United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Paper
PNW-RP-568
August 2006

Effects of Vegetation Control and Organic Matter Removal on Soil Water Content in a Young Douglas-Fir Plantation

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Cover Photos (clockwise from top left): Total-tree harvest plus removal of woody material with vegetation control; bole-only harvest with vegetation control; bole-only harvest without vegetation control; PR1 Profile Probe® partially inserted into a soil access tube.

Abstract

Devine, Warren D.; Harrington, Constance A. 2006. Effects of vegetation control and organic matter removal on soil water content in a young Douglas-fir plantation. Res. Pap. PNW-RP-568. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

We evaluated the effects of vegetation control and organic matter (OM) removal on soil water content (SWC) in a Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation from age 3 through age 5. Treatments were presence versus absence of vegetation control through year 5 and bole-only harvest of the previous stand versus total-tree harvest of the previous stand including removal of all coarse woody residues. In the presence of vegetation control, SWC was approximately 0.02 to 0.04 $m^3 \cdot m^{-3}$ greater between depths of 10 and 60 cm; the effect was greatest from July to September. Soil water content was negatively correlated with percentage cover of competing vegetation and positively correlated with tree diameter growth across all treatments. Soil water content at depths between 10 and 100 cm did not differ between OM removal treatments. Accurate measurement of SWC required a soil-specific instrument calibration. On this highly productive site with high annual precipitation, SWC was greater through plantation age 5 when competing vegetation was controlled.

Keywords: Soil water, vegetation control, organic matter, harvest residue, Douglas-fir, *Pseudotsuga menziesii*, Andisol, soil water measurement, instrument calibration.

Summary

Soil water content (SWC) in a forest stand is influenced by silvicultural treatments that affect the rates of plant transpiration and evaporation from the soil surface. We evaluated the effects of vegetation control and organic matter (OM) removal on SWC in a Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation from age 3 through 5. The study area was a highly productive site in the Coast Range of southwestern Washington, USA, with mean annual precipitation of 2260 mm. Soil was a Typic Fluvudand, formed in basalt residuum with andic influence in surface horizons. Treatments were presence versus absence of vegetation control through year 5 and bole-only harvest of the previous stand versus total-tree harvest of the previous stand including removal of all coarse woody residues. Growing-season volumetric SWC was measured on 24 plots at 3- to 4-week intervals at soil depths of 10, 20, 30, 40, 60, and 100 cm with a PR1 Profile Probe® soil water probe (Delta-T Devices, Ltd.). