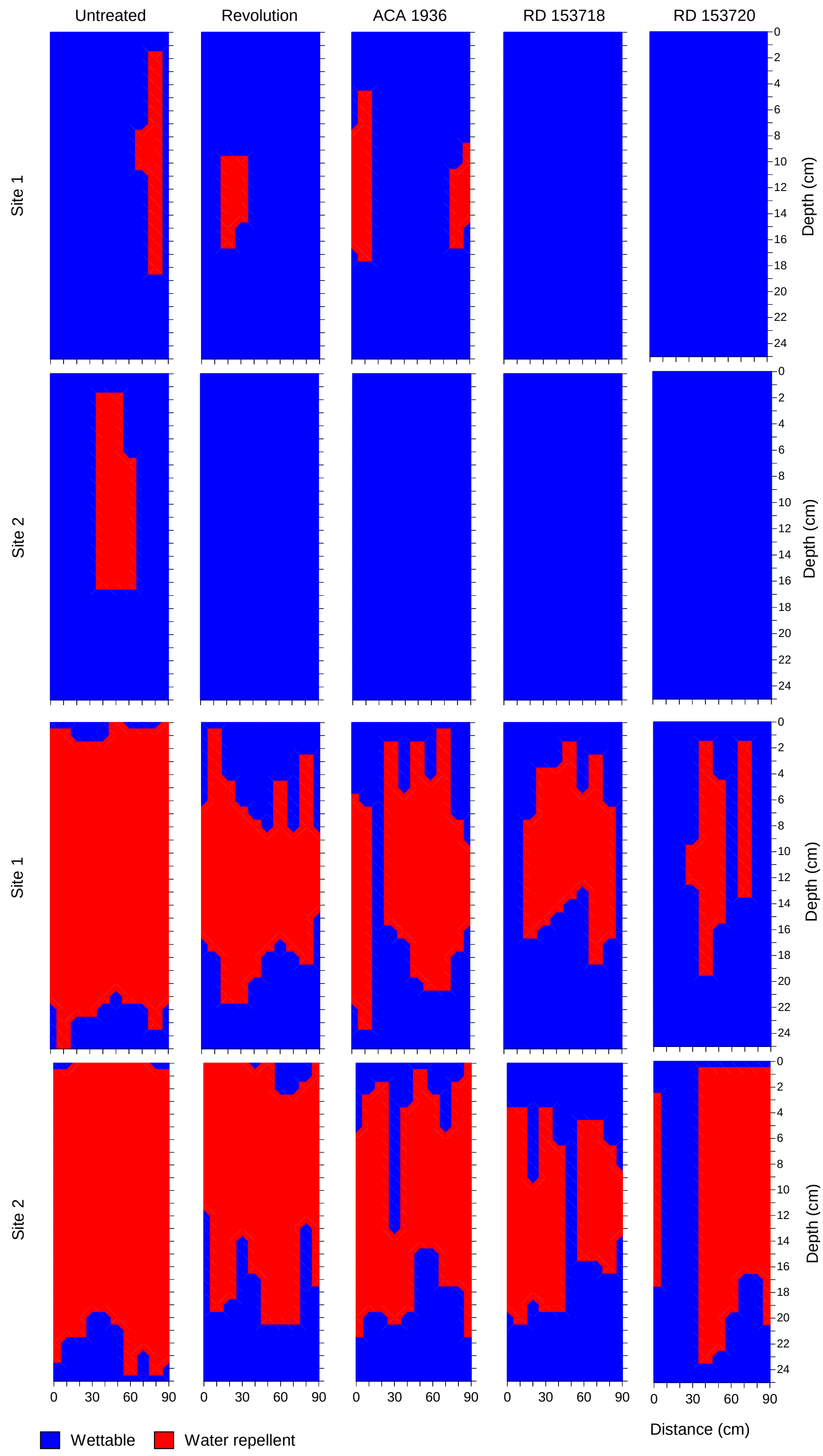


Figure 3.5 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of site 1 and site 2 from the 2007 experiment, measured on 20 November, 2007 (upper diagrams) and on 16 June, 2008 (lower diagrams).

Figure 4.1 The Revolution treated ridges of fairway 11 were still green on 11 and 18 June, while the lower lying surroundings changed in color in spring.

4. Revolution Treated and Untreated Ridges of the Fairways

The surfaces of the fairways of the golf course De Pan are undulating with the higher ridges being more susceptible to drought and turning in color in late spring and summer. During dry periods gets the turf on these ridges the first a yellow or brown color, while the lower lying environment still keeps green.

The head greenkeeper treated some ridges of the fairways once in March and once again in April, 2008 with the Surfactant Revolution. The surfactant was sprayed mechanically at a rate of 19 L per ha in 800 L water.

The effects of the applications were clearly visible during the relatively dry periods in May and June. The treated ridges exhibited green grass, while a brown coloring of the turf represented the lower lying surroundings. The upper picture of Figure 4.1 shows this reversed image of the grass colors, as photographed for a treated ridge on 11 June, 2008. Also on 18 June and 22 July was the difference in grass color between the treated ridge and untreated adjacent part of the fairway sharp and clear.

Some measurements were made in a cross section over the ridge of fairway 11 on 18 June and 22 July, 2008. We measured at intervals of 50 cm the level of the surface, the water content of the upper 5 cm of the soil with the TDR-device (see Fig. 2.1 in chapter 2) and the presence and depth of water repellency with the core sampler (see Fig. 2.2 in chapter 2).

The upper diagrams of Figure 4.2 with the level line show that the center of the ridge was 160 cm higher than the lower places in the surrounding. The water contents in the upper 5 cm of the soil were less than 5 vol.% at the untreated shoulders of the ridge on 18 June, while contents between 5 and 20 vol.% were measured at the Revolution treated higher part of the ridge. It is also remarkable that soil water repellency was present from the surface to depths of 15-25 cm in the untreated parts, while it only locally was present between 10 and 17 cm depth in the treated part of the ridge (Figure 4.2, left side).

Due to the total amount of 105 mm precipitation between 18 June and 22 July increased the soil water content in the treated part of the ridge to 25-35 vol.%, while an irregular wetting of the surface layer with water contents between 5 and 35 vol.% were measured in the untreated parts (Figure 4.2, right side). In the untreated parts started the water repellency at around 2 cm and a number of preferential flow paths with wettable soil were present. A major part of the profiles in the Revolution treated ridge were again completely wettable.

For comparison we did similar measurements across an untreated ridge in fairway 18 on 22 July, 2008. The top of the ridge amounted to about 90 cm above the adjacent area (Fig. 4.3). An irregular pattern of soil water contents, varying between 7 and 33 vol.% was present in the upper 5 cm of the soil. No significant differences in soil water content and in occurrence of water repellency were established between the ridge and the lower surface at the right-hand side of the ridge. Relatively higher and less variable soil water contents and more wettable soil were present at the left-hand side of the ridge, as illustrated in the diagrams of Figure 4.3.

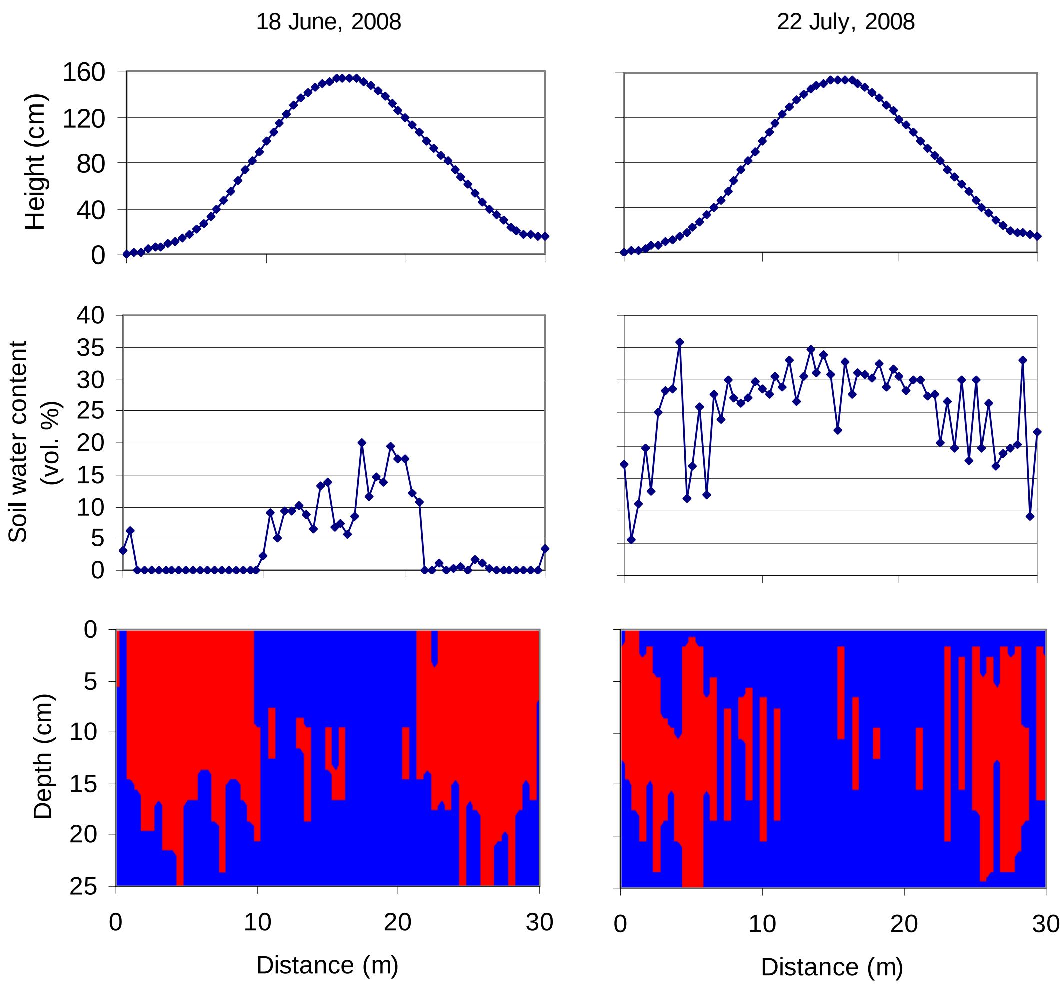


Figure 4.2 Soil water contents in the surface layer (0-5 cm depth) and water repellency present in the soil profiles till 25 cm depth in cross sections through the treated ridge of fairway 11 on 18 June and 22 July, 2008. Also the level line of the surface has been indicated.

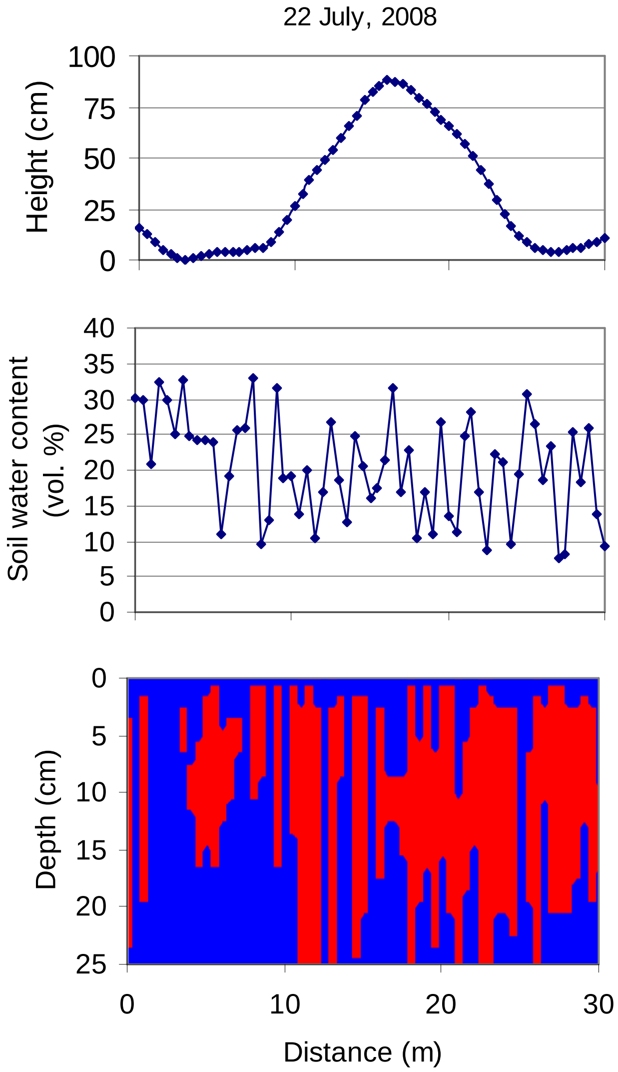


Figure 4.3 Soil water contents in the surface layer (0-5 cm depth) and water repellency present in the soil profiles till 25 cm depth in a cross section through un untreated ridge of fairway 18 on 22 July, 2008. Also the level line of the surface has been indicated.

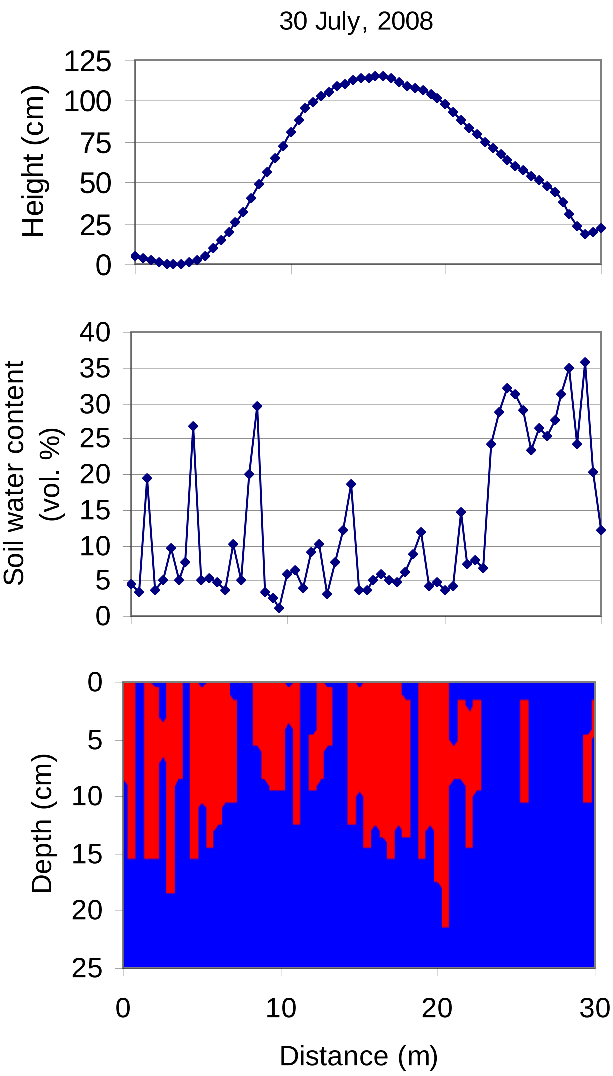


Figure 4.4 Soil water contents in the surface layer (0-5 cm depth) and water repellency present in the soil profiles till 25 cm depth in a cross section through un untreated ridge of fairway 5 on 30 July, 2008. Also the level line of the surface has been indicated.

Another untreated ridge for comparison was studied at fairway 5 on 30 July, 2008. The center of the ridge lies about 115 cm above the adjacent lower area, as illustrated in the upper diagram of Figure 4.4. The month July was relatively wet with a total precipitation of 127 mm. In spite of this large amount of rain, contained the surface layer (0-5 cm) in the central part of the ridge mainly soil water contents between 3 and 10 vol.%. Remarkable was also the high variability in soil water content (5-30 vol.%) on the left side of the shoulder of the ridge, whereas on the right side mainly water contents between 25 and 35 vol.% were measured. Striking was also the presence of water repellency starting at the surface in the center and left side of the ridge after only 3 days without precipitation, which followed a relatively wet period. Much of the rainwater has probably been moved to the right side of the ridge, where higher soil water contents in the surface layer were measured and a major part of the soil profiles were wettable. Another part of the rain has probably been moved to the subsoil via the preferential flow paths, which were locally present in the ridge, as indicated by the presence of wettable soil.

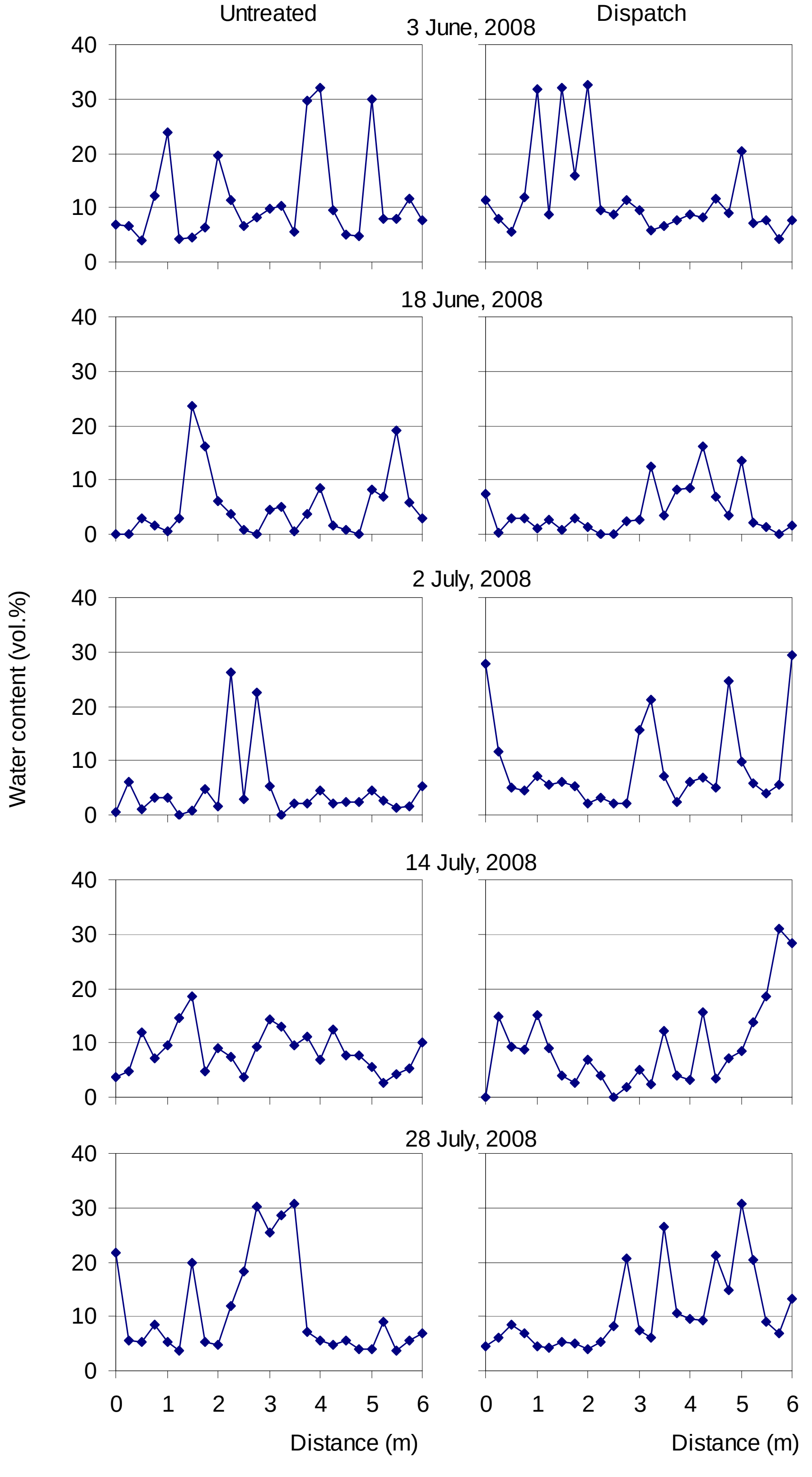


Figure 5.1 Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and Dispatch treated parts of fairway 7, measured every 25 cm over an distance of 6 m on 5 dates between 3 June and 28 July, 2008.

5. Influence of Low-rate Dispatch Applications on Fairway 7

It is hypothesized that fairways can be protected to become water repellent by regular Dispatch applications, keeping the soil above its critical soil water content. In a split fairway experiment on fairway 7 we investigated if Dispatch could achieve this. One part of the fairway was not treated, the other part once every week during the period June until the end of August, 2008. The Dispatch was applied at a rate of 1 L/hectare.

Soil water contents of the upper 5 cm and the presence of water repellency at depths of 0-25 cm were established 7 times between 3 June and 27 August, 2008. These measurements were made along transects across the fairway over a distance of 6 m with intervals of 25 cm, in the untreated as well as treated parts of the fairway.

The soil water contents in the upper 5 cm ranged between 5 and 32 vol.% at both parts of the fairway on 3 June, as illustrated in Figure 5.1. The soil water contents decreased to between 0 and 23 vol.% on 18 June, due to the relatively dry period in the preceding two weeks, with only 11 mm rain. More or less the same water contents were measured on 2 July, after another 11 mm rain. On both parts of the fairway were mainly water contents measured of 5-15 vol.% on 14 July, although 59 mm rain fell between 2 and 14 July. Another 63 mm rain in the next two weeks resulted in an irregular wetting in both parts of the fairway on 28 July, with soil water contents varying between 5 vol.% and 30 vol.% (Fig. 5.1). The low-rate treatments with Dispatch in June and July did not have clear effects on the height of the soil water contents in the upper 5 cm nor on the homogeneity of the wetting.

Large parts of the soil profile between 1 and 15 cm depth were water repellent at the start of the experiment on 3 June, 2008, as illustrated in Figure 5.2. Besides were preferential flow paths present with wettable soil. Water repellency increased in the weeks that followed, with a maximal extension on the untreated as well as the treated part of the fairway on 2 July. Water repellency was on this date on several places present from 0 to 25 cm. No significant differences in the presence of water repellency between the Dispatch and untreated part of the fairway were established in June and July, as is made visible in Figure 5.2.

Preferential flow paths in the profiles and higher soil water contents in the surface layer are clearly related as one can be aware by comparison of Figure 5.2 with Figure 5.1.

Also on 13 and 27 August, 2008 were no significant differences in soil water contents present between the upper 5 cm of the untreated and Dispatch treated soil, as shown in Figure 5.3. The variability was high on both dates and on both parts of the fairway with soil water contents varying over short distances between 1 and 20-30 vol.%.

The higher soil water contents were again related to the presence of preferential flow paths, as can be seen by comparing Figure 5.3 with Figure 5.4. Also on 13 and 27 August were no evident differences in water repellency present between the untreated and Dispatch treated part of the fairway (Fig. 5.4).

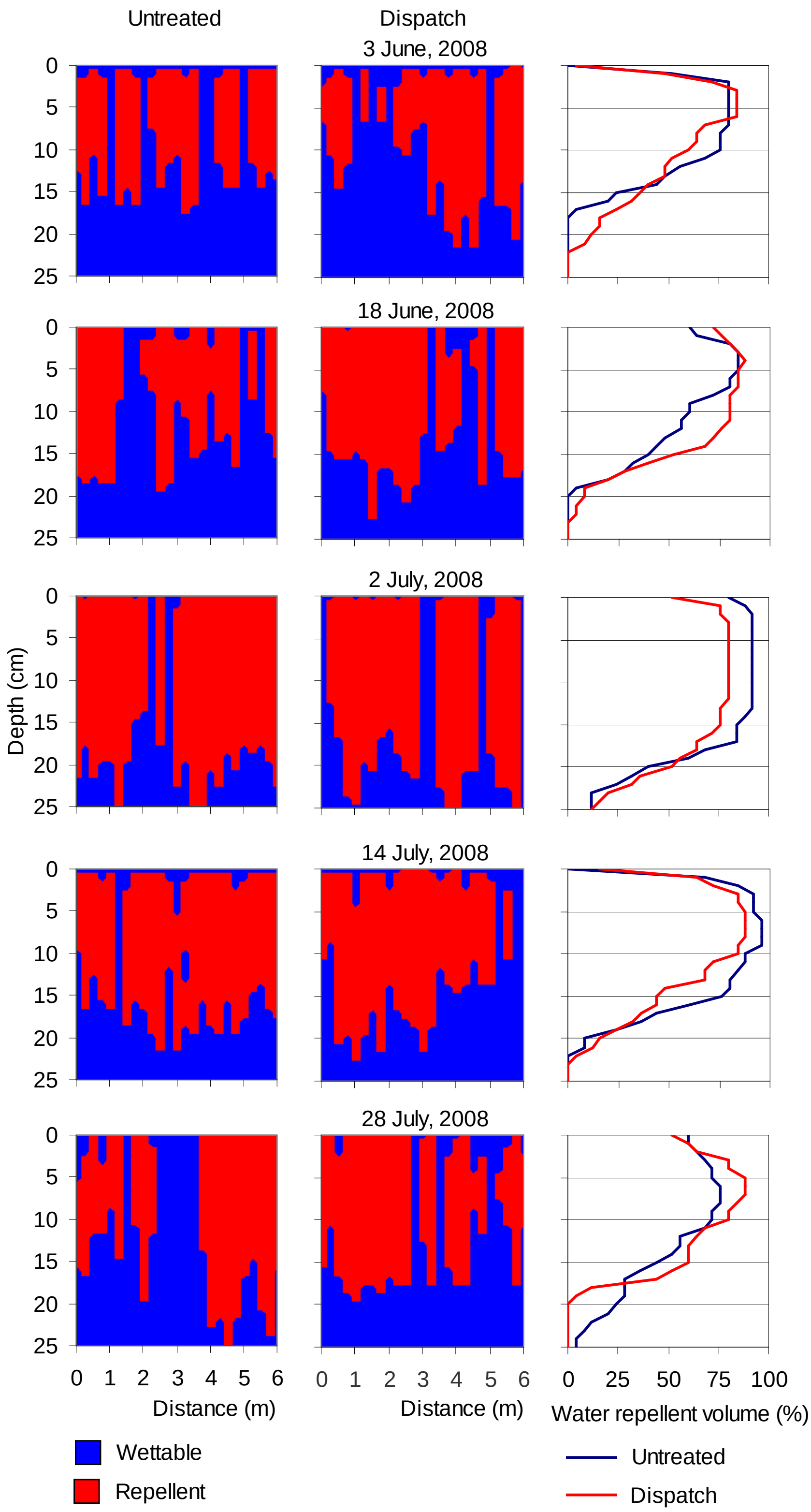


Figure 5.2 Contours of actual water repellency in the topsoil of the untreated and Dispatch treated parts of fairway 7 on 5 dates between 3 June and 28 July, 2008. Also the percentage of total water repellent volume at different depths has been indicated.

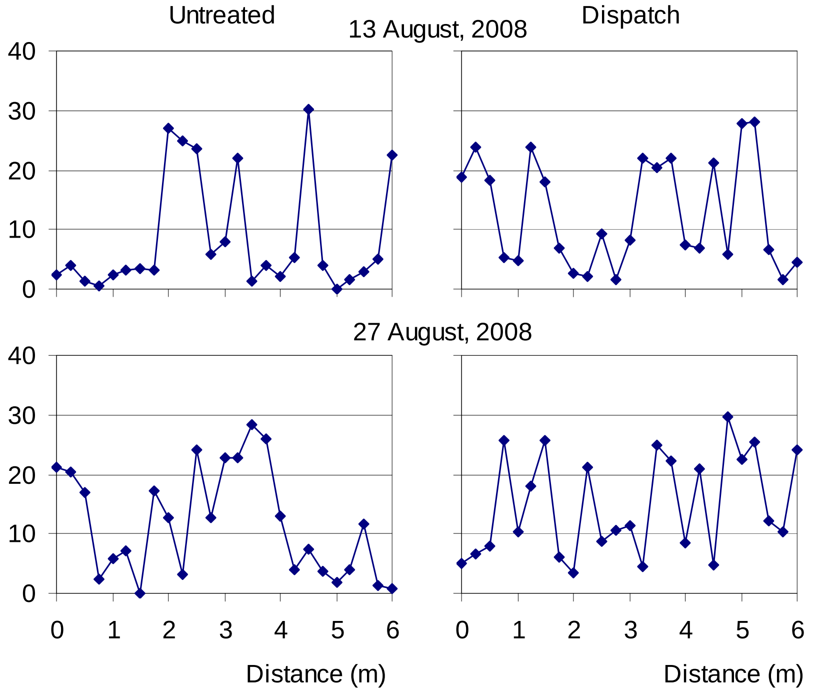


Figure 5.3 Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and Dispatch treated parts of fairway 7, measured every 25 cm over an distance of 6 m on 13 and 27 August, 2008.

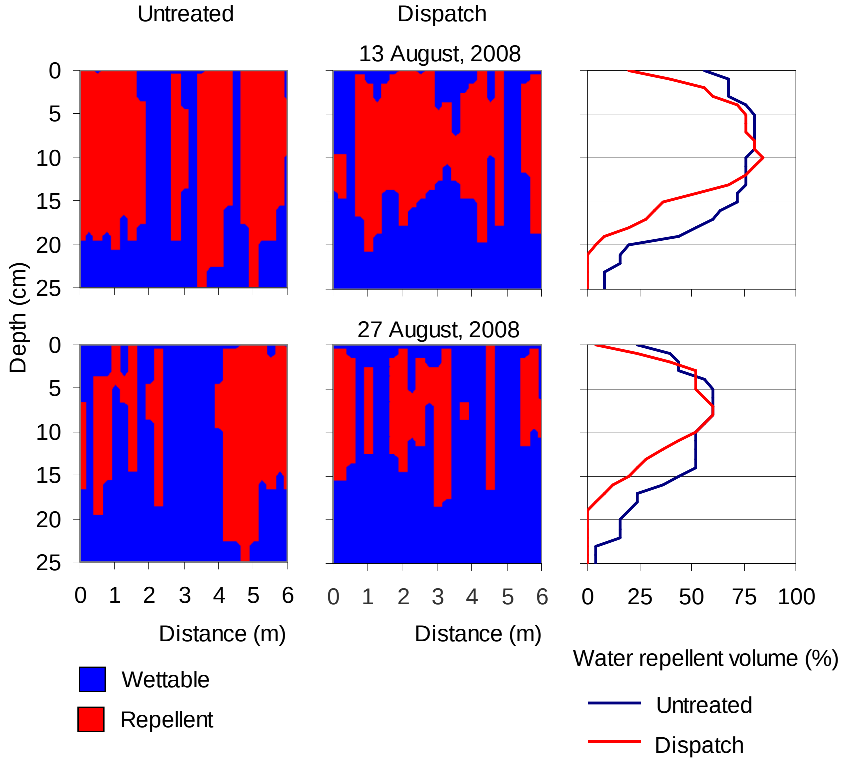


Figure 5.4 Contours of actual water repellency in the topsoil of the untreated and Dispatch treated parts of fairway 7 on 13 and 27 August, 2008. Also the percentage of total water repellent volume at different depths has been indicated.

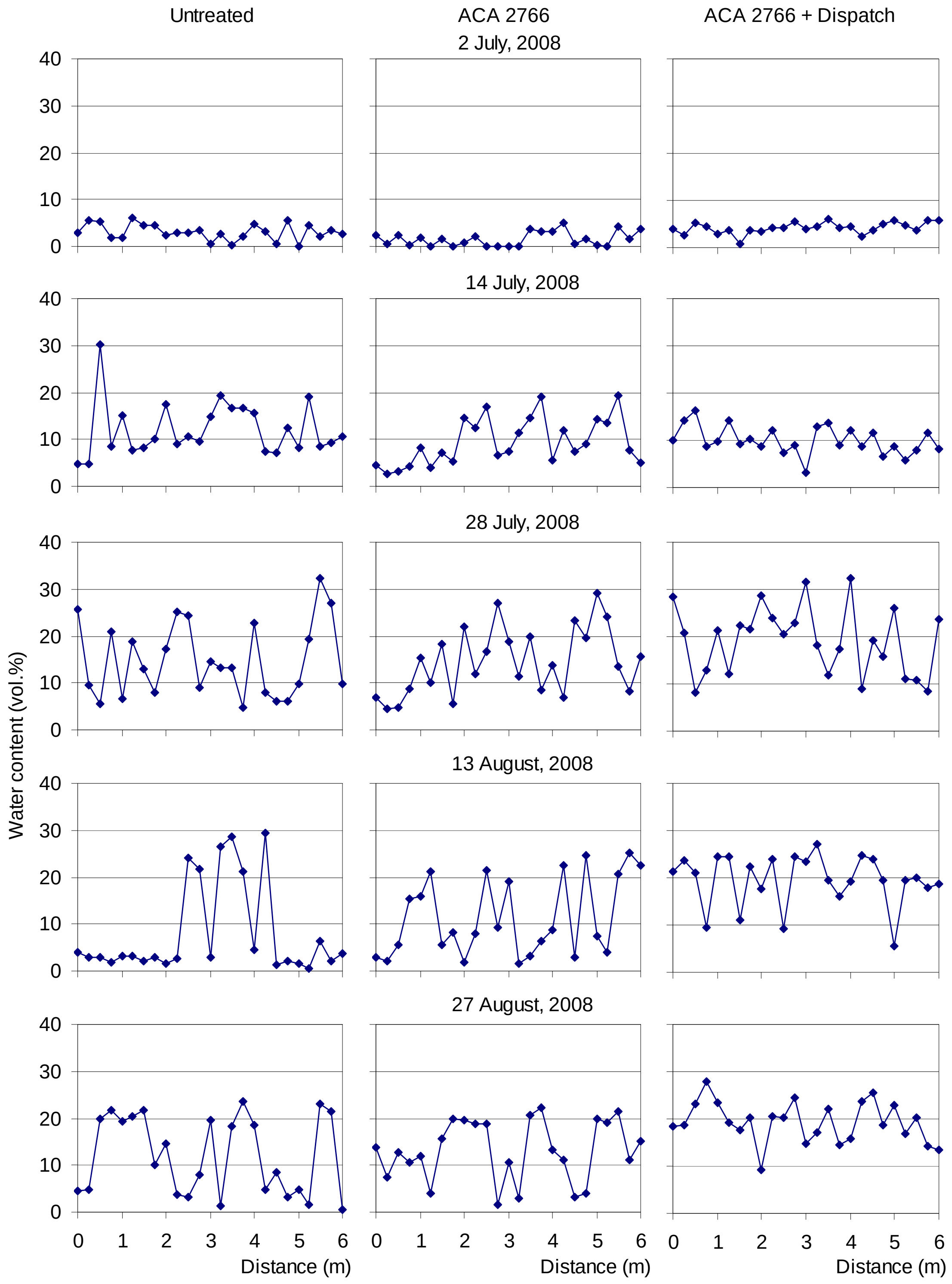


Figure 6.1 Volumetric soil water contents in the surface layer (0-5 cm) of the untreated, ACA 2766 and ACA 2766 + Dispatch treated parts of fairway 5, measured every 25 cm over an distance of 6 m on 5 dates between 2 July and 27 August, 2008.

6. Effects of Two Surfactants on Fairway 5

Across fairway 5 one strip with a length of 45 m and a width of 6 m was treated with ACA 2766 in a concentration of 30 ml/100 m^2 in 4 L water and another strip with the same dimensions was treated with ACA 2766 in a concentration of 30 ml/100 m2 + 150 ml/100 m^2 Dispatch in 4 L water. Besides, an untreated strip was used as control. The surfactants were applied fortnightly between 2 July and 10 September, 2008.

Soil water contents of the upper 5 cm and the presence of water repellency at depths of 0-25 cm were established 7 times between 2 July and 6 October, 2008. These measurements were made along transects across the fairway over a distance of 6 m with intervals of 25 cm, in the untreated as well as treated parts of the fairway.

On 2 July at the start of the experiment were the soil water contents in the 3 strips very low and ranged between 0 and 5 vol.%, as shown in Figure 6.1. Soil water contents varied mainly between 5 and 20 vol.% in the 3 strips on 14 July. Slightly higher soil water contents were measured in the ACA 2766 + Dispatch strip compared with the ACA 2766 and untreated strip on 28 July, 2008. On 13 and 27 August varied the soil water contents in the upper 5 cm of the ACA 2766 + Dispatch strip between 10 and 25 vol.%, while in the untreated and ACA 2766 strips many times less than 5 vol.% was measured.

On 2 July was the soil profile on all 3 strips water repellent from the surface till depths between 15 and 25 cm, as illustrated in Figure 6.2. Water repellent volumes and preferential flow paths were clearly present in all 3 strips between 28 July and 27 August. The upper 1-3 cm was wettable in the ACA 2766 + Dispatch strip on 13 and 27 August, while water repellency in the untreated and ACA 2766 strips on several spots started at the surface.

Large variations in soil water content varying between 8 and 35 vol.% were measured in the upper 5 cm of the untreated and ACA 2766 strips on 10 September and 6 October, 2008, while fluctuations between 20 and 32 vol.% were noted in the ACA 2766 + Dispatch strip on 10 September and only a variation between 25 and 33 vol.% on 6 October (see Figure 6.3).

The water repellent soil volume in the ACA 2766 + Dispatch strip was also less in comparison with the other 2 strips on 10 September and 6 October, 2008, as illustrated in Figure 6.4.

The higher soil water contents in the surface layer of the ACA 2766 + Dispatch strip resulted in a better grass performance, as evidently shown on the photo of Figure 6.5 taken on 10 September, 2008.

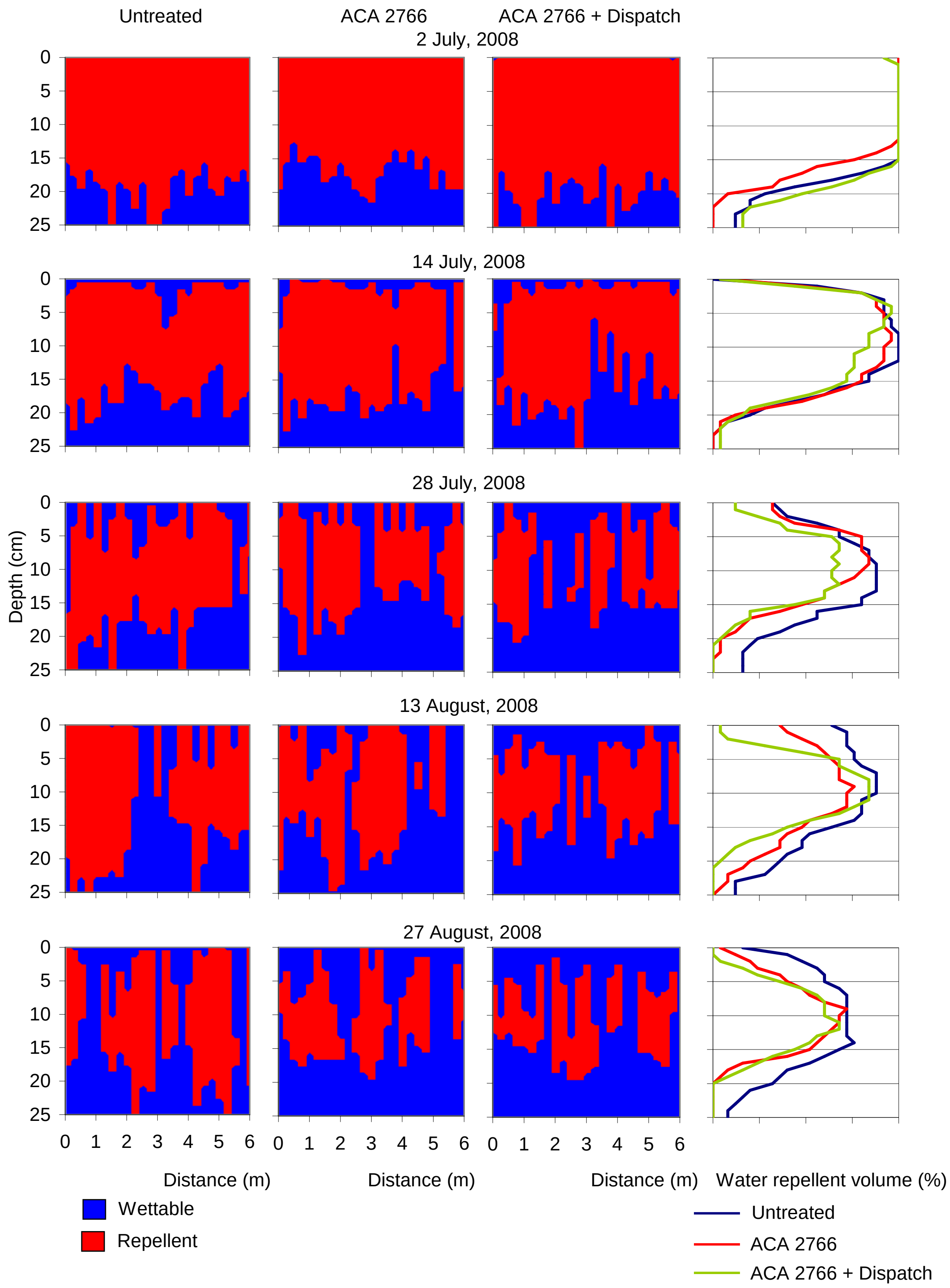


Figure 6.2 Contours of actual water repellency in the topsoil of the untreated, ACA 2766 and ACA 2766 + Dispatch treated parts of fairway 5 on 5 dates between 2 July and 27 August, 2008. Also the percentage of total water repellent volume at different depths has been indicated.

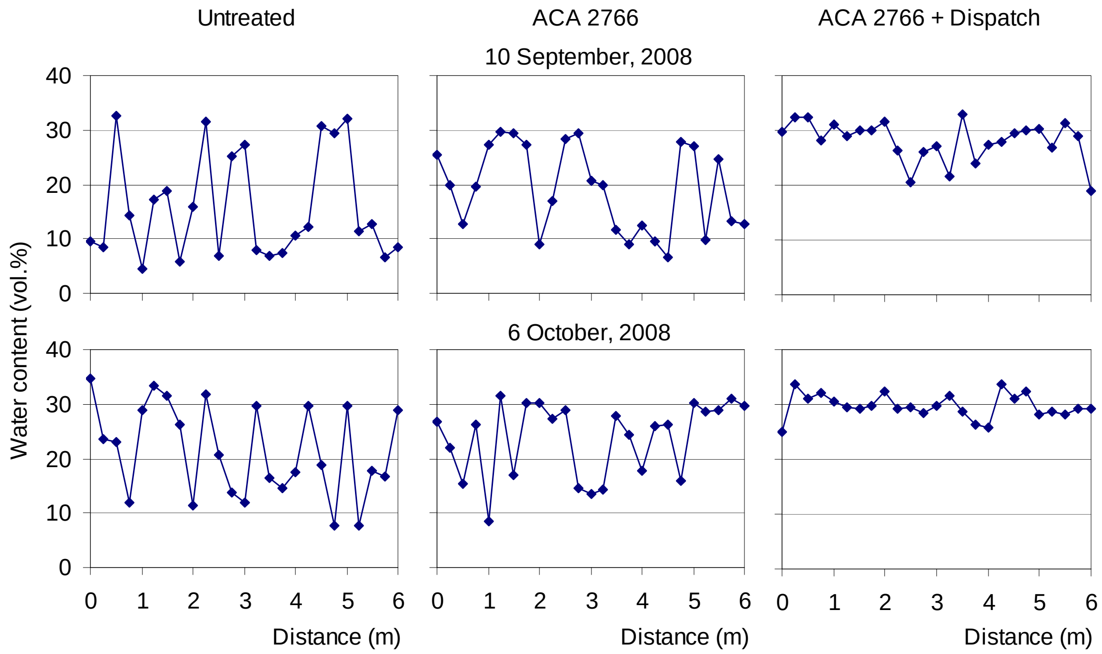


Figure 6.3 Volumetric soil water contents in the surface layer (0-5 cm) of the untreated, ACA 2766 and ACA 2766 + Dispatch treated parts of fairway 5, measured every 25 cm over an distance of 6 m on 10 September and 6 October, 2008.

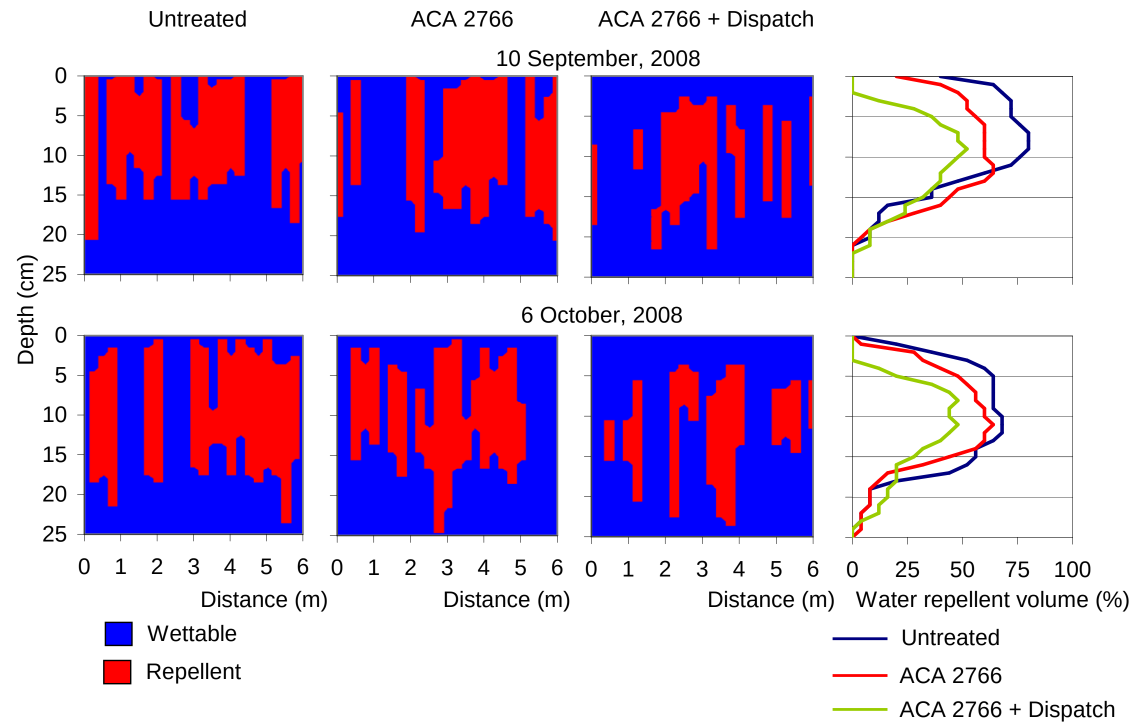


Figure 6.4 Contours of actual water repellency in the topsoil of the untreated, ACA 2766 and ACA 2766 + Dispatch treated parts of fairway 5 on 10 September and 6 October, 2008. Also the percentage of total water repellent volume at different depths has been indicated.

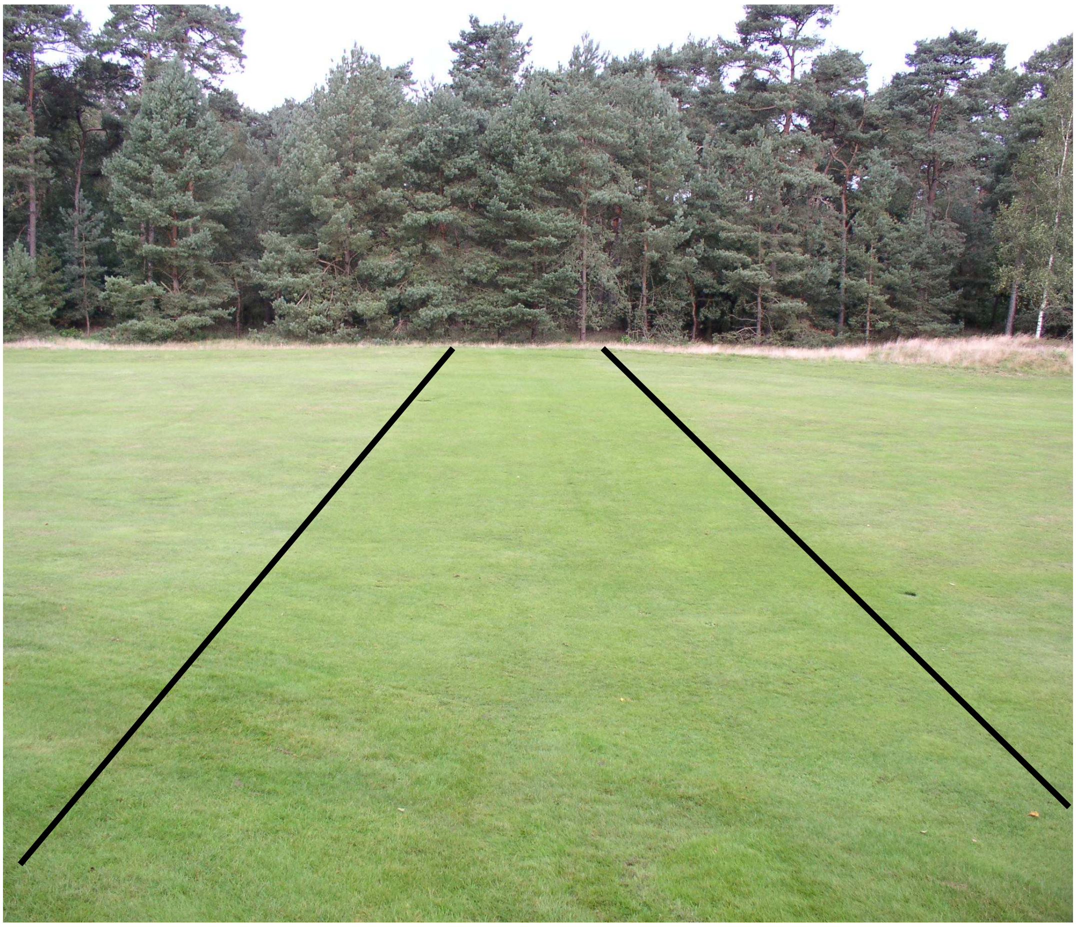


Figure 6.5 The grass performance at the ACA 2766 + Dispatch treated strip on 10 September, 2008.

7. Effects of Revolution and ACA 2787 on Soil Wetting and Grass Performance of Fairway 18

7.1. Surfactant Applications

The sandy topsoil of fairway 18 exhibits extreme water repellency after a prolonged dry period. To study the effects of surfactant applications on the wetting of the soil, three experimental sites were chosen on this fairway (Fig. 7.1). These sites were divided into three plots with an area of 1.5 m by 1.5 m. At each site one plot was randomly used as control and two plots were randomly treated with one of the surfactants Revolution and ACA 2787 (Aquatrols, Paulsboro, New Jersey, USA). The surfactants were applied 9 times between 21 May and 10 September, 2008 at a rate of 1.85 ml/m^2 in a water volume of 70 ml/m^2, using a backpack sprayer. The 9 dates of applications are given in Table 7.1. 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.

Table 7.1 Dates of treatments with surfactants and dates of measurements of turf performance, soil water content and actual soil water repellency in the plots of the 3 study sites in 2008.

Application Surfactants	Date	Measurements: Turf performance Soil water content Water repellency	Date
1	21 May	1	21 May
2	3 June	2	3 June
3	18 June	3	18 June
4	2 July	4	2 July
5	16 July	5	16 July
6	30 July	6	30 July
7	13 August	7	13 August
8	27 August	8	27 August
9	10 September	9	10 September
		10	6 October
		11	17 November

7.2. Estimation of Turf Performance

The turf performance of the 9 plots was mapped 11 times between 21 May and 17 November, 2008 (Table 7.1). For this purpose we made use of the iron grid of 1 m by 1 m consisting of 10 cm by 10 cm cutting faces (see Fig. 3.2 in chapter 3). In any of these compartments the percentage of green grass was estimated by using the following classes: >80%, 50-80%, and <50% green grass.

Digital photographs of the grass performance of the 9 plots were made on all sampling days and have been separately delivered to Aquatrols on a CD.

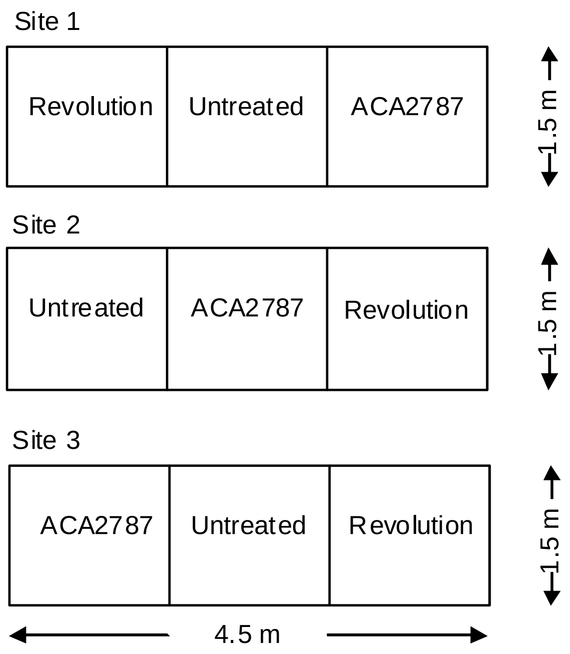


Figure 7.1 Layout of the experimental field with the three plots on the three sites of fairway 18.

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

Beginning on 21 May, 2008 soil water contents were measured with the portable TDR-device (see Fig. 2.1 in chapter 2) in the upper 0-5 cm across the surfactant treated and untreated plots on eleven dates, as indicated in Table 7.1. Measurements were made at intervals of 10 cm over a length of 90 cm.

Additionally 100 soil water content measurements were made in the upper 5 cm at intervals of 10 cm in horizontal planes of 100 cm by 100 cm. These measurements were done in the plots of site 1 on 8 September and 17 November, in those of site 2 on 10 September, and in the plots of site 3 on 6 October, 2008.

7.4. Assessment of Actual Soil Water Repellency

At the same time of the soil water content measurements soil cores were taken at these points, using a small core sampler, and the actual water repellency was determined in the field by placing drops of water on the cores with intervals of 1 cm (see Fig. 2.2 in chapter 2). Depth and thickness of the actual water repellent soil were recorded. Dates of determination of actual water repellency are given in Table 7.1.

Additionally actual soil water repellency was measured at 36 places at intervals of 10 cm by 10 cm in the central parts of the horizontal planes of 100 cm by 100 cm, where soil water contents were measured as described in section 7.3.

7.5. Precipitation

Precipitation at the experimental field has been recorded with a rain gauge, provided with a tipping bucket system. The accuracy of this device is 0.1 mm. Date and time of each 0.1 mm precipitation were stored in the memory and retrieved regularly. The total amount of precipitation between the dates of estimating the turf performance, measuring the soil water content of the surface layer and assessing the actual soil water repellency in the topsoil are presented in Table 7.2.

The precipitation before the start of the experiment amounted in total to 96.3 mm for the month of January, to 39.2 mm for February, to 91.9 mm for March and to 33.9 mm for April, whereas 15.9 mm precipitation fell between 1 May and 21 May, 2008.

Table 7.2 Precipitation (mm) between the dates of estimation turf performance, measurement soil water content in the surface layer (0-5 cm) and assessment of actual water repellency in the untreated and treated plots of fairway 18 in 2008.

Dates of measurements	Precipitation	Dates of measurements	Precipitation
21 May – 3 June	39.0	30 July – 13 August	55.4
3 June – 18 June	9.7	13 August – 27 August	58.3
18 June – 2 July	11.1	27 August – 10 September	28.7
2 July – 16 July	59.3	10 September – 6 October	124.7
16 July – 30 July	64.2	6 October – 17 November	87.5

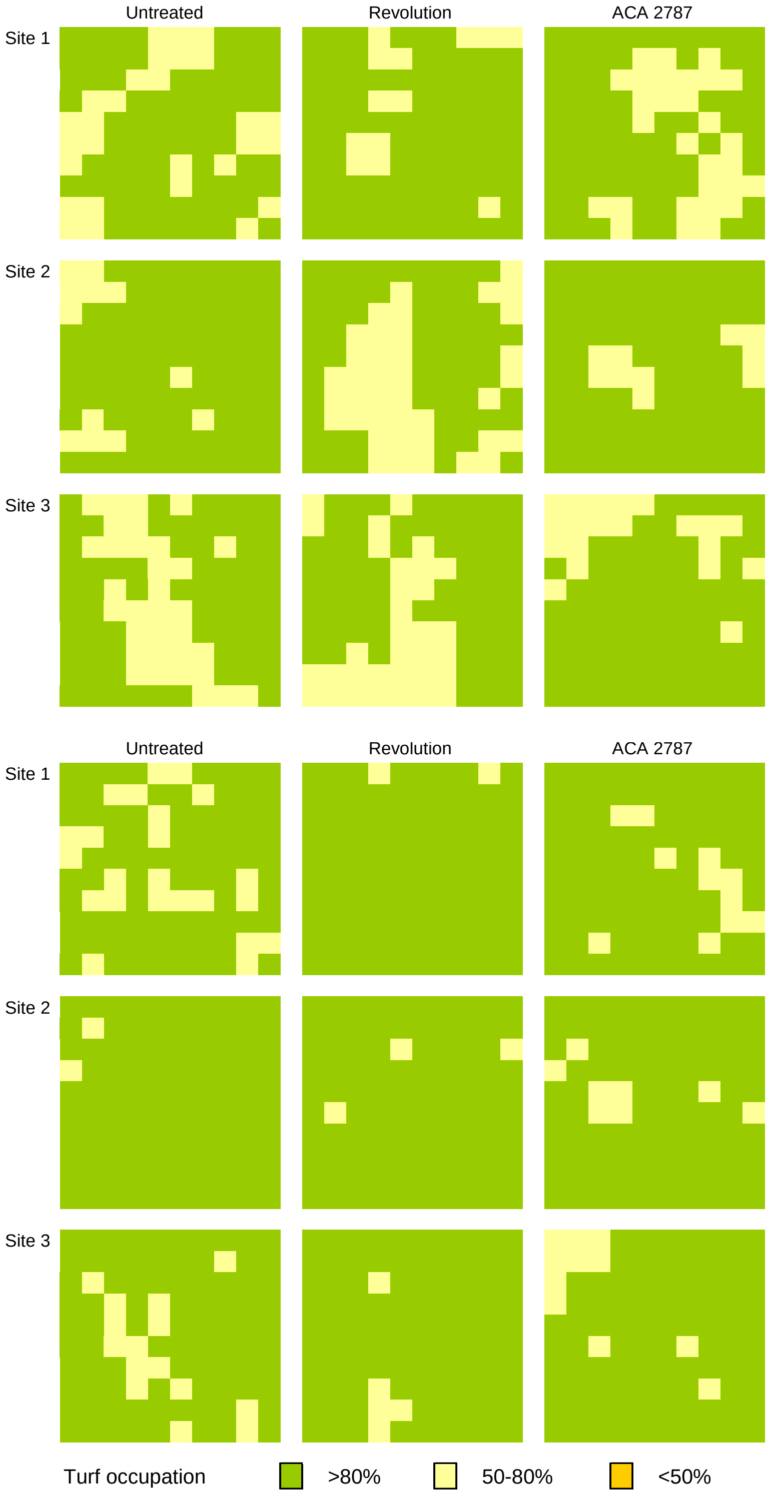


Figure 7.2 Turf performance on the untreated and surfactant treated plots on 21 May (upper diagrams) and 3 June, 2008 (lower diagrams), of respectively site 1, 2, and 3.

7.6. Effects of the Surfactants on Turf Performance

At the start of the experiment on 21 May, 2008 there were slight differences in the grass performance between the nine plots of the three sites of fairway 18. A substantial part of the 10 cm by 10 cm compartments on all plots contained more than 80% green grass (upper diagrams of Fig. 7.2). On the randomly chosen plots exhibited 12-32% of the compartments on the untreated plots 50-80% green grass, while this varied from 13 to 40% on the Revolution, and from 10 to 30% on the ACA 2787 plots. A significant increase in grass growth for most plots was noticed on 3 June (lower diagrams of Fig. 7.2), after a total of 39 mm precipitation in the preceding two weeks (Table 7.2). A decrease in grass growth was observed for all plots on 18 June, after two weeks with only 9.7 mm precipitation, as shown in the upper diagrams of Figure 7.3. However, significant differences in grass growth were established between the untreated plots compared with the two times surfactant treated plots. More compartments of the untreated plots contained less than 80% green grass, and locally even less than 50%. A further decrease in grass quality was noticed for the untreated plots on 2 July with more compartments containing less than 50% green grass (Fig. 7.3, lower diagrams). The precipitation in the two weeks before amounted to only 11.1 mm. The differences between the untreated and three times surfactant treated plots increased evidently, because only slight changes in the grass quality of the surfactant treated plots occurred.

The better quality of the grass on the 3 Revolution and 3 ACA 2787 treated plots compared with the 3 untreated plots is illustrated by the photo of Figure 7.4, made on 2 July.

Due to the total amount of 59.3 mm rain fallen between 2 and 16 July, a slight improvement in grass quality was observed on the untreated plots, while on the surfactant treated plots 90-100% of the compartments exhibited more than 80% green grass (Fig. 7.5, upper diagrams).

In the two weeks that followed a significant decrease in grass quality took place in the 3 untreated plots (Fig. 7.5, lower diagrams), although the precipitation amounted to 64.2 mm during this period. Unlike decreased the quality of the grass in the 6 surfactant treated plots only slightly during this period.

The grass quality improved clearly on all 9 plots between 30 July and 13 August (with a total of 55.4 mm rain), as shown in the upper diagrams of Figure 7.6. Although, still evidently more green grass was present on the 6 surfactant treated plots than on the three untreated plots. This was again the case on 27 August, after another 58.3 mm of rain (Fig. 7.6, lower diagrams).

More than 80% green grass was established in all 100 compartments of the 6 surfactant treated plots on 10 September, 6 October, and 17 November, 2008 (Fig. 7.7 and Fig. 7.8). However, in the untreated plots contained 32-49% of the compartments still 50-80% green grass on 10 September and 6 October. A significant improvement of the grass quality in the untreated plots took finally place on 17 November, 2008 (Fig. 7.8).

Figure 7.9 clearly shows the differences in percentages of compartments with >80% green grass between the surfactant and untreated plots of the three sites between 21 May and 17 November, 2008. Both surfactants had quite similar effects on the grass performance during the period studied.

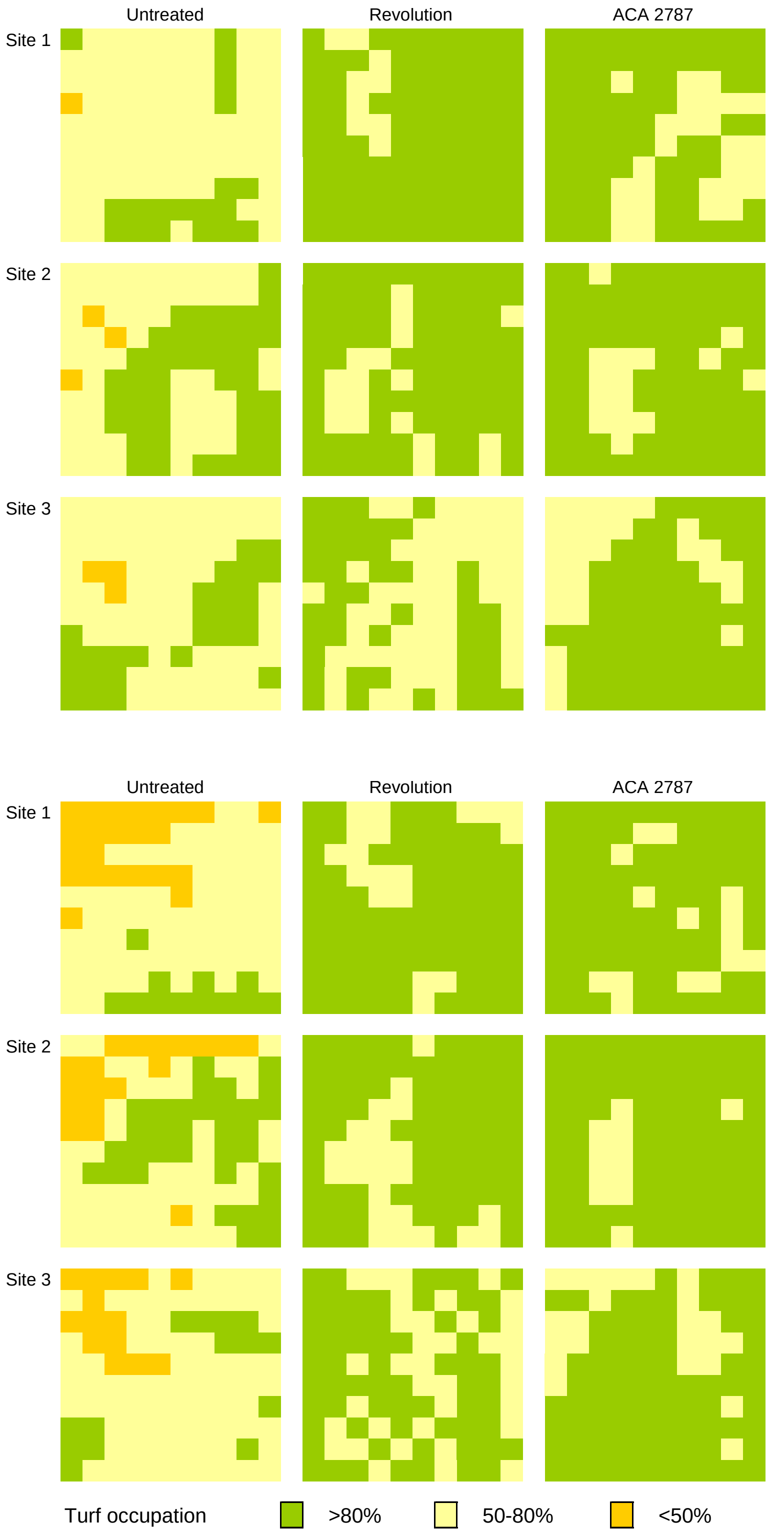
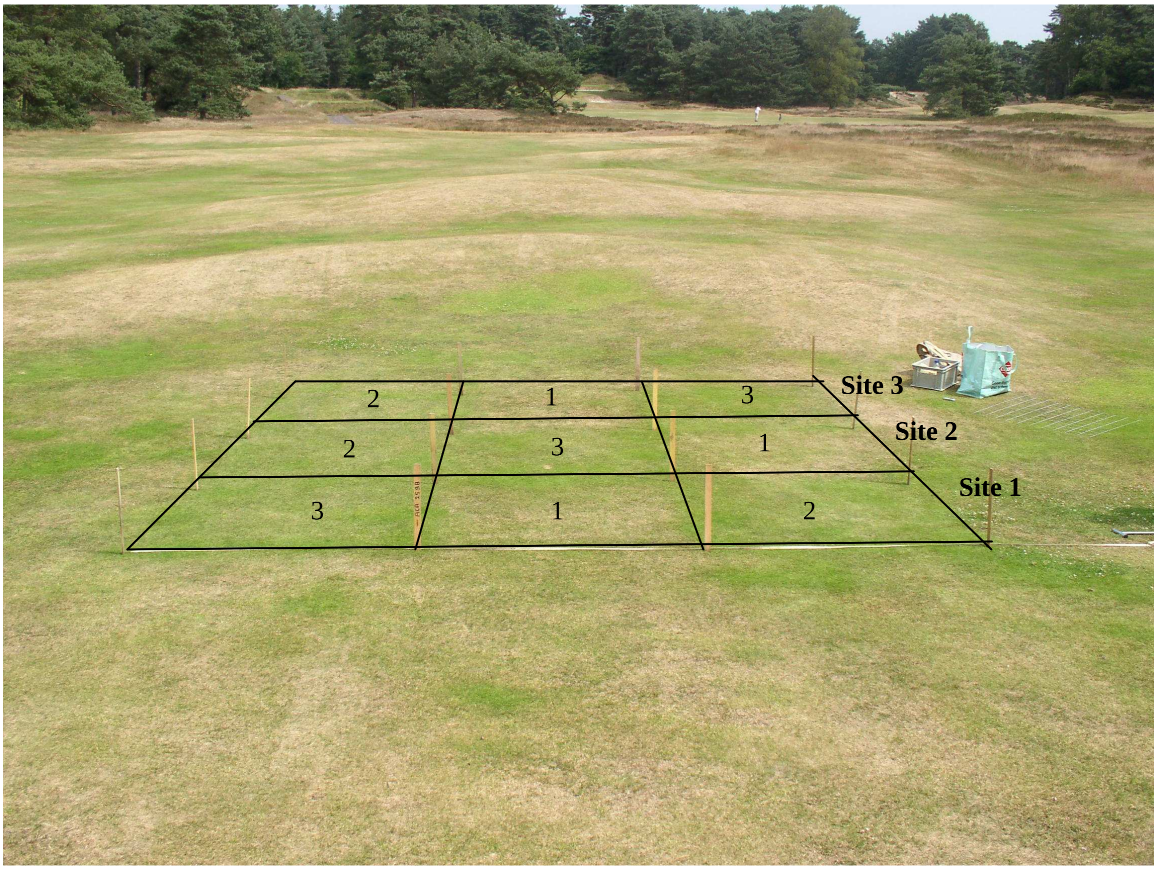


Figure 7.3 Turf performance on the untreated and surfactant treated plots on 18 June (upper diagrams) and 2 July, 2008 (lower diagrams), of respectively site 1, 2, and 3.



1	**Untreated**
2	**Revolution**
3	**ACA 2787**

Figure 7.4 Overview of the grass performance on the nine experimental plots of fairway 18 on 2 July, 2008.

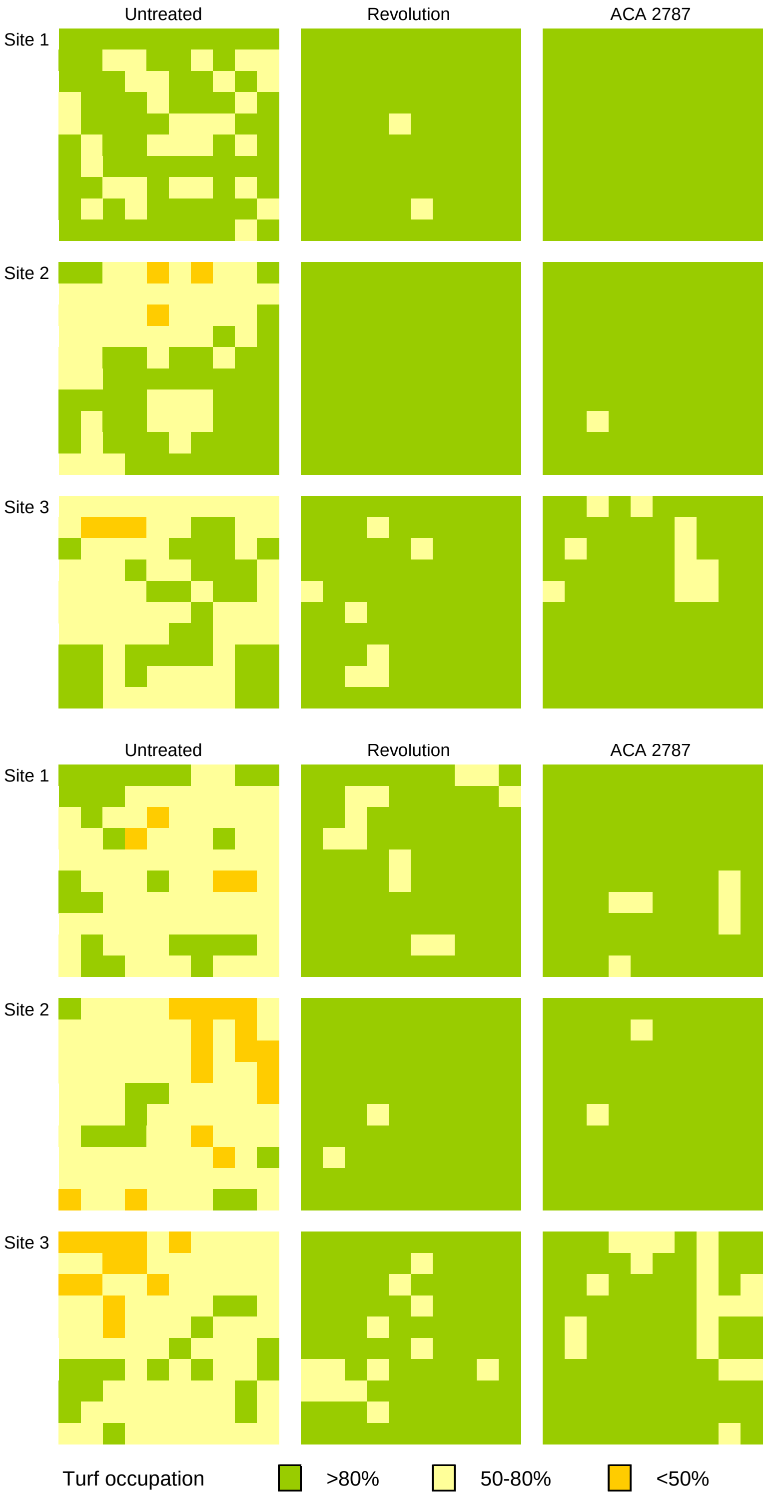


Figure 7.5 Turf performance on the untreated and surfactant treated plots on 16 July (upper diagrams) and 30 July, 2008 (lower diagrams), of respectively site 1, 2, and 3.

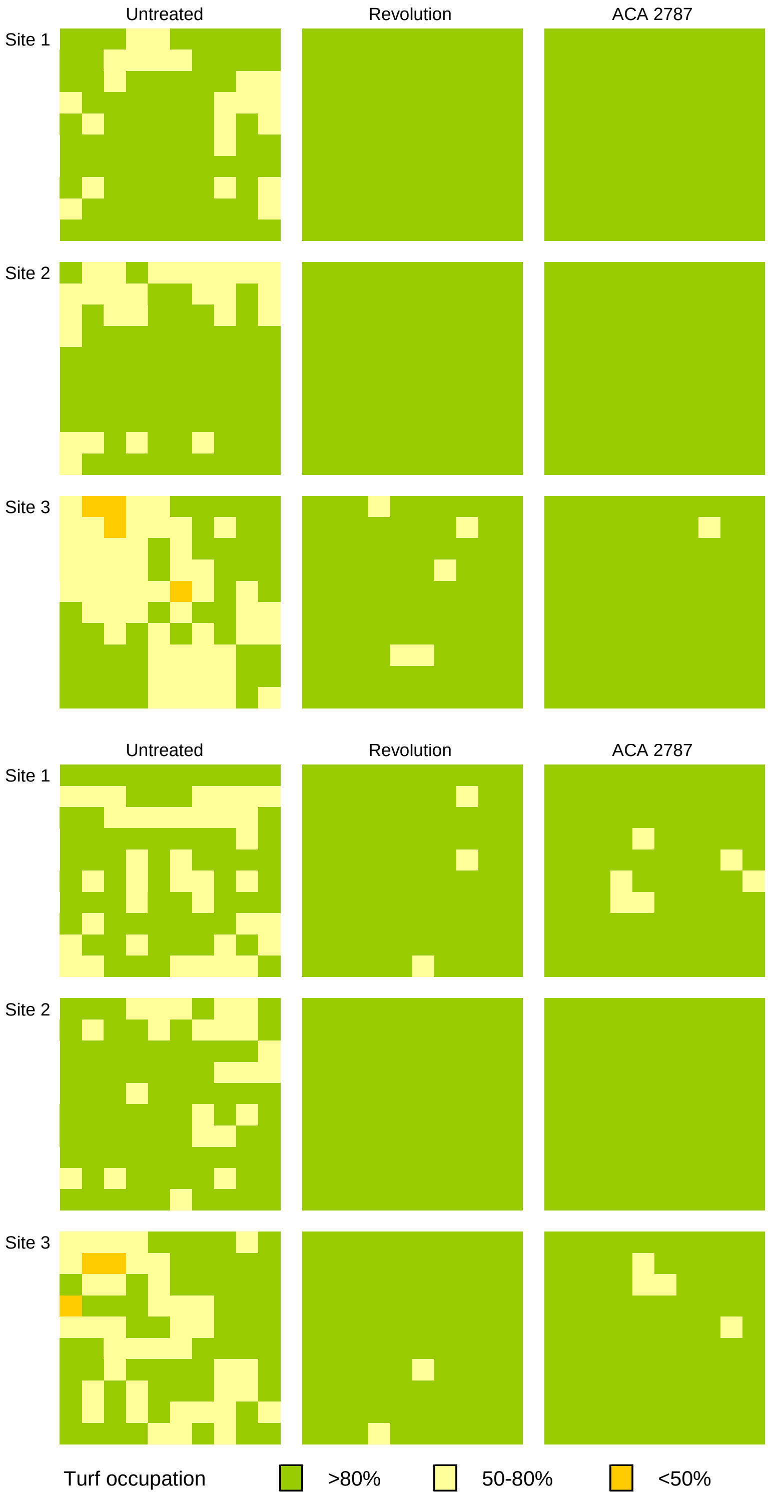


Figure 7.6 Turf performance on the untreated and surfactant treated plots on 13 August (upper diagrams) and 27 August, 2008 (lower diagrams), of respectively site 1, 2, and 3.

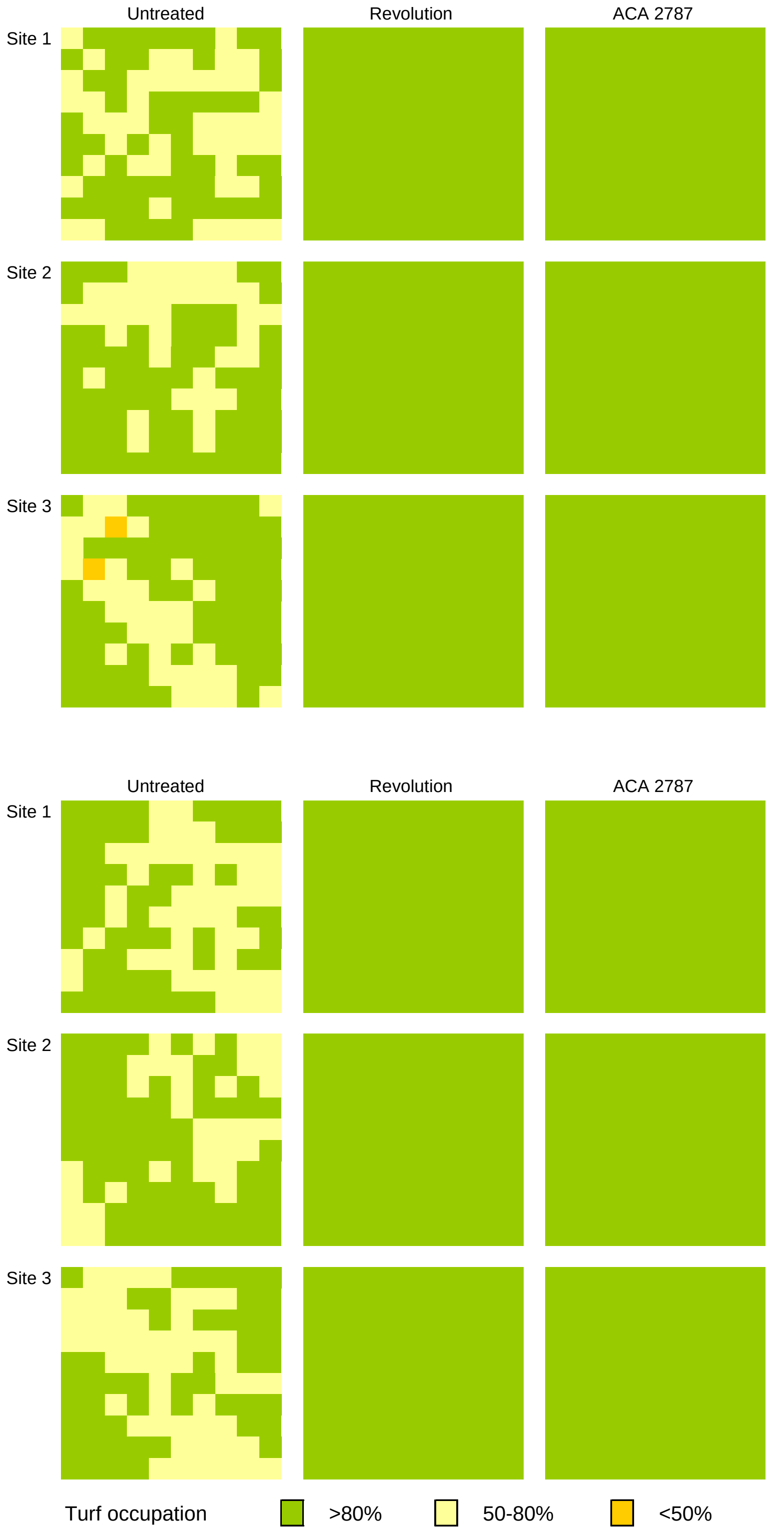


Figure 7.7 Turf performance on the untreated and surfactant treated plots on 10 September (upper diagrams) and 6 October, 2008 (lower diagrams), of respectively site 1, 2, and 3.

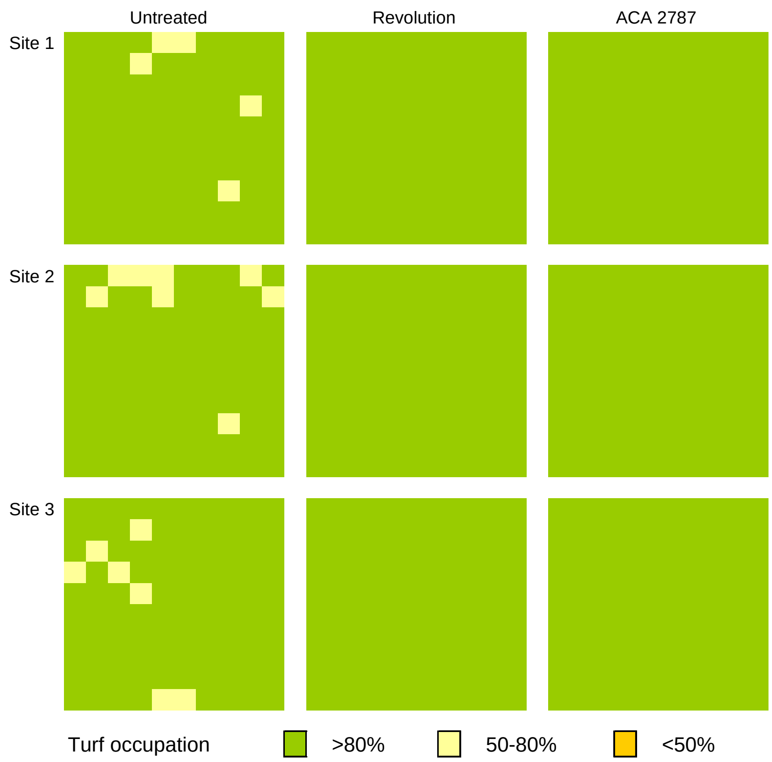


Figure 7.8 Turf performance on the untreated and surfactant treated plots on 17 November, 2008 of respectively site 1, 2, and 3.

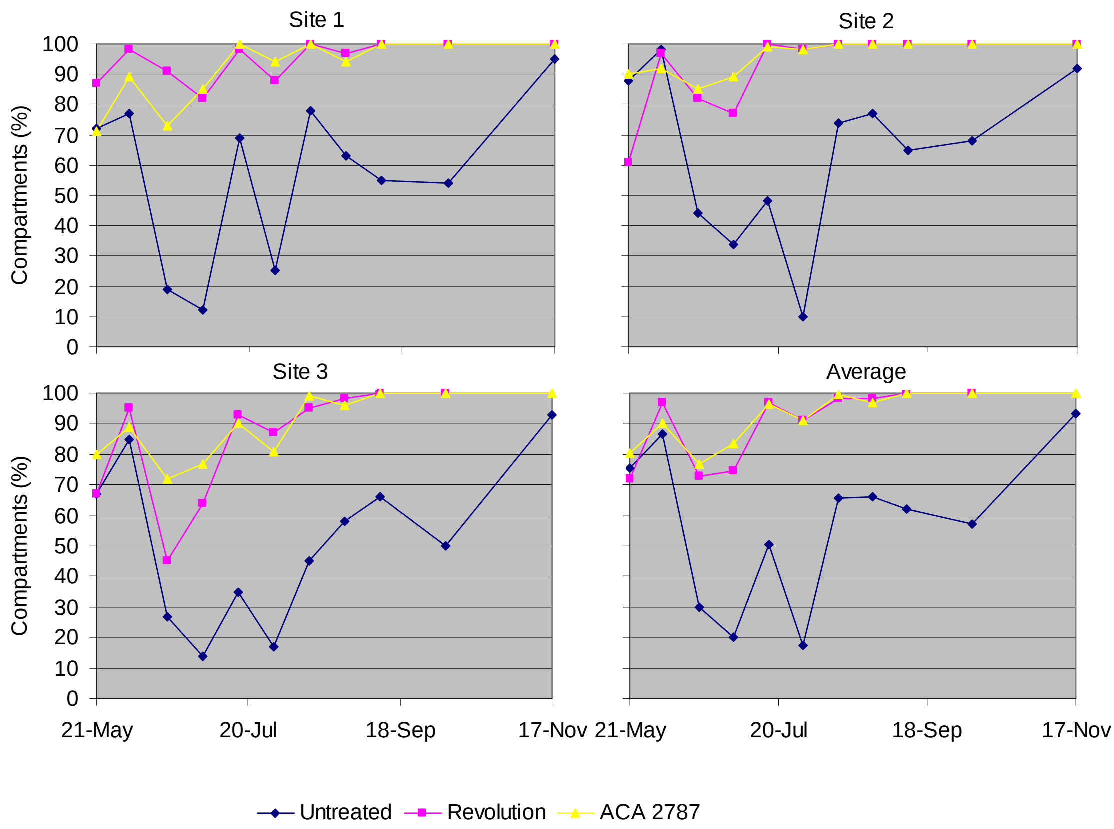


Figure 7.9 Percentage of the 100 compartments (10 cm by 10 cm) with >80% green grass on the untreated and surfactant treated plots of the three sites between 21 May and 17 November, 2008.

7.7. Effects of the Surfactants on Soil Water Content in the Surface Layer (0-5 cm)

At the start of the experiment on 21 May, 2008 varied the soil water content of the surface layer in the 9 plots between 0 and 25 vol.%, as shown in Appendix Figure I-A. The surface layers of the plots of site 3 were the driest and those of site 2 were the wettest. The surface layer of 2 plots of site 3 contained throughout the cross sections less than 5 vol.% water. This maybe due to the relatively dry period between 1 May and 21 May with in total merely 16 mm rain.

The soil water content in the surface layer increased in the plots, as shown in the diagrams of 3 June (Appendix Fig. I-B), due to the supplementary precipitation of 39 mm during the period 21 May to 3 June (Table 7.2). The soil water content varied over short distances between 10 and 20-30 vol.% in the surface layer of the surfactant treated plots, whereas a remarkable homogeneous wetting with a water content of around 10 vol.% was measured in the 3 untreated plots.

The relatively dry period between 3 and 18 June with only 9.7 mm rain resulted in a very dry surface layer of the untreated plots and of both surfactant treated plots of site 3, as shown in Appendix Fig. I-C. Only locally soil moisture contents above 10 vol.% were measured in the surfactant treated plots of site 1 and 2.

The 11.1 mm rain that fell between 18 June and 2 July scarcely changed the soil moisture status of the surface layer on 2 July when compared with 18 June as shown in Appendix Fig. I-D.

During the period between 2 and 16 July 59.3 mm rain was registered. However, the surface layer of the untreated plots remained very dry with soil water contents below 5 vol.% (Appendix Fig. I-E). The soil water contents in the surface layer of the surfactant treated plots was on all 3 sites higher than in the untreated plots. Although, still relatively low soil water contents were present in the Revolution treated plots of site 2 and 3 and in the ACA 2787 plot of site 3.

A slight increase in soil water content to around 5 vol.% was measured in the surface layer of the 3 untreated plots on 30 July after 64.2 mm rain in the previous two weeks. An irregular wetting with water contents between 10 and 30 vol.% was established in the surface layer of the Revolution and ACA 2787 plots (Appendix Fig. I-F).

On 13 August we measured on all nine plots more or less the same soil water content values as on 30 July, after an amount of 55.4 mm precipitation in the previous 2 weeks (Appendix Fig. I-G).

Also the 58.3 mm precipitation in the next two weeks caused only a slight increase of the soil water content in the surface layer of the Revolution and ACA 2787 plots of site 1, as measured on 30 August (Appendix Fig. I-H).

Although in the two weeks that followed only 28.7 mm rain fell, a clear increase in soil water content was detected in the surface layer of all 9 plots, as measured on 10 September. A soil water content of around 10 vol.% was established in the 3 untreated plots and of 20 to 30 vol.% in the surfactant treated plots (Appendix Fig. I-i).

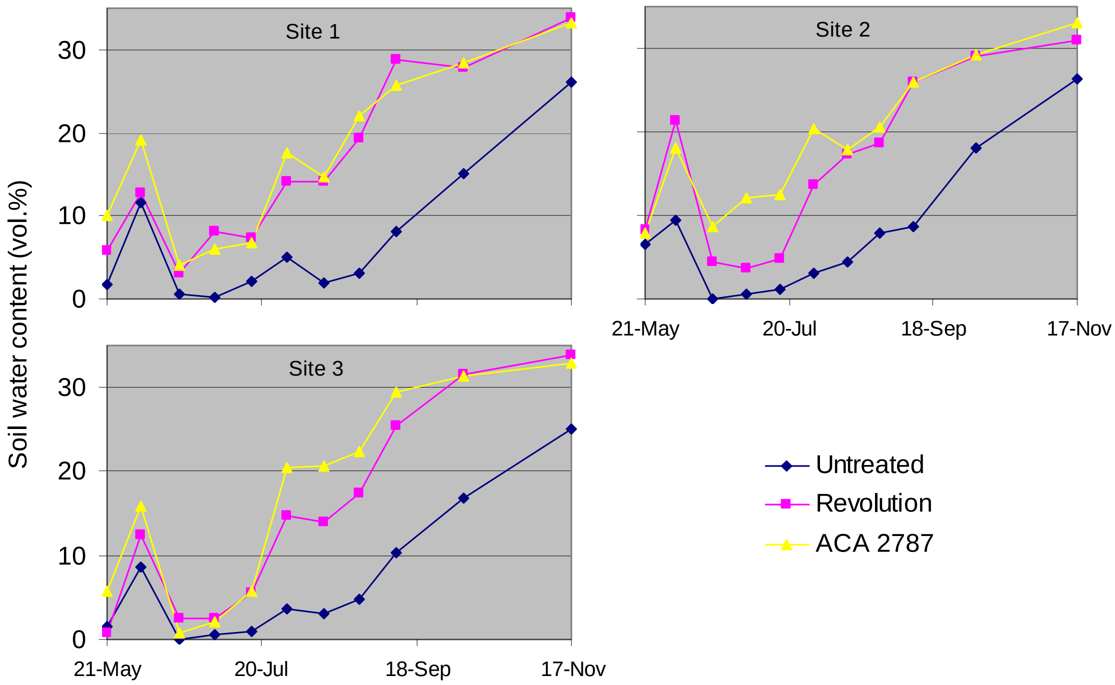


Figure 7.10 Mean volumetric soil water content in the surface layer of the untreated and surfactant treated plots of site 1, 2, and 3 between 21 May and 17 November, 2008.

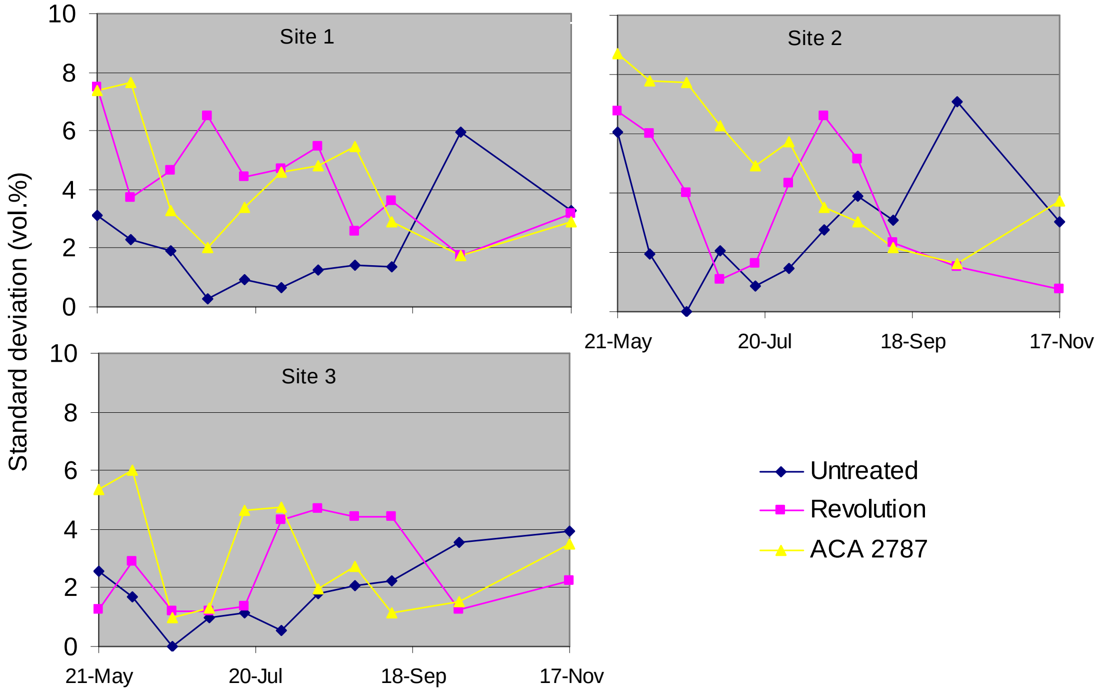


Figure 7.11 Standard deviation of the volumetric soil water content in the surface layer of the untreated and surfactant treated plots of sites 1, 2 and 3 between 21 May and 17 November, 2008.

The 124.7 mm precipitation between 10 September and 6 October resulted in a homogeneous wetting of the 3 Revolution and 3 ACA 2787 plots with soil water contents in the surface layer of around 30 vol.%, while in the 3 untreated plots the soil water content ranged between 10 and 30 vol.% (Appendix Fig. I-J).

The soil water content increased in the untreated plots to 20-30 vol.% and in the surfactant treated plots to 30-40 vol.% after another 87.5 mm rain, as shown for the 17 November measurements in Appendix Fig. I-K.

Mean soil water content and standard deviation

Figure 7.10 shows the mean soil water contents in the surface layer of the untreated and surfactant treated plots during the period studied. The Revolution and ACA 2787 treated plots contained evidently higher mean soil water contents in the surface layer than the untreated plots after three applications till the end of the experiment. The mean soil water contents in the Revolution and ACA 2787 plots of site 1 were quite similar on all sampling dates. Soil water contents in the ACA 2787 plots of site 2 and site 3 were on several dates slightly higher than in the Revolution treated plots.

The standard deviations of the soil water contents ranged between 0 and 9 vol.%, as illustrated in Figure 7.11. Till September they were evidently lower in the untreated plots compared with the surfactant treated plots.

Figure 7.12 gives an overview of the mean soil water contents and mean standard variations of the soil water contents in the surface layer of the 3 untreated, 3 Revolution and 3 ACA 2787 treated plots during the period studied. The mean soil water contents in the surfactant treated plots were 5-15 vol.% higher than in the untreated plots. The standard deviations of the soil water content were decreasing for the surfactant treated plots and increasing for the untreated plots during the experiment.

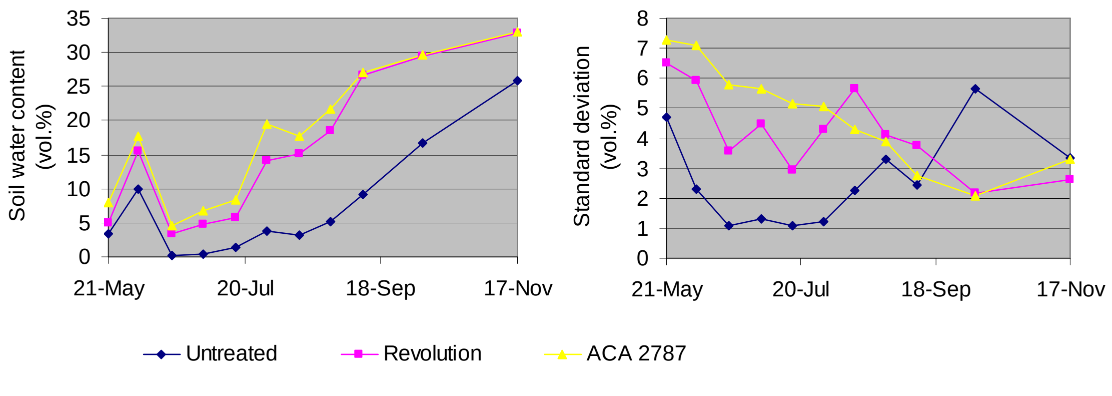


Figure 7.12 Mean and standard deviation of the volumetric soil water content in the surface layer of the three untreated, three Revolution, and three ACA 2787 treated plots between 21 May and 17 November, 2008.

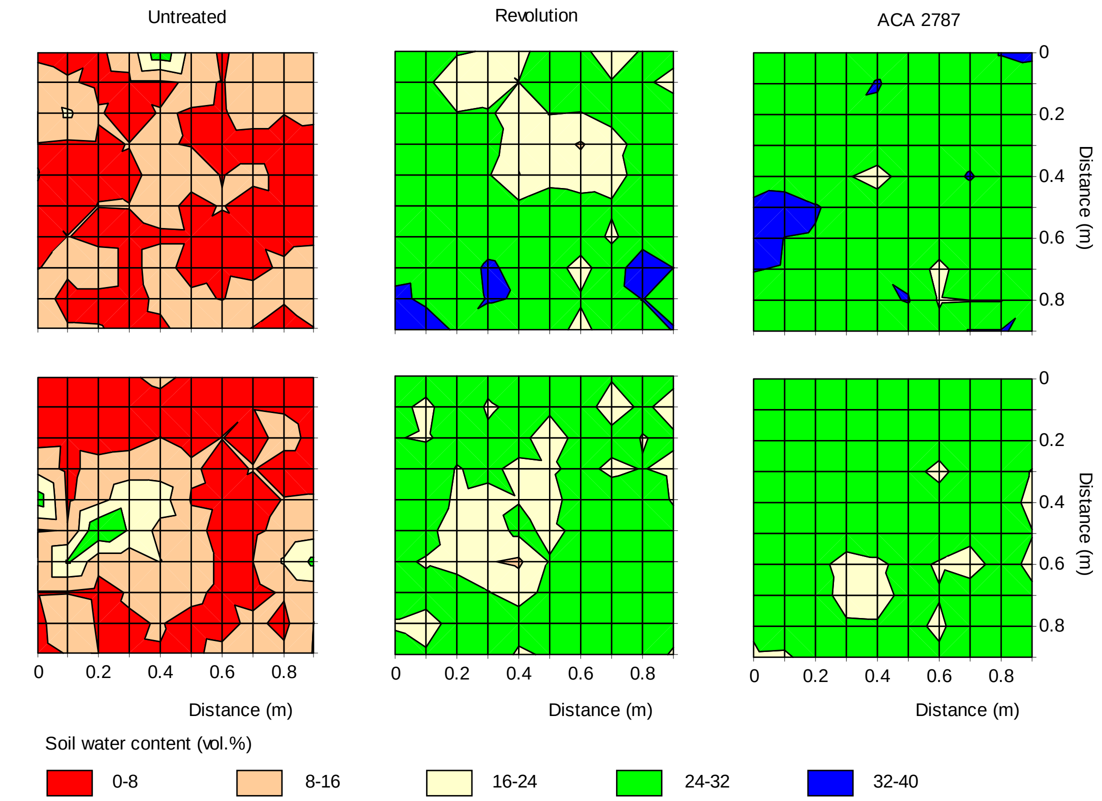


Figure 7.13 Top views with contours of the volumetric soil water content at 0-5 cm depth in the untreated and treated plots on 8 September and 10 September, 2008, respectively in site 1 and site 2 of fairway 18.

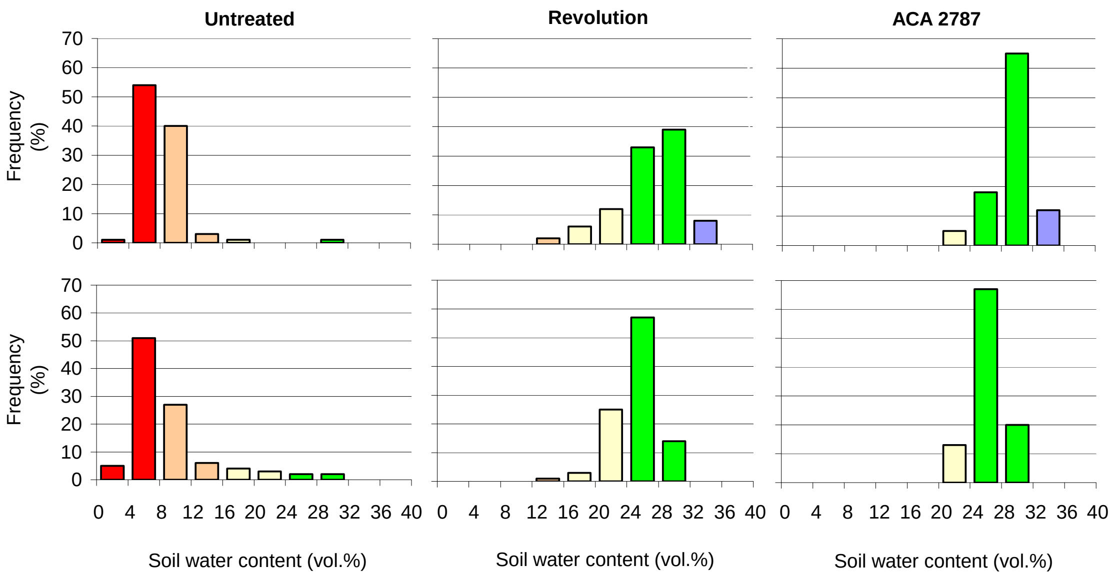


Figure 7.14 Relative frequency histograms of the volumetric soil water content at 0-5 cm depth in the untreated and treated plots on 8 and 10 September, 2008, respectively in site 1 and site 2 of fairway 18 (n = 100).

Soil water distribution in the upper 5 cm of the untreated and treated plots

The spatial variability of the soil water content in the surface layer (0-5 cm) of the three plots of site 1 on 8 September, and of site 2 on 10 September, 2008 are shown in the diagrams of Figure 7.13. Large areas with water contents below 8 vol.% were detected in both untreated plots, while large parts of the Revolution and ACA 2787 plots contained water contents of more than 24 vol.%. The variability of the soil water content was high in the untreated plot of site 2 and was least in both ACA 2787 plots, as also is clearly to see in the diagrams with the frequency distributions of the soil water contents in Figure 7.14.

Soil water contents measured at site 3 on 6 October varied mainly between 8-24 vol.% in the untreated plot and between 24 and 40 vol.% in both treated plots, as illustrated in the diagrams of Figure 7.15 and Figure 7.16.

The measurements at site 1 on 17 November show an evident increase of the soil water content in the untreated plot, nearly approaching the soil water contents in the surface layer of both surfactant treated plots (see Fig. 7.17 and Fig. 7.18).

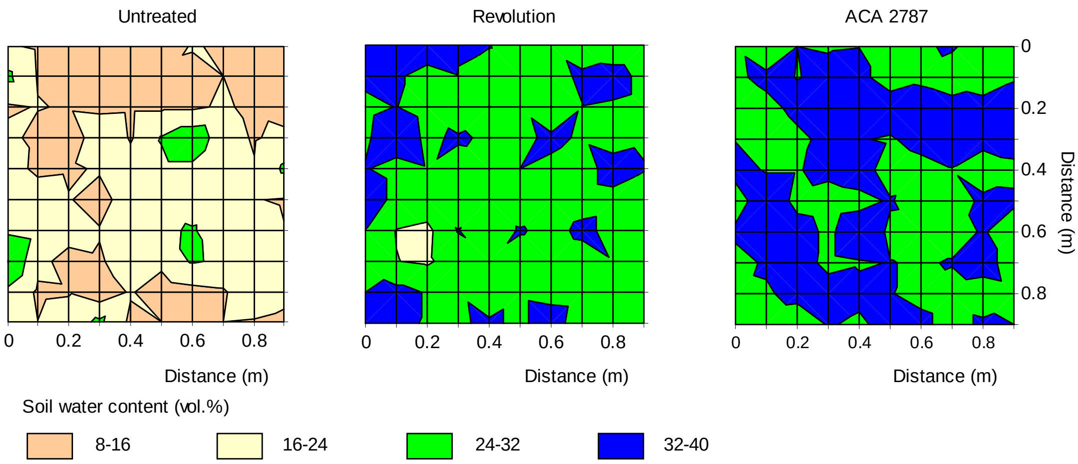


Figure 7.15 Top views with contours of the volumetric soil water content at 0-5 cm depth in the untreated and treated plots of site 3 on 6 October, 2008.

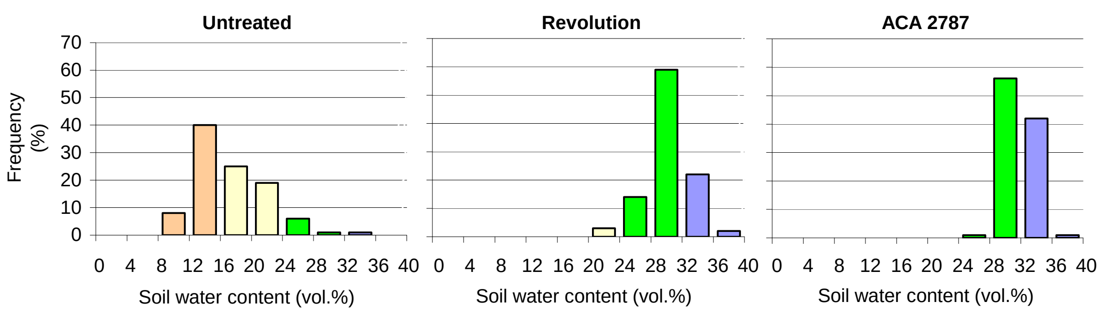


Figure 7.16 Relative frequency histograms of the volumetric soil water content at 0-5 cm depth in the untreated and treated plots of site 3 on 6 October, 2008 (n = 100).

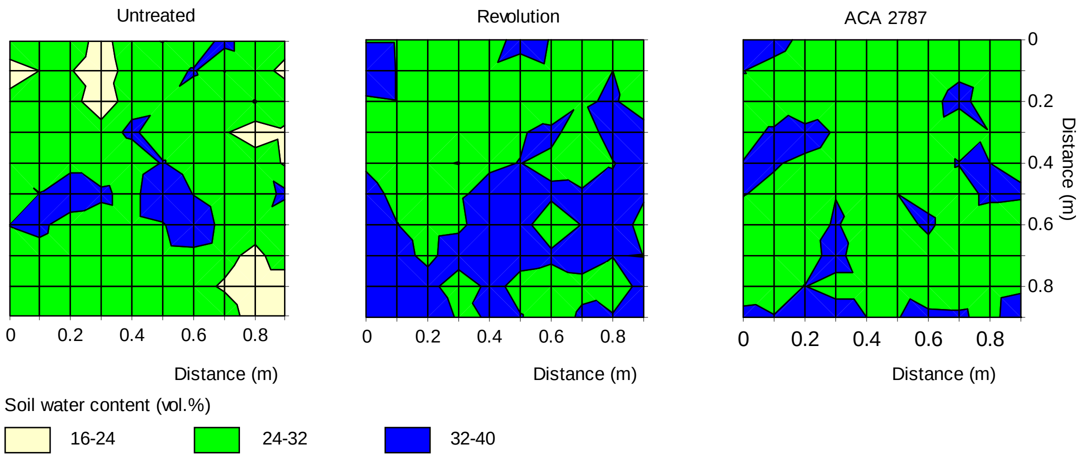


Figure 7.17 Top views with contours of the volumetric soil water content at 0-5 cm depth in the untreated and treated plots of site 1 on 17 November, 2008.

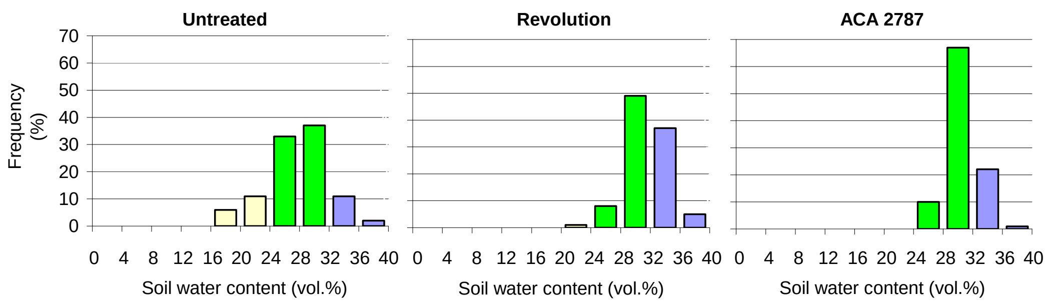


Figure 7.18 Relative frequency histograms of the volumetric soil water content at 0-5 cm depth in the untreated and treated plots of site 17 November, 2008 (n = 100).

7.8. Effects of the Surfactants on the Presence of Actual Water Repellency in the Soil Profile

At the start of the experiment (21 May, 2008) contained the profiles of all nine plots of the sites a minor to major part of actually water repellent soil till a depth of 12 to 20 cm, as presented in the diagrams of Figure 7.19. Water repellency started at the soil surface and besides were preferential flow paths present with wettable soil.

The precipitation amount of 39 mm between 21 May and 3 June (Table 7.2) mainly wetted only the upper centimeter in the plots of all three sites, as shown in the diagrams of Figure 7.20.

The merely 10 mm rain that fell between 3 and 18 June was far beyond the evaporation of the grass vegetation and resulted in an increase of the water repellency and disappearance of preferential flow paths in the 3 untreated plots at both surfactant treated plots of site 3 (see Fig. 7.21).

A slight increase in the presence of actual water repellency was detected in the profiles on 2 July in comparison with 12 June, after 11 mm of rain during this period (Fig. 7.22). However, some preferential flow paths and an irregular wetting of the surface layer are present in and restricted to the six surfactant treated plots, as is shown in the respective diagrams of Figure 7.22.

Another 59 mm of rain between 2 and 16 July resulted in the disappearance of most dry soil pockets with actual water repellency in the ACA 2787 plot of site 2, and preferential flow paths with wettable soil developed in the ACA 2787 plots of site 1 and 3, as illustrated in Figure 7.23. Besides, a larges area of actual water repellent soil was present in the untreated plots in comparison with the surfactant treated plots.

Figure 7.24 shows that also on 30 July a larger area of the untreated plots exhibited actual water repellency in comparison with the surfactant treated plots. The 64 mm precipitation in the previous two weeks resulted in the wetting of the upper centimeters of the 6 surfactant treated plots, but did not change the water repellent behavior of the surface layer of the 3 untreated plots.

On 13 August, after another 55 mm of rain, more or less the same situations occurred in the soil profiles as on 30 July (Fig. 7.25).

Also on 27 August, 10 September and 6 October the differences in water repellent soil volumes between the untreated plots and surfactant treated plots were remarkably (Fig. 7.26, Fig. 7.27, and Fig. 7.28).

A slight decrease in actual water repellency in the soil profiles was noticed on 17 November, 2008 (Fig. 7.29). However, actual water repellency was still present in a major part of the profiles of the untreated plots, but also locally present in the Revolution and ACA 2787 plots.

Figure 7.30 shows that the decrease of actual water repellency in time in the treated plots was more obvious than in the untreated plots. Besides, it is remarkable that actual water repellency in the surfactant treated plots often starts at depths of more than 5 cm, whereas in the untreated plots water repellency mostly starts within 5 cm. From 16 July to 17 November were more completely wettable soil cores detected in the ACA 2787 plots than in the Revolution plots.

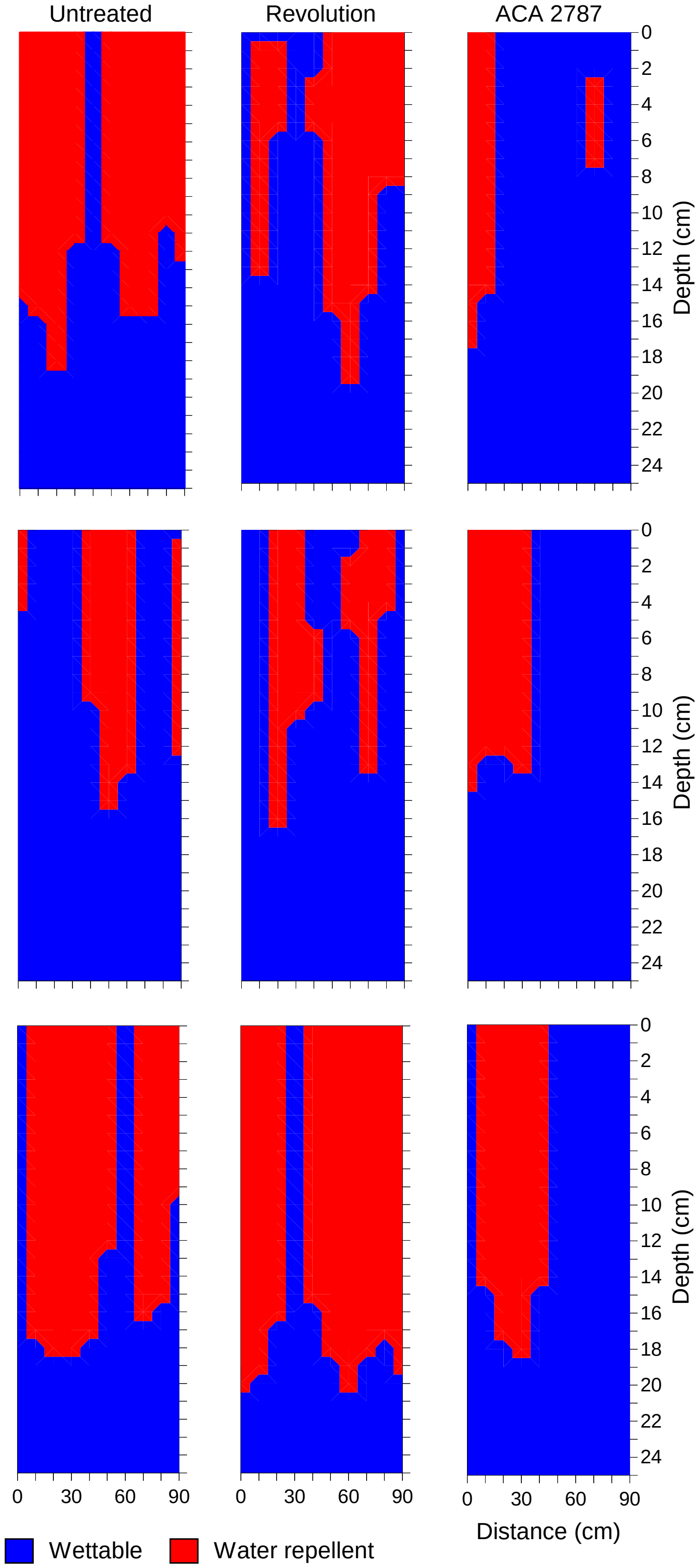


Figure 7.19 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 21 May, 2008.

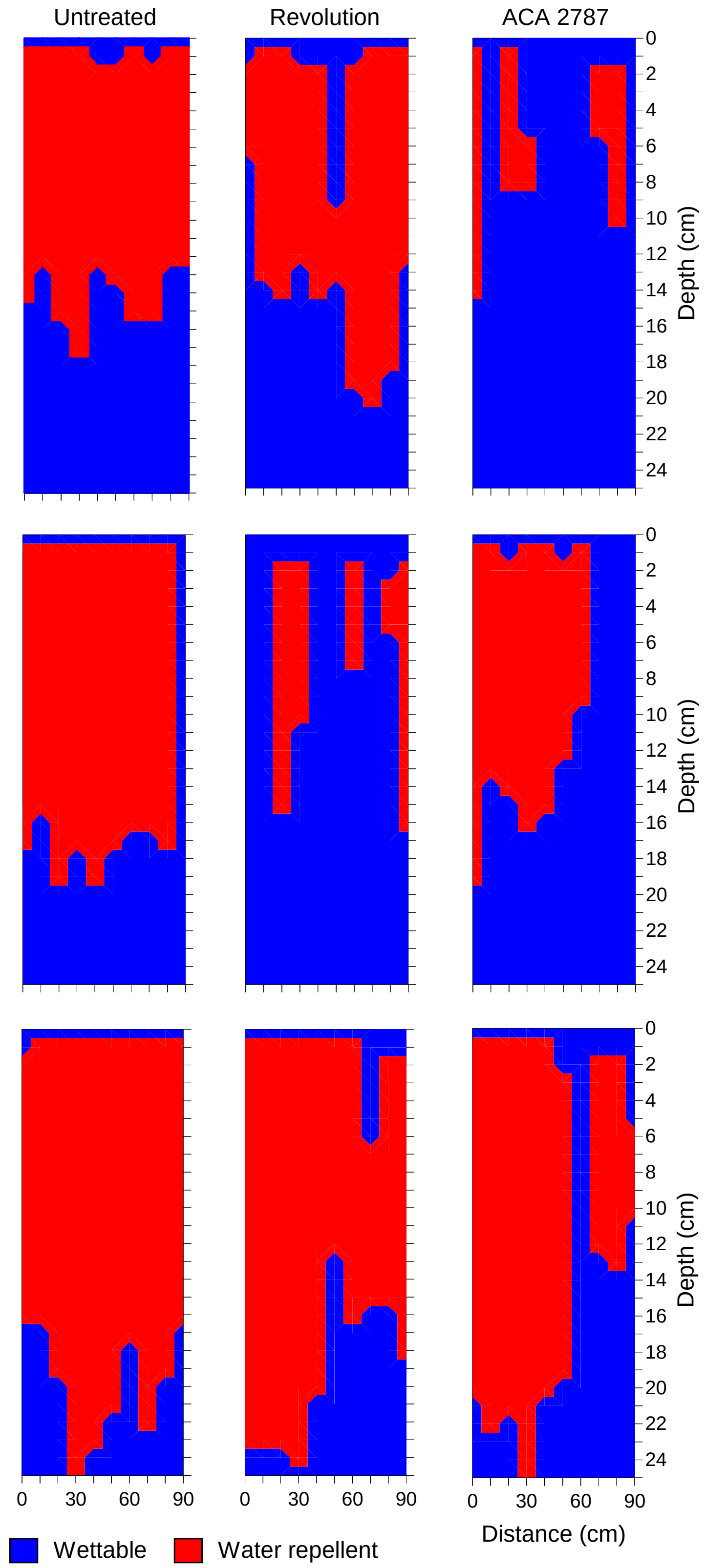


Figure 7.20 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 3 June, 2008.

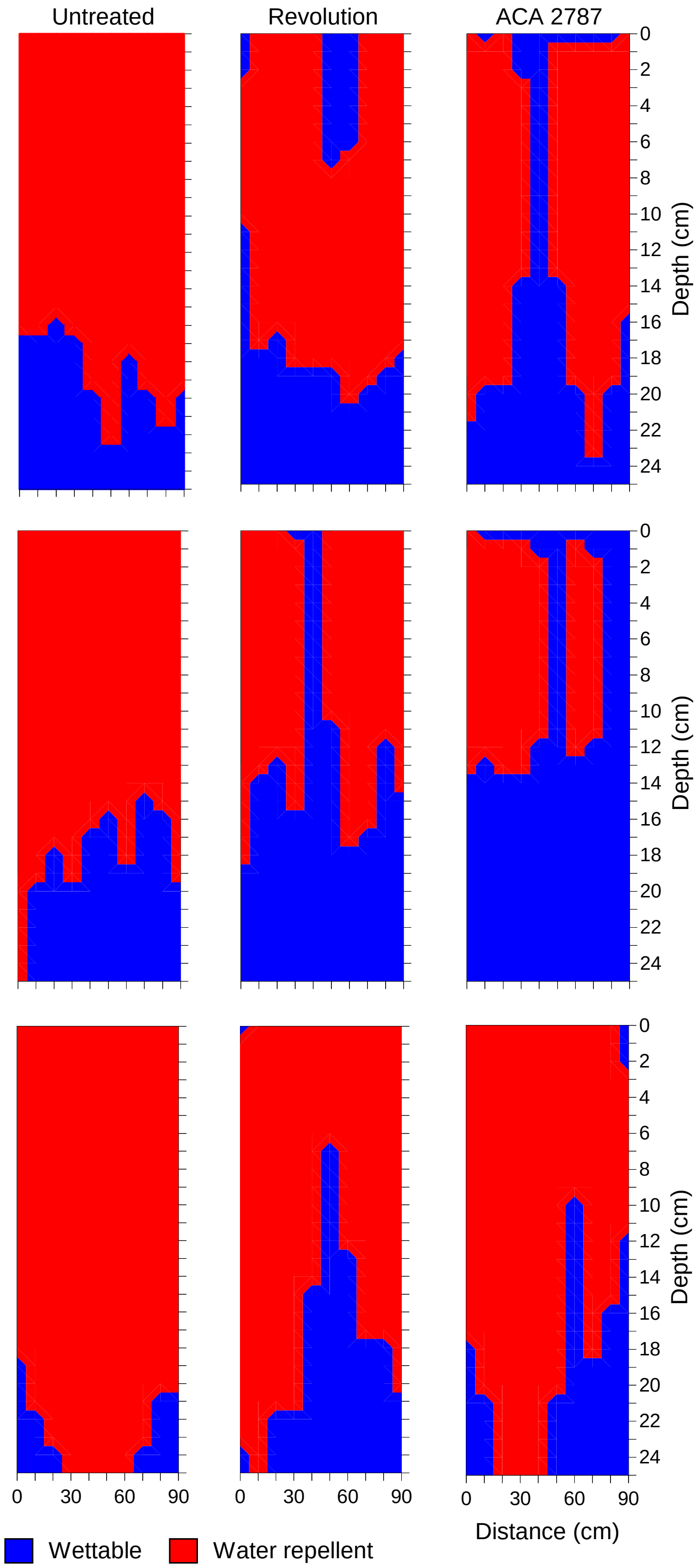


Figure 7.21 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 18 June, 2008.

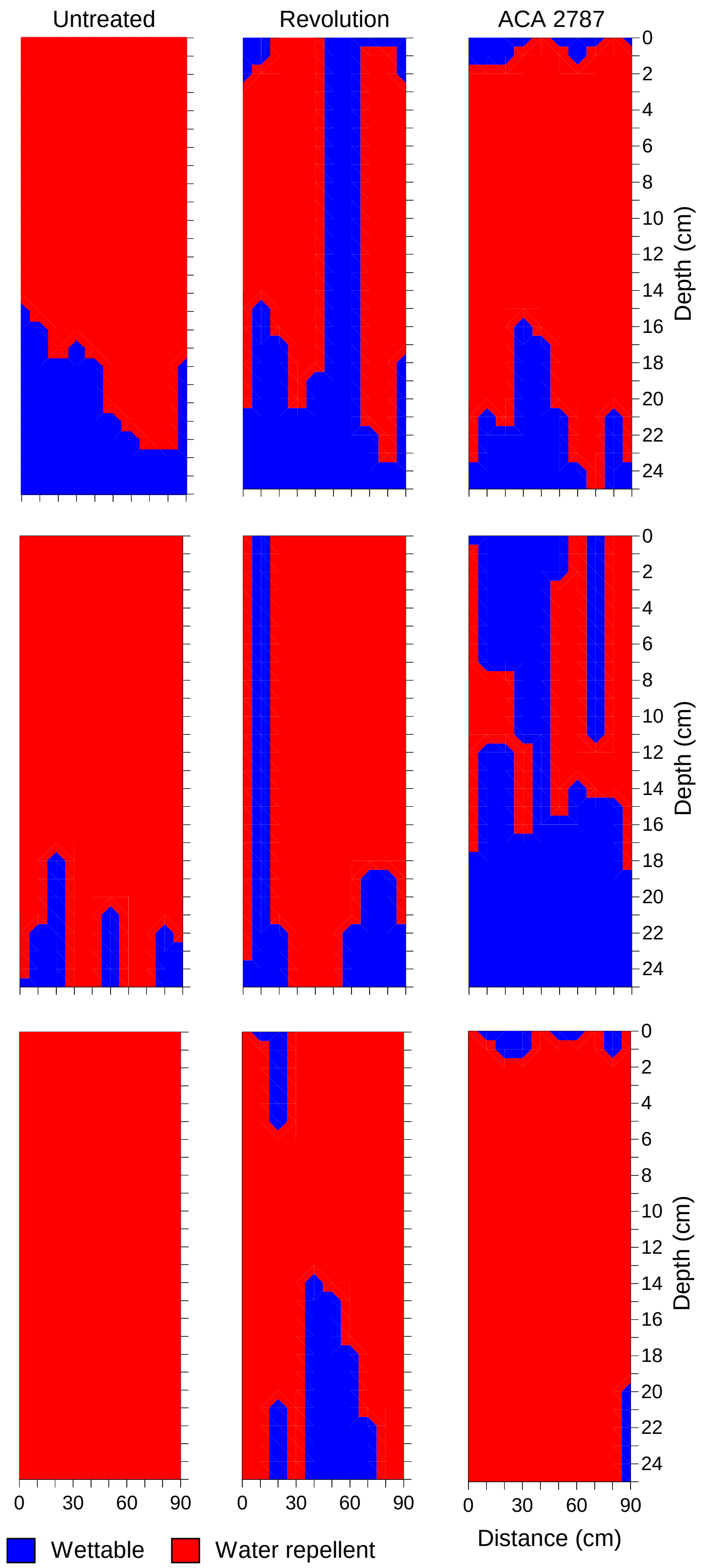


Figure 7.22 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 2 July, 2008.

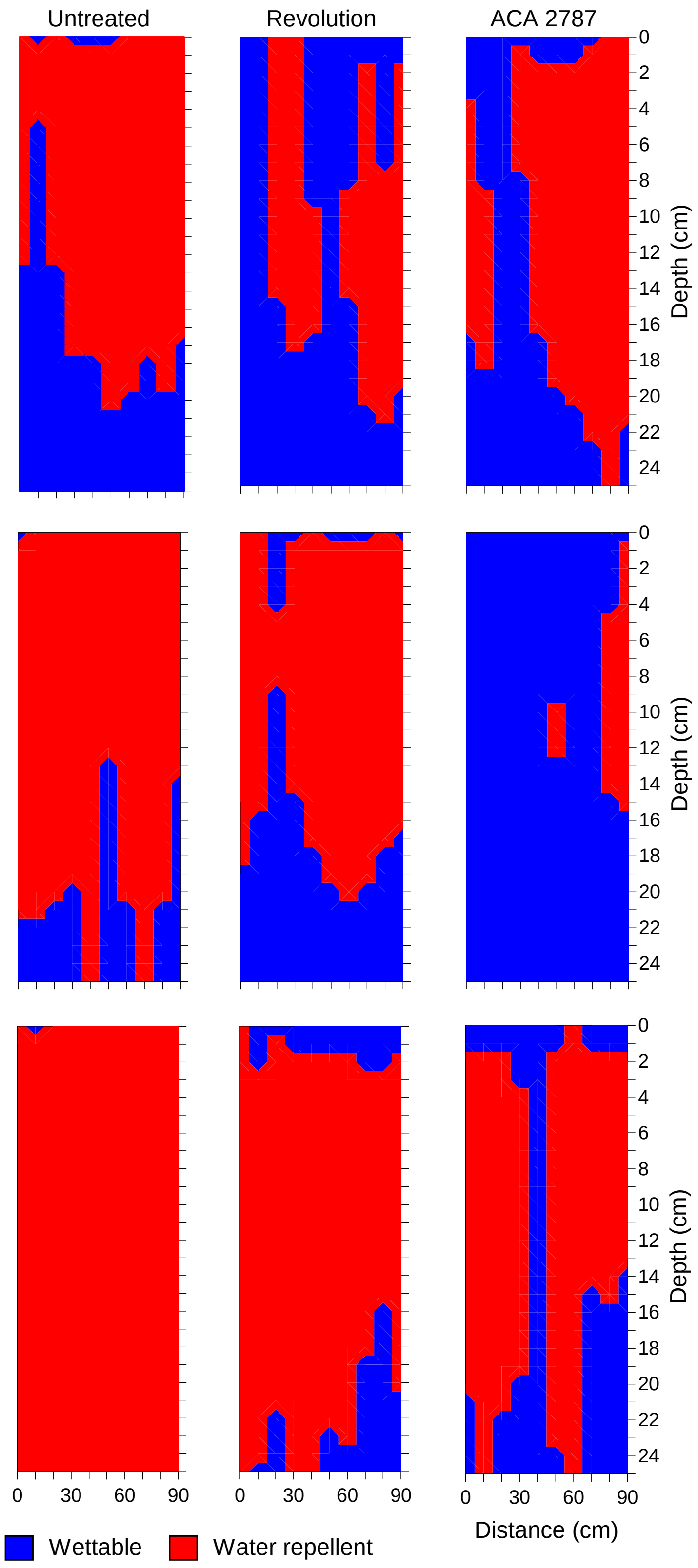


Figure 7.23 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 16 July, 2008.

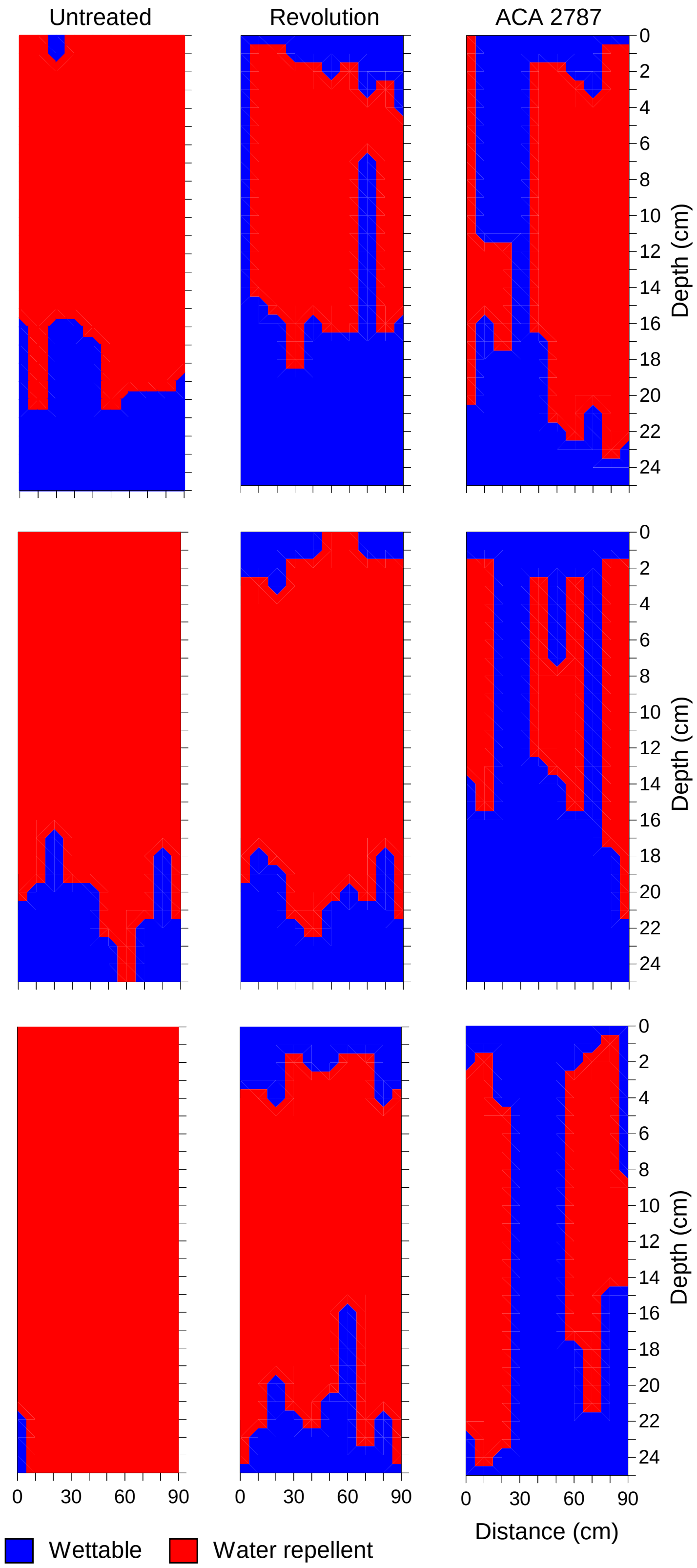


Figure 7.24 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 30 July, 2008.

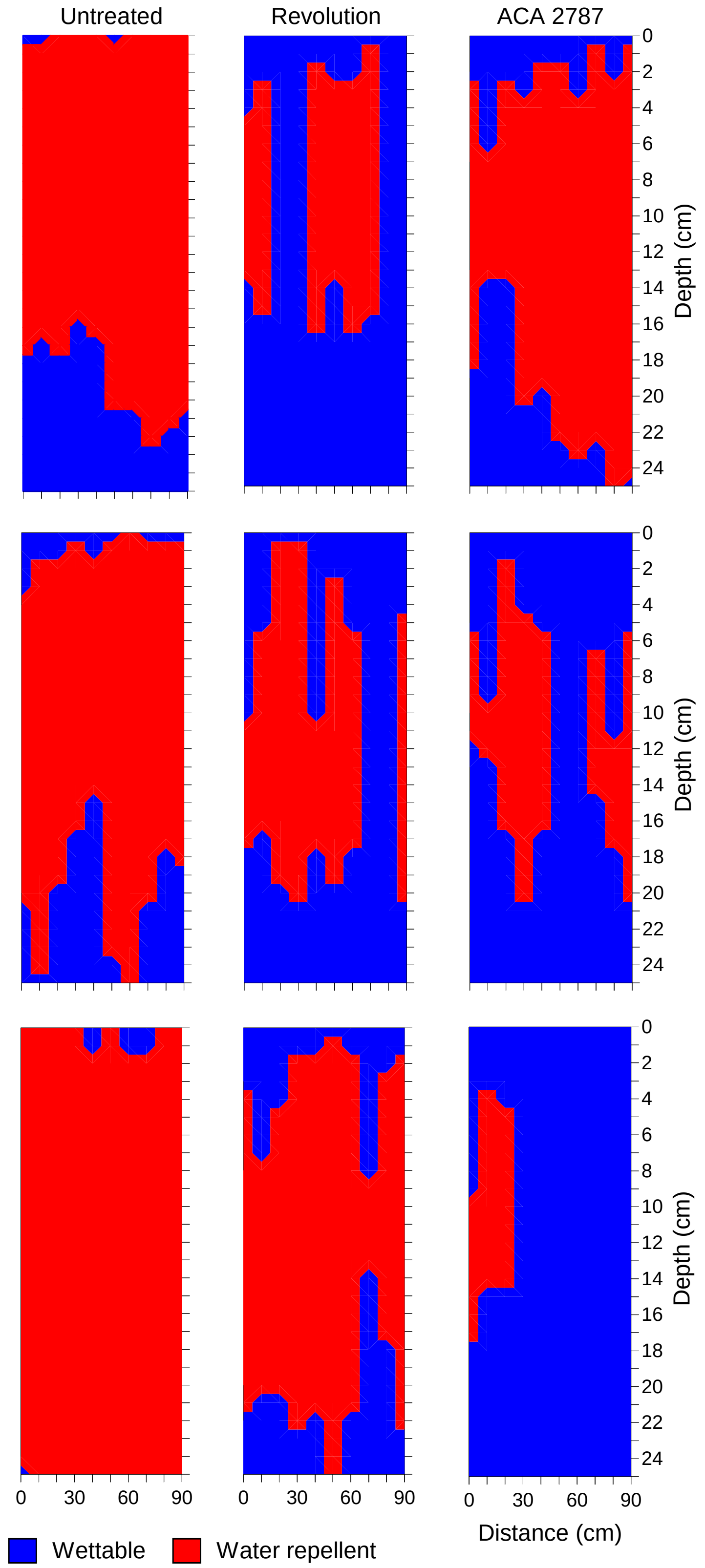


Figure 7.25 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 13 August, 2008.

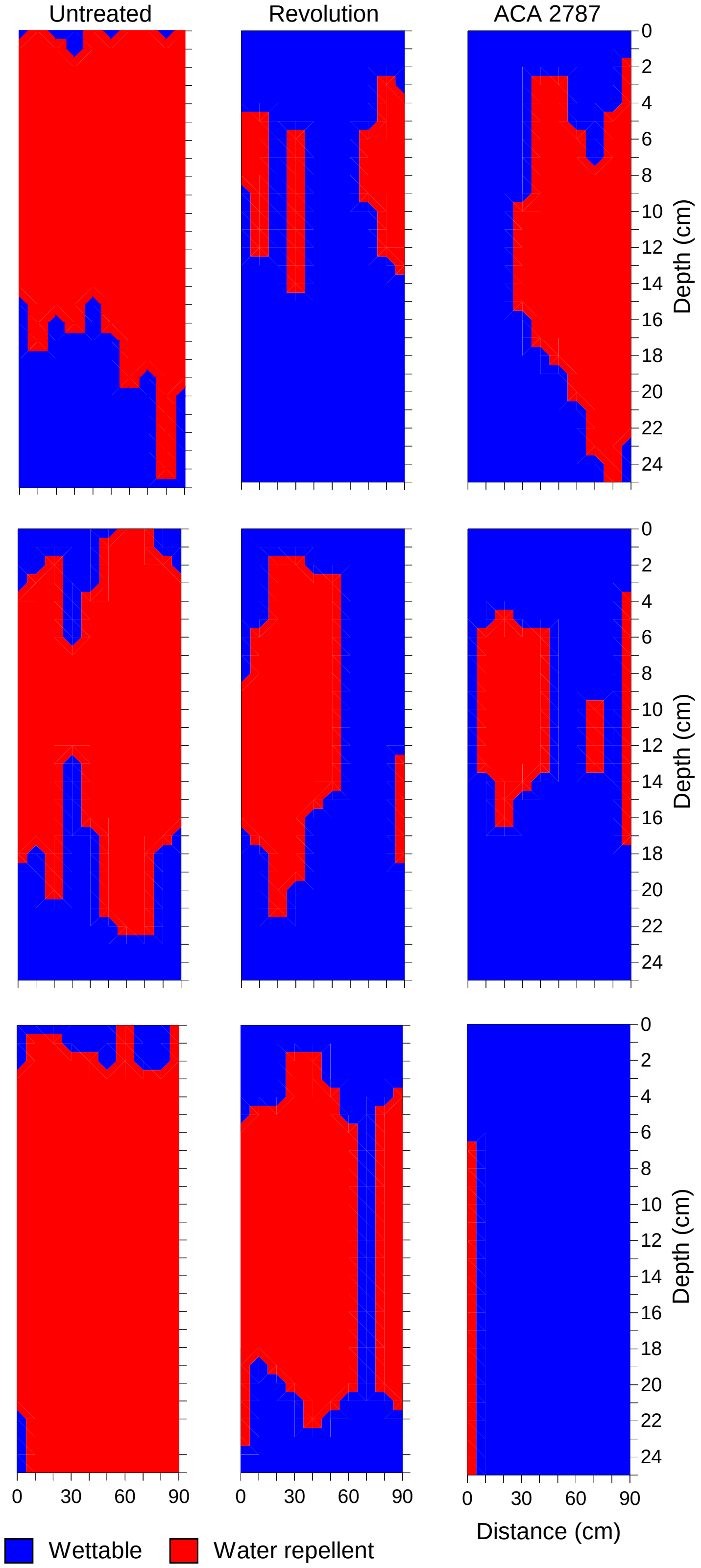


Figure 7.26 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 27 August, 2008.

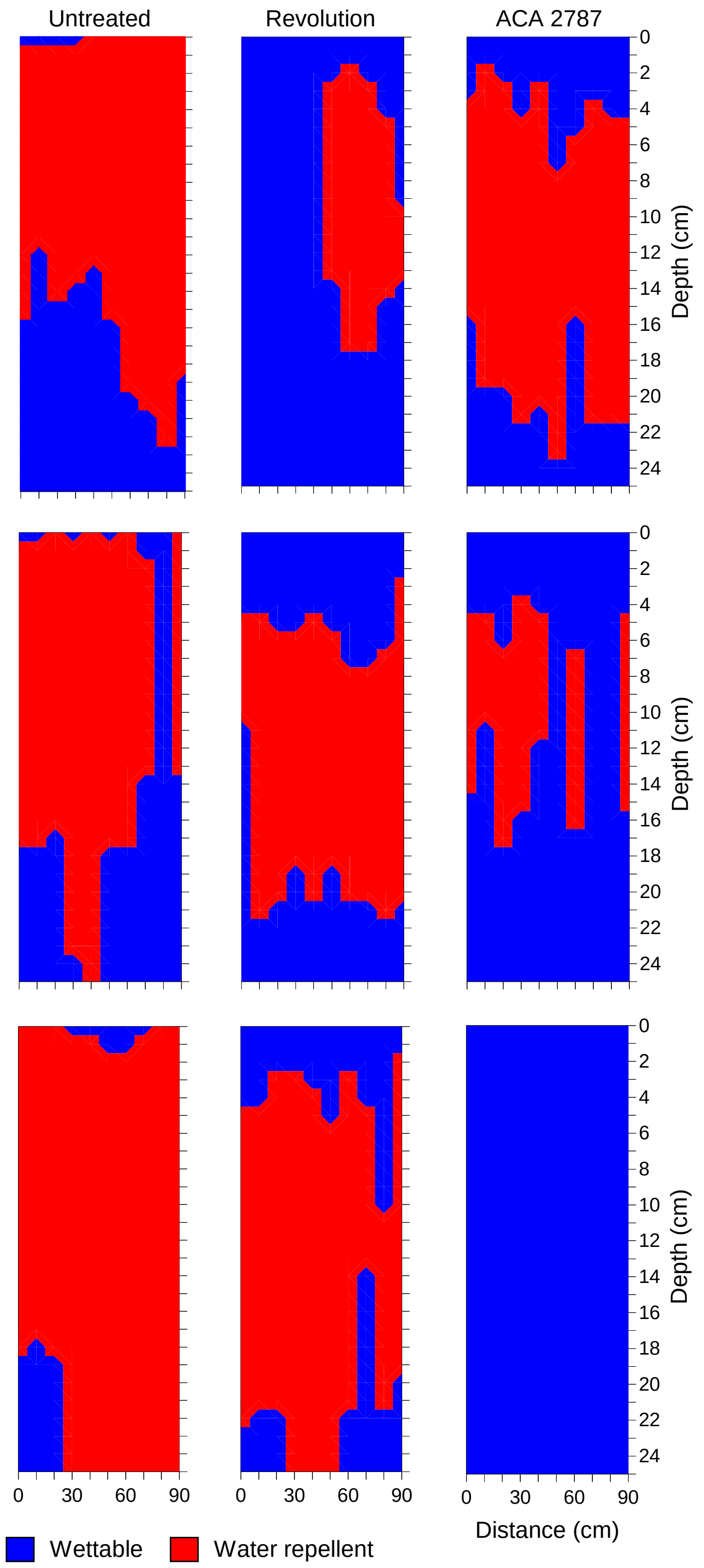


Figure 7.27 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 10 September, 2008.

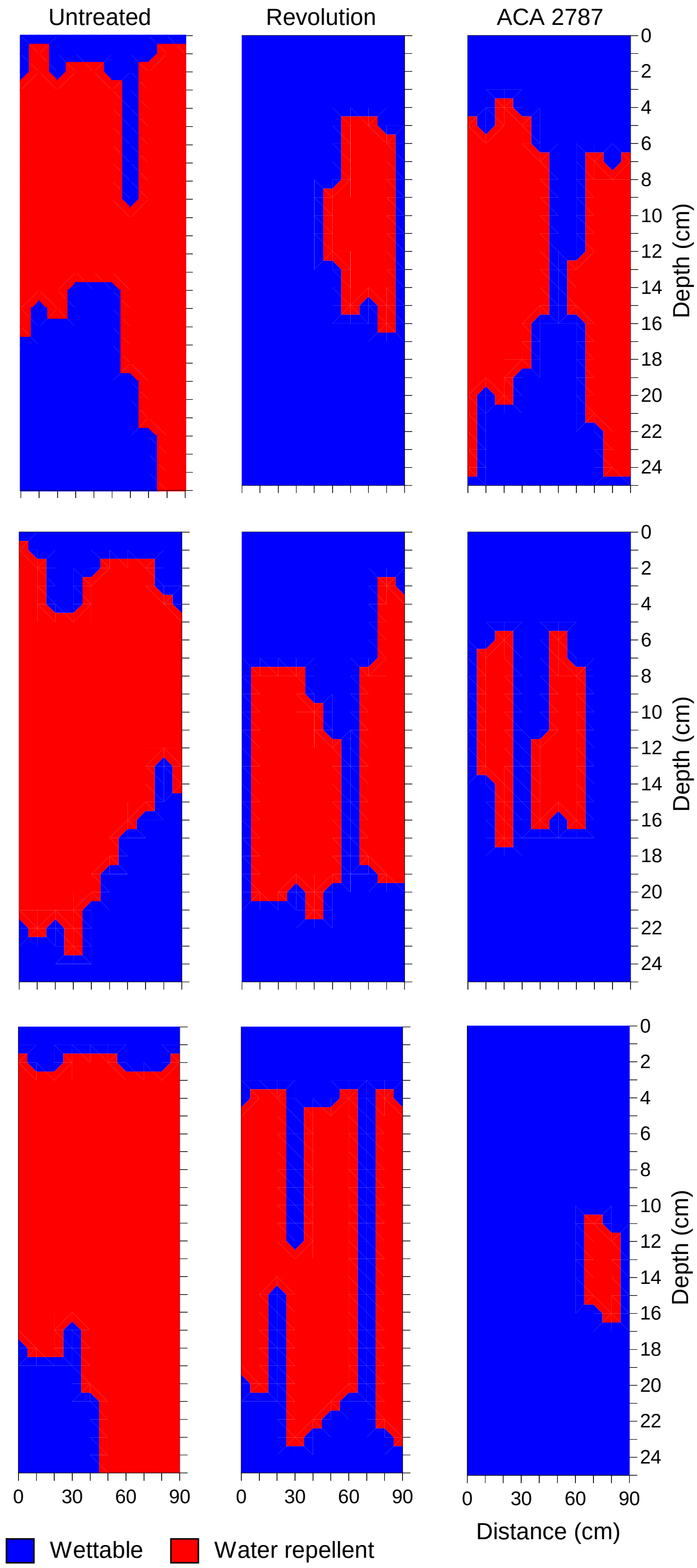


Figure 7.28 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 6 October, 2008.

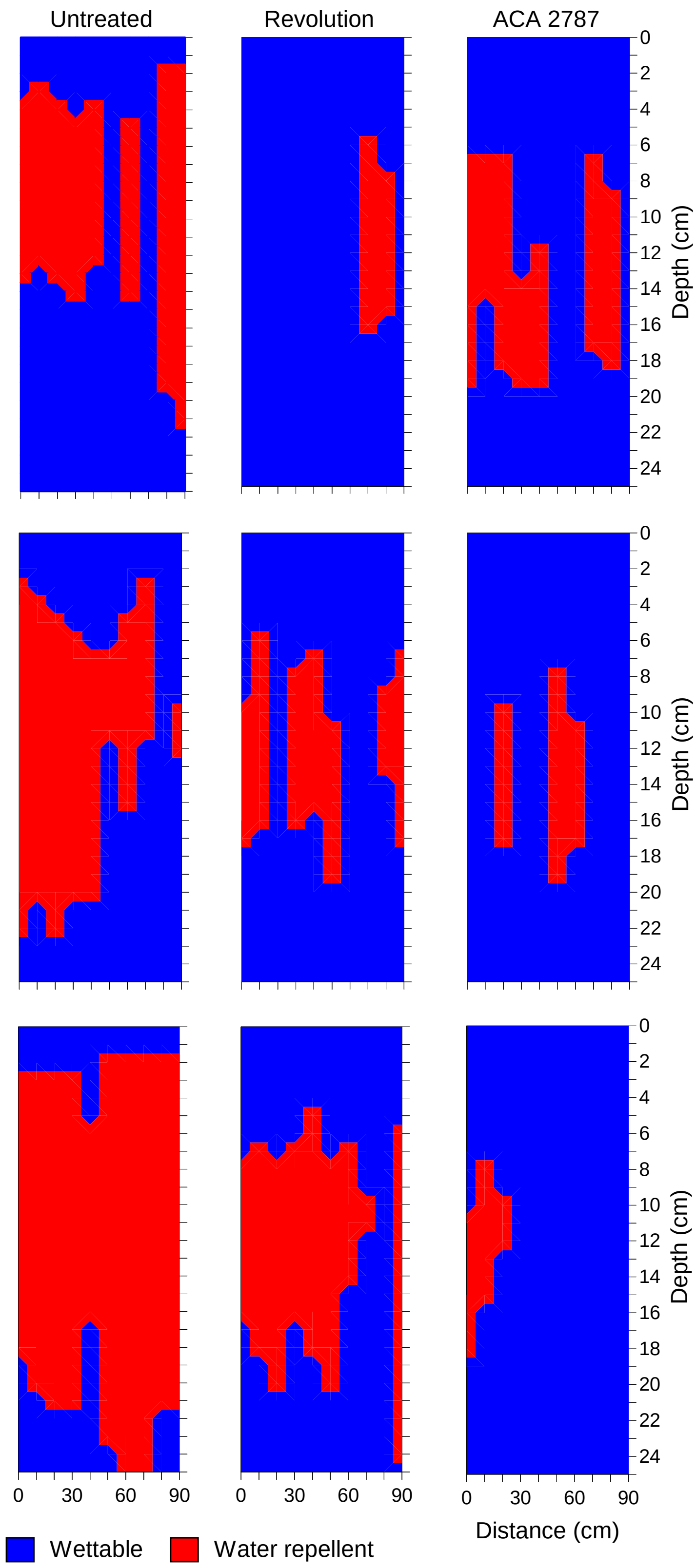


Figure 7.29 Contours of actual water repellency in the topsoil of the untreated and surfactant treated plots of respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 17 November, 2008.

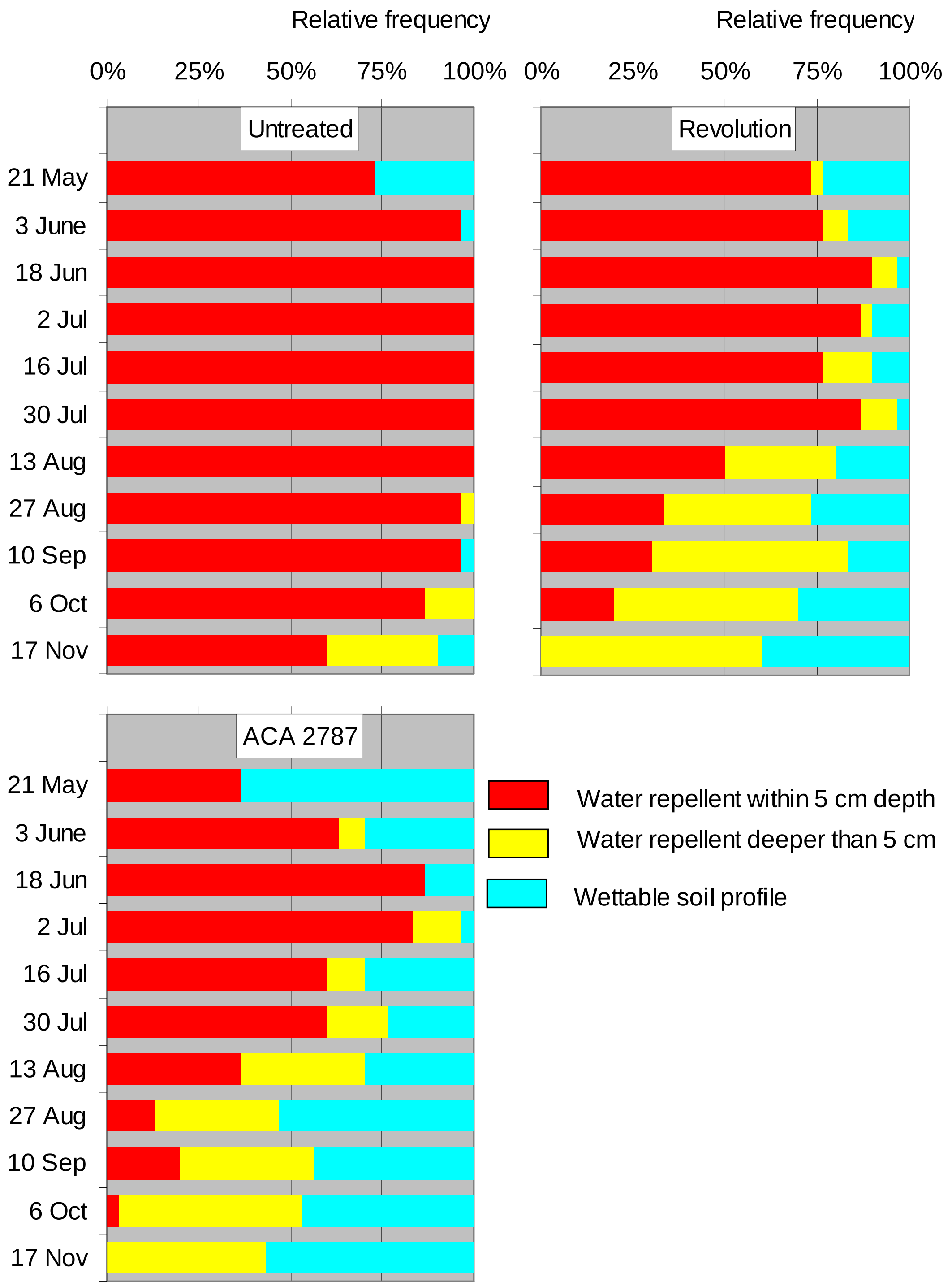


Figure 7.30 The relative frequency of the presence of actual water repellency within or deeper than 5 cm depth in the 30 soil cores taken in the untreated and surfactant treated plots between 21 May and 17 November, 2008.

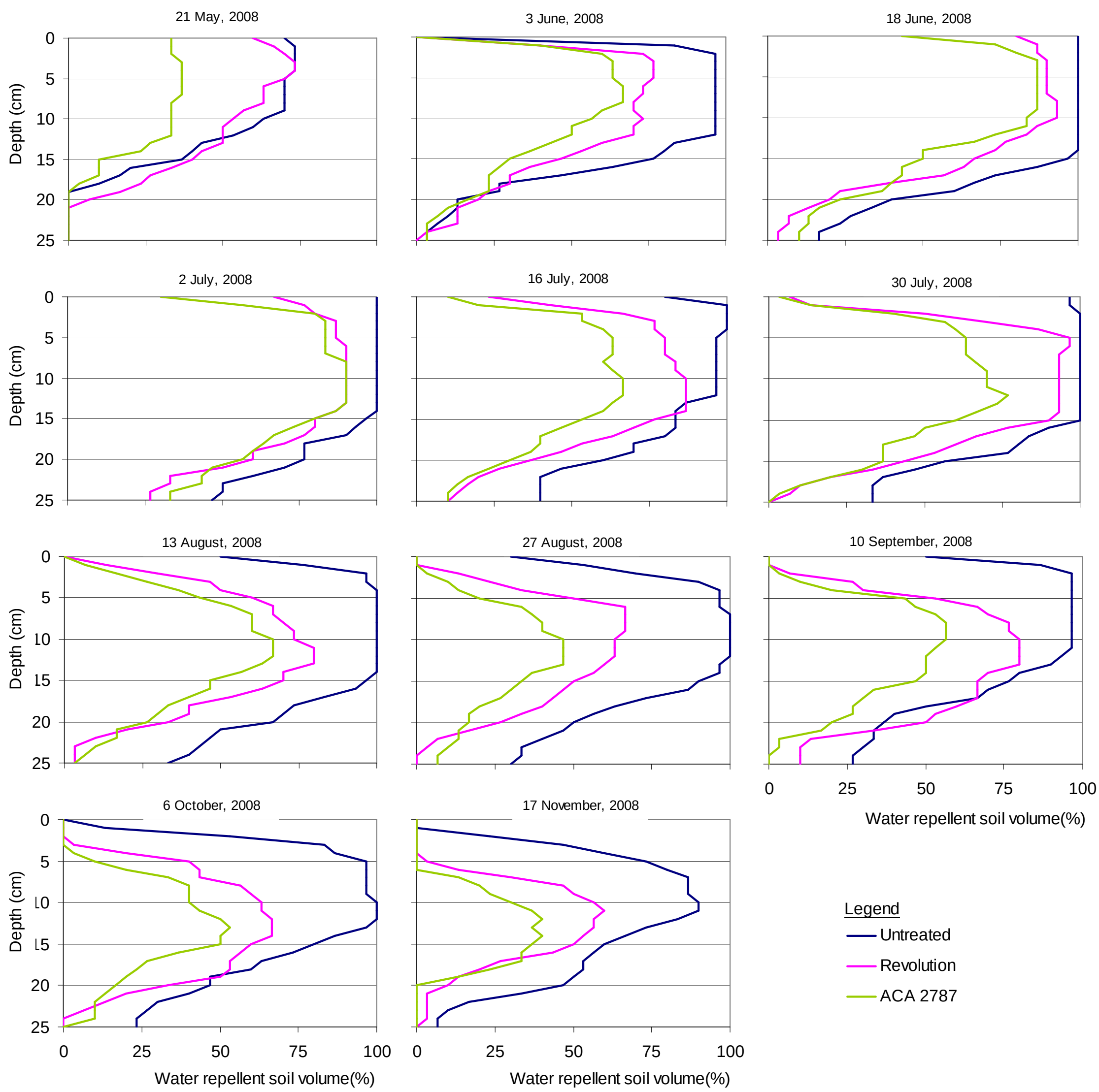


Figure 7.31 Percentage of water repellent soil volume (n = 30) between 1 and 25 cm depth in the untreated and Revolution and ACA 2787 treated plots on the 11 sampling occasions.

Figure 7.31 shows that the water repellent soil volume in the untreated plots at all depths between 0 and 25 cm is higher than in the surfactant treated plots between 18 June and 17 November, 2008. The water repellent soil volume in the ACA 2787 plots was on nearly all sampling occasions less than in the Revolution plots.

Figure 7.32 gives an overview of the volumes of actually water repellent soil between 0 and 25 cm depth in the untreated and surfactant treated plots of the 3 sites between 21 May and 17 November, 2008. The total area of the soil profiles of the distinguished plots on one date were 3 x (90 x 25 cm) = 6750 cm^2. This means that for instance on 21 May 40% or a total area of 2700 cm^2 of the soil profiles till 25 cm depth in the three Revolution treated plots was water repellent. The actually water repellent volume in the soil profiles increased in all plots from the start of the experiment to 2 July, after which it decreased. However, the water repellent volume in the untreated plots was from 3 June till the end of the experiment always evidently higher than in the Revolution and ACA 2787 treated plots, as shown in Figure 7.32.

Figure 7.33 shows the distribution of actually water repellent and wettable soil as assessed with the core sampler on 36 places in the center (60 cm by 60 cm) of the plots at site 2 on 10 September, 2008. The soil in both surfactant treated plots was wettable at 2 cm depth, while in the untreated plot the soil was repellent with the exception of one core. The whole horizontal plane of 60 cm by 60 cm was repellent in the untreated plot at 4 and 7 cm depth, whereas a part of the planes were repellent in the Revolution and ACA 2787 plots. The figure shows that the untreated and ACA 2787 profiles were completely wettable at 25 cm depth.

Figure 7.34 illustrates the large differences in the distribution of water repellency at different depths between the untreated plot and surfactant treated plots at site 3 on 6 October. Most wettable soil was detected at this site on 6 October in the ACA 2787 plot. A large portion of the untreated profile was still water repellent at 25 cm depth.

Figure 7.35 shows the differences in water repellency between the untreated and surfactant treated plots in the horizontal planes at different depths on 17 November, 2008. Most wettable soil was detected at this site on 17 November in the Revolution plot.

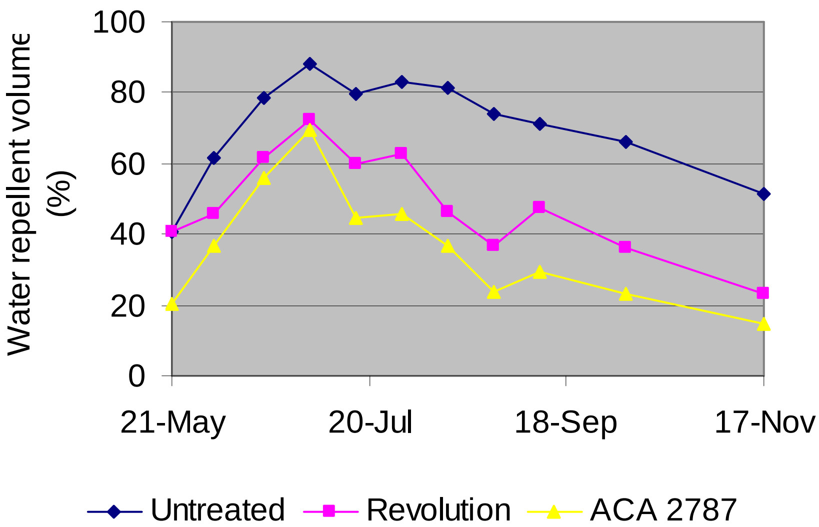


Figure 7.32 Course of the mean total actually water repellent soil volume in the untreated and surfactant treated plots of the 3 sites between 21 May and 17 November, 2008.

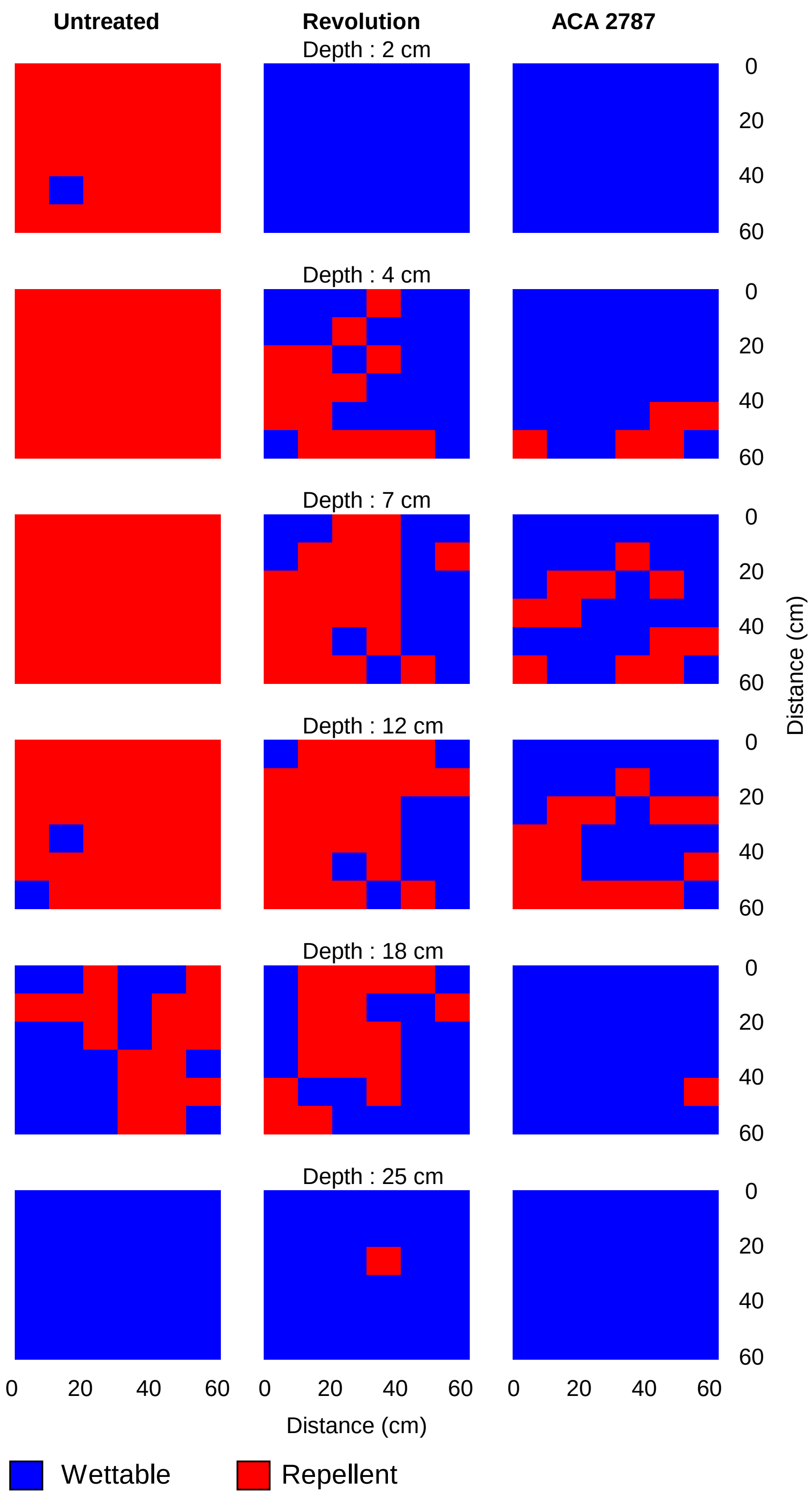


Figure 7.33 Distribution of actual water repellent and wettable soil in horizontal planes of 60 cm by 60 cm at 6 depths in the untreated, Revolution and ACA 2787 plots of site 2 on 10 September, 2008.

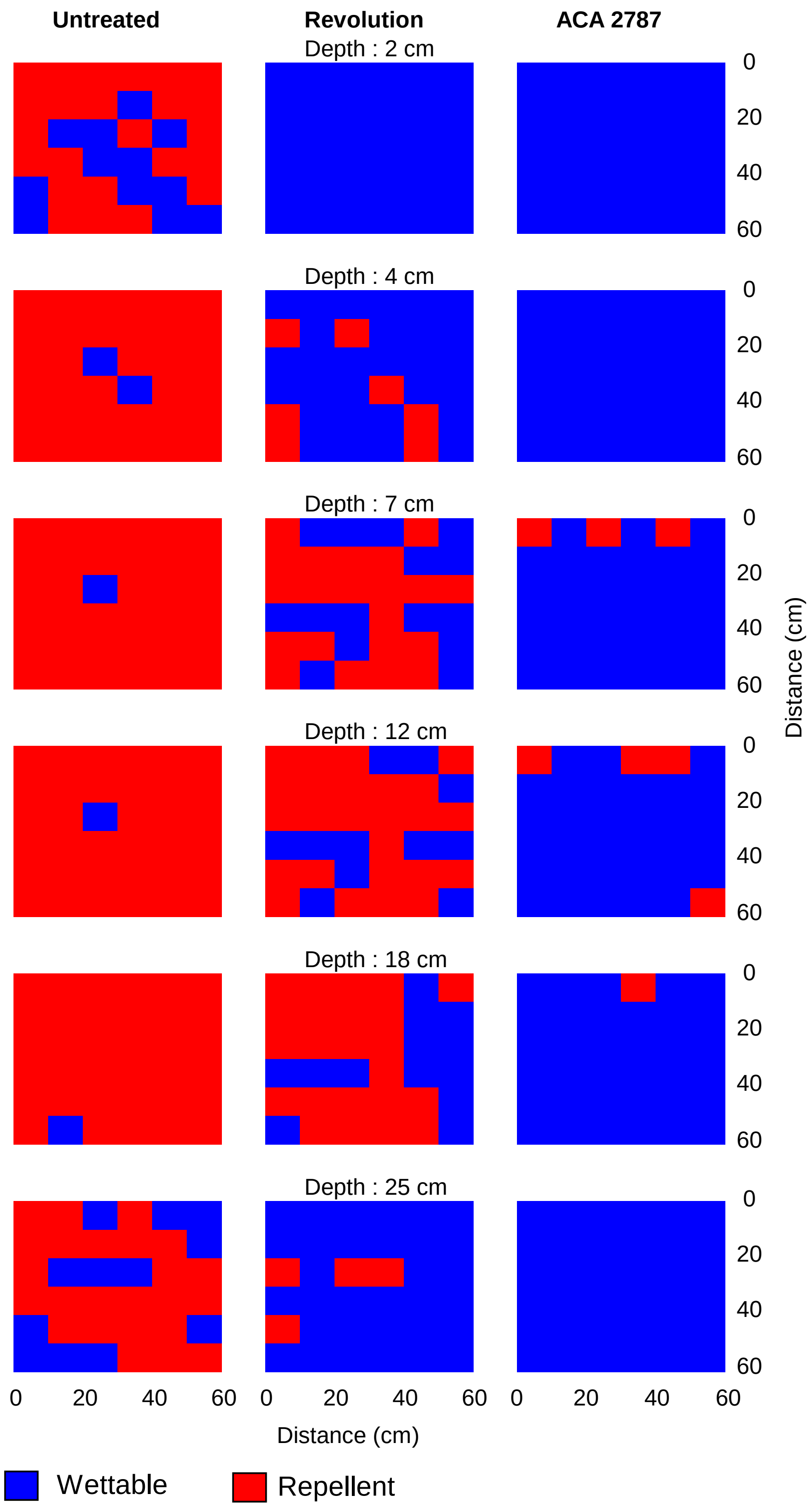


Figure 7.34 Distribution of actual water repellent and wettable soil in horizontal planes of 60 cm by 60 cm at 6 depths in the untreated, Revolution and ACA 2787 plots of site 3 on 6 October, 2008.

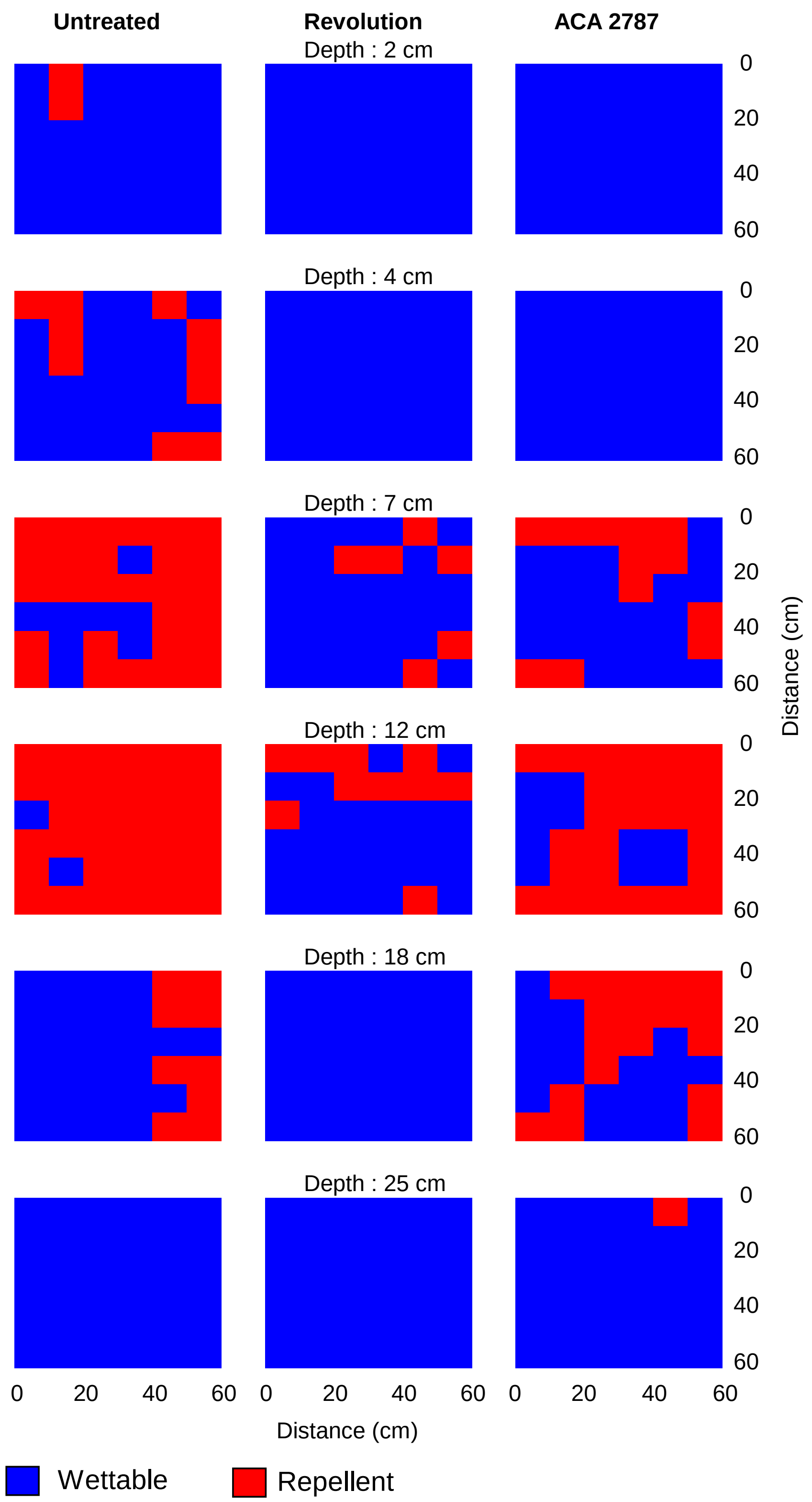


Figure 7.35 Distribution of actual water repellent and wettable soil in horizontal planes of 60 cm by 60 cm at 6 depths in the untreated, Revolution and ACA 2787 plots of site 1 on 17 November, 2008.

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Appendix I: Soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of the three sites of fairway 18 on eleven dates between 6 June and 17 November, 2008.

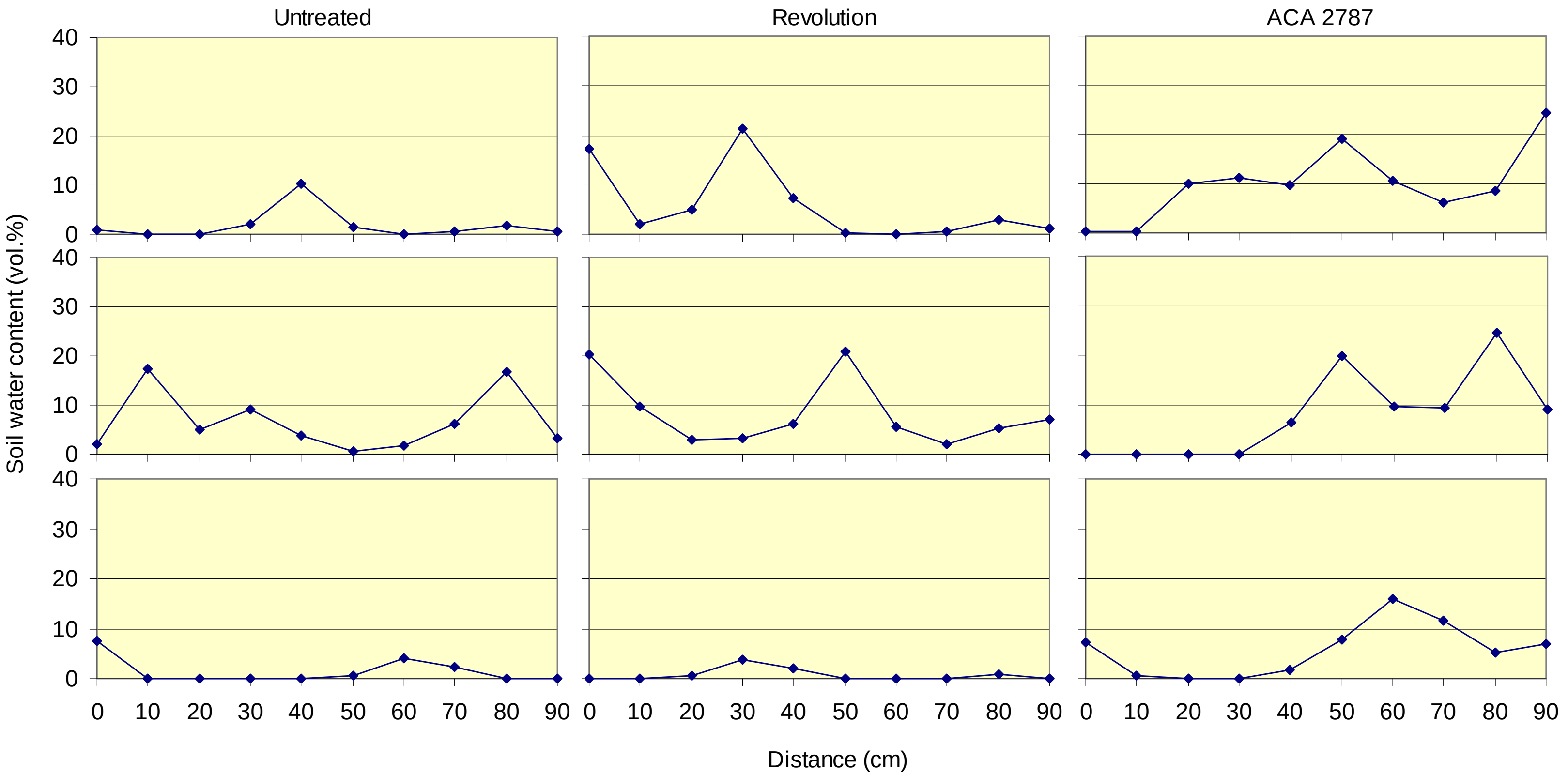

Figure I-A Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 21 May, 2008.

Figure I-B Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 3 June, 2008.

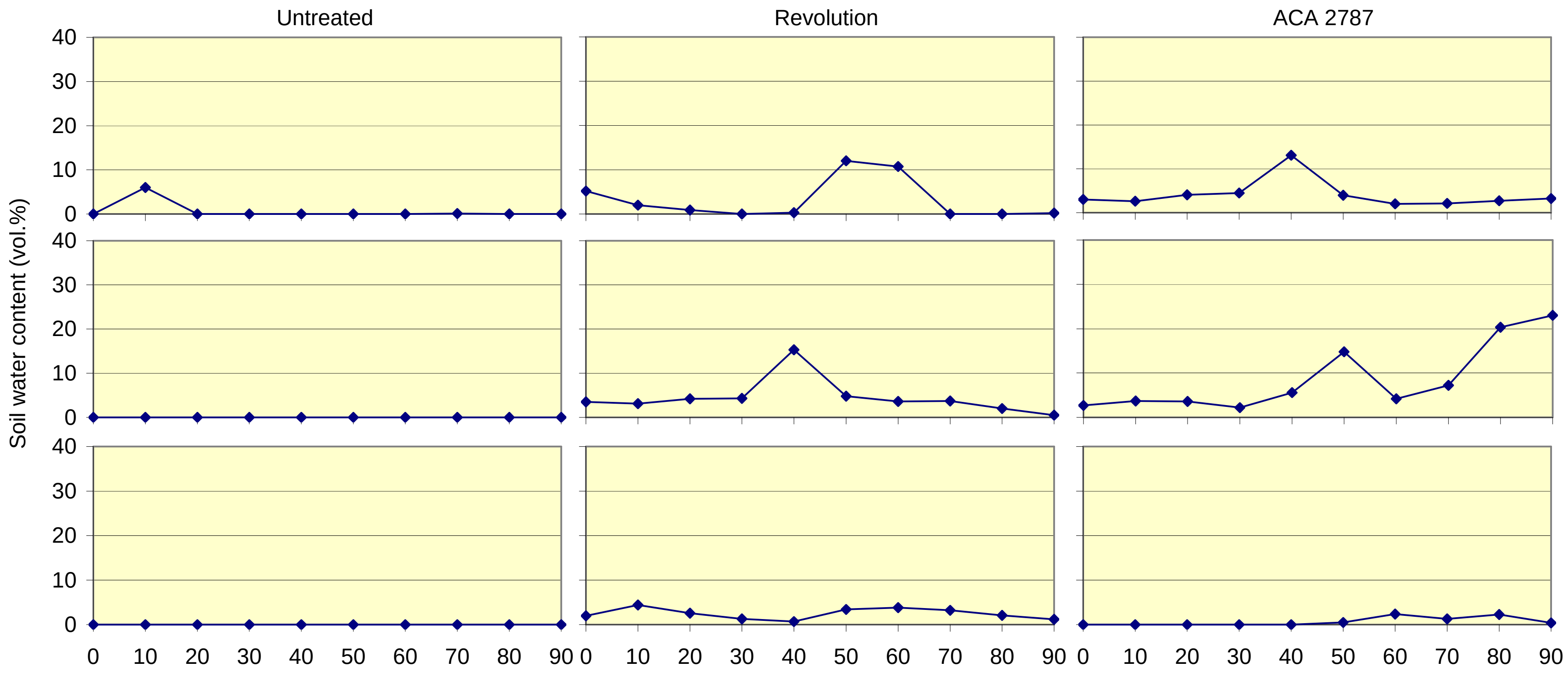

Figure I-C Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 18 June, 2008.

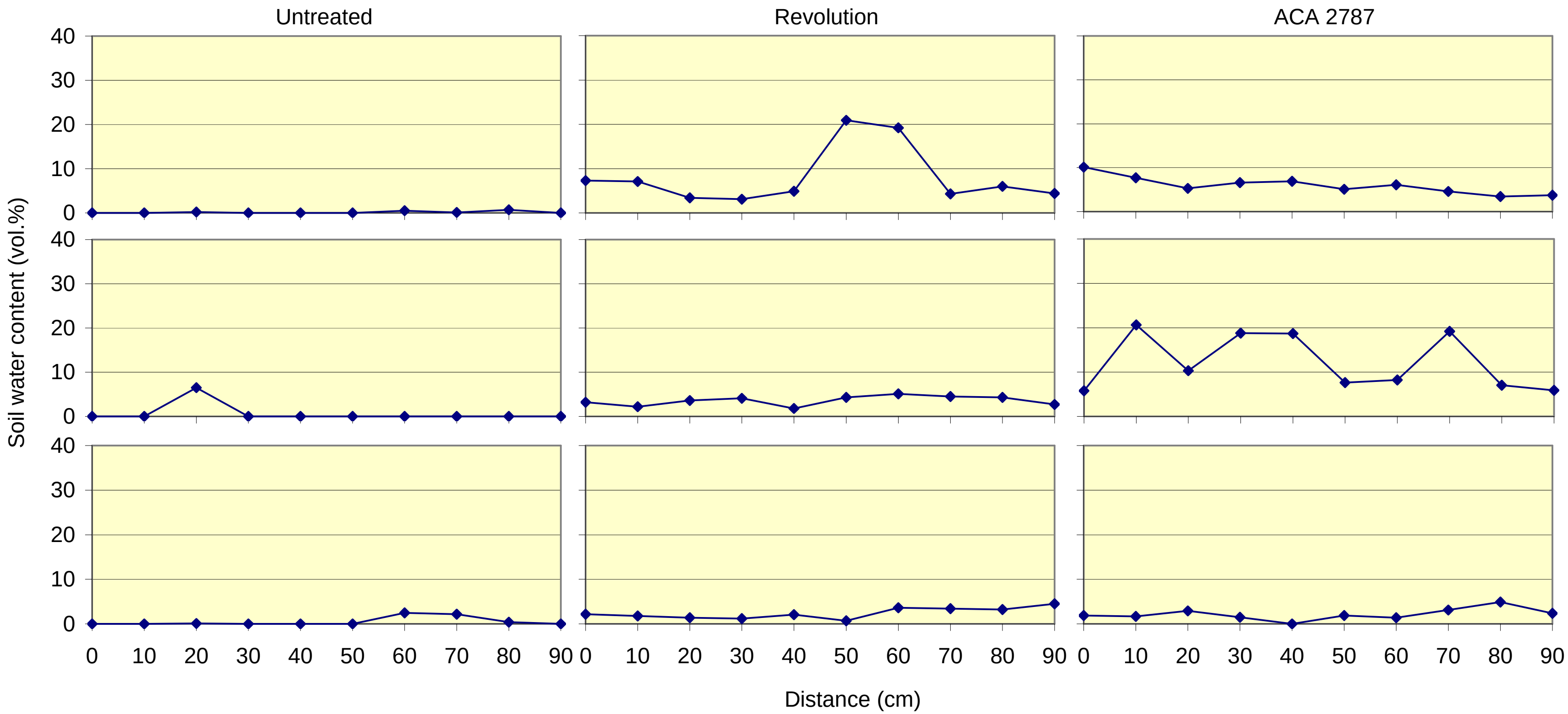

Figure I-D Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 2 July, 2008.

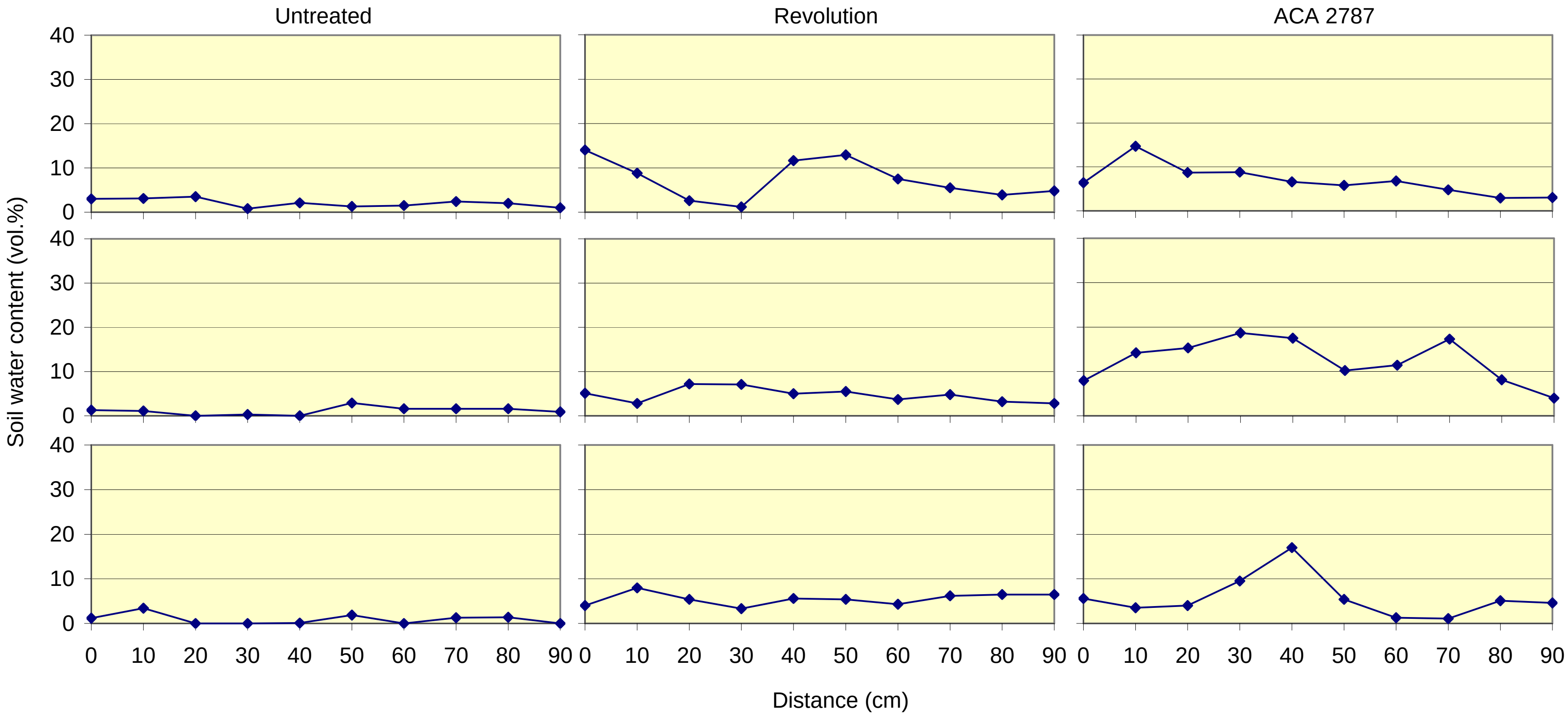

Figure I-E Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 16 July, 2008.

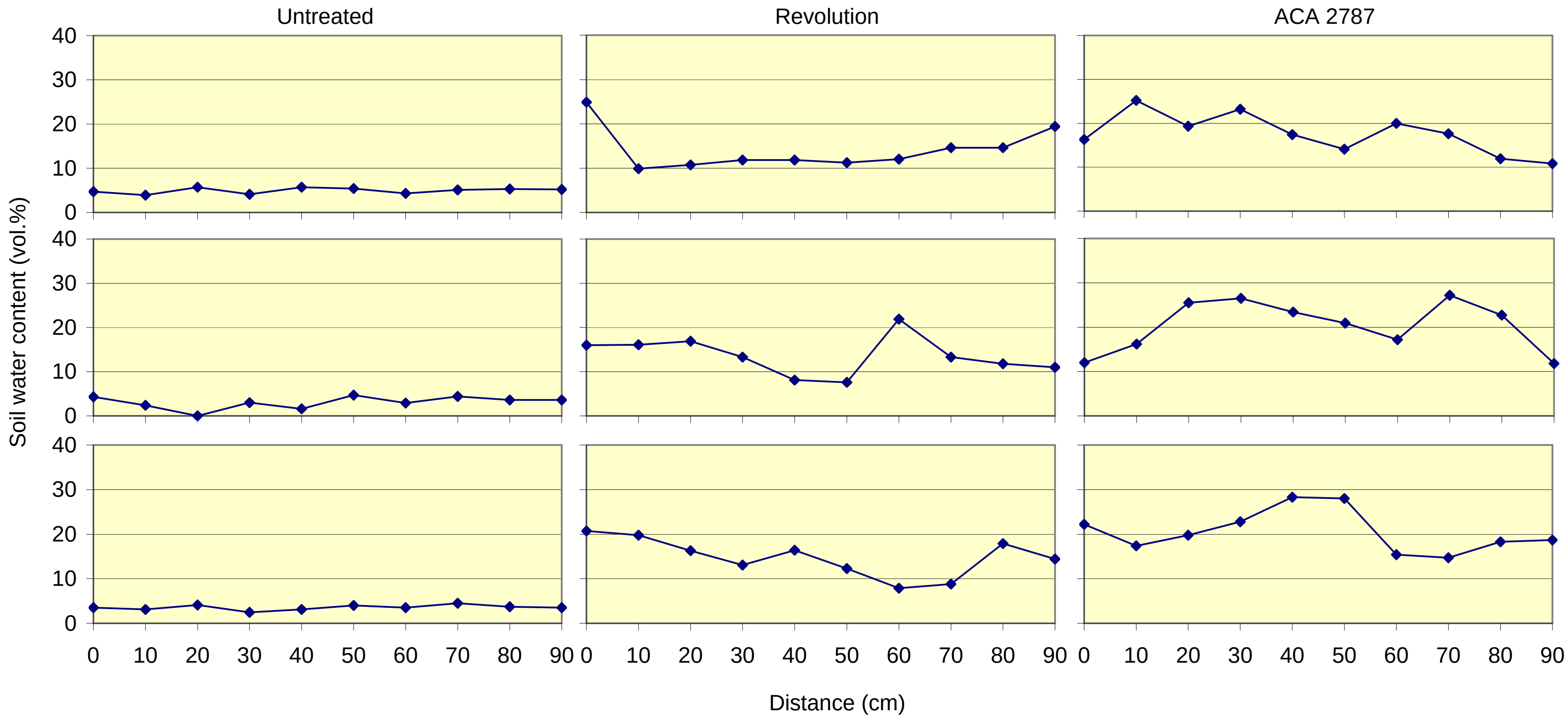

Figure I-F Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 30 July, 2008.

Figure I-G Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 13 August, 2008.

Figure I-H Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 27 August, 2008.

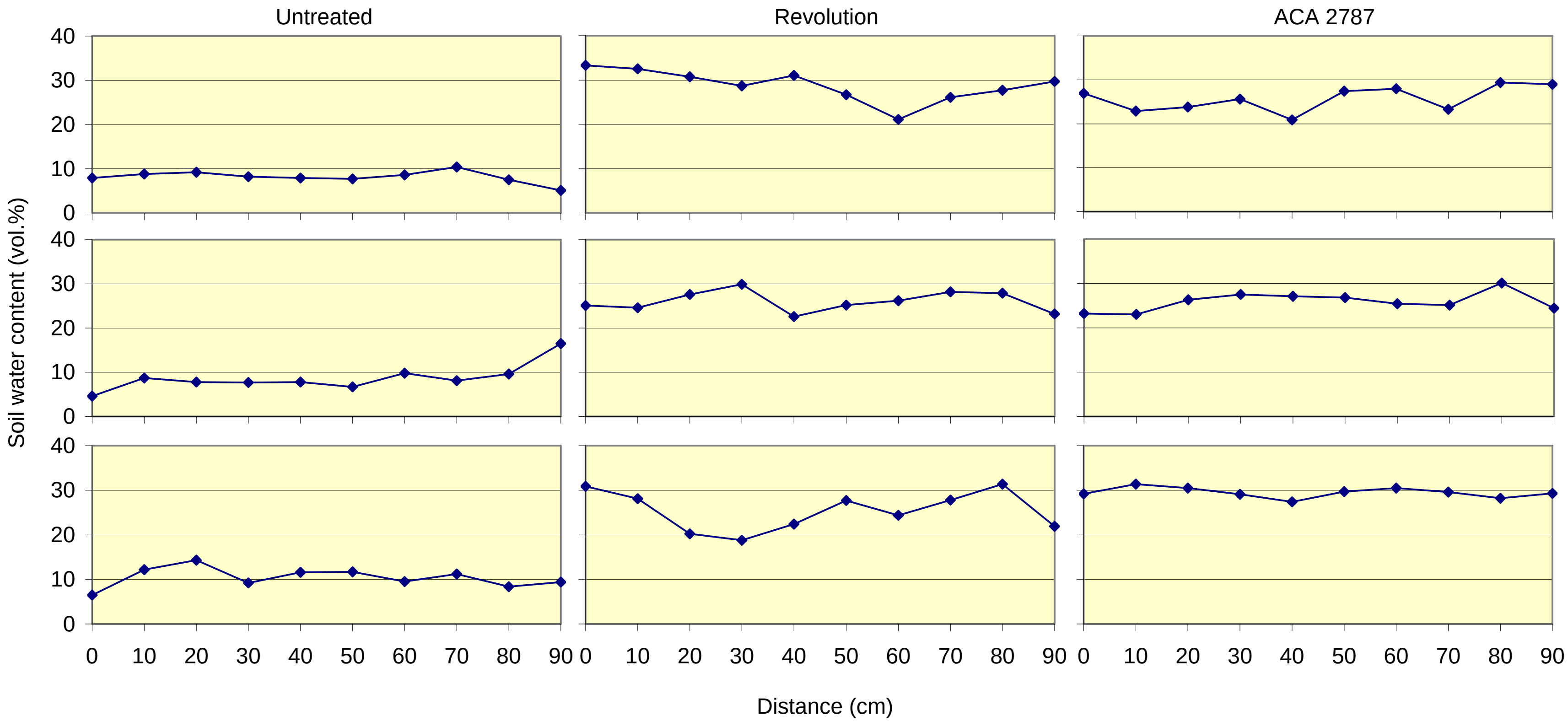

Figure I-i Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 10 September, 2008.

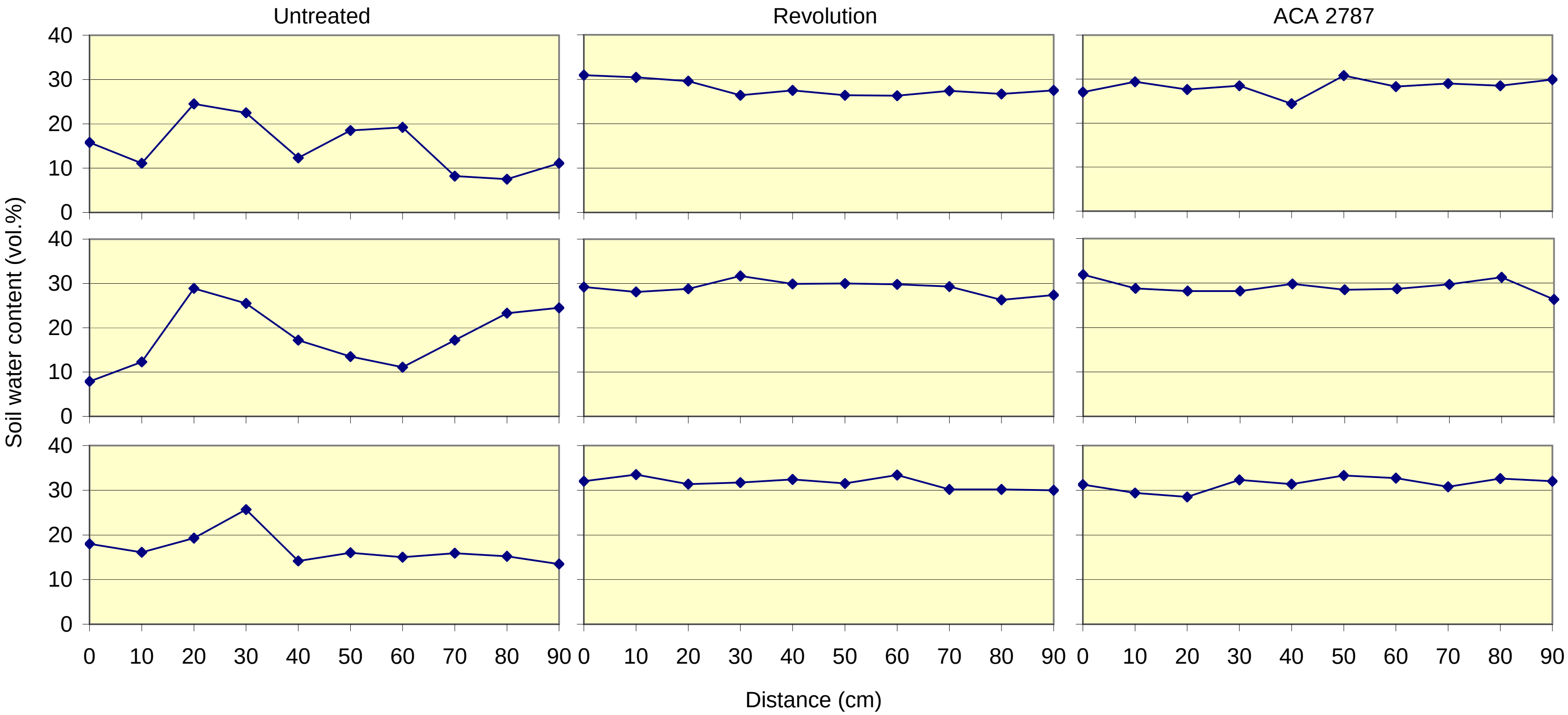

Figure I-J Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 6 October, 2008.

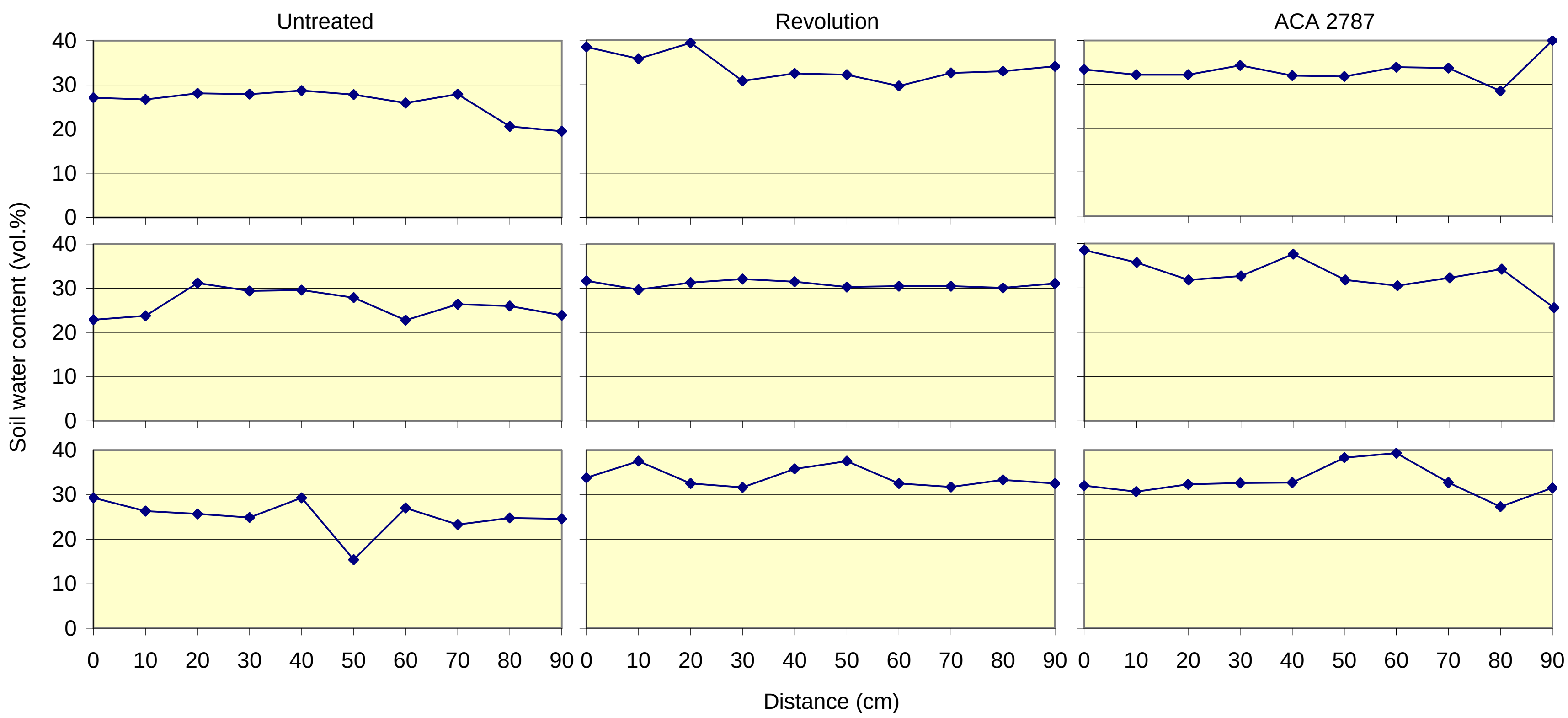

Figure I-K Volumetric soil water contents in the surface layer (0-5 cm) of the untreated and surfactant treated plots of fairway 18, over a distance of 90 cm, at respectively site 1 (upper diagrams), site 2, and site 3 (lower diagrams) on 17 November, 2008.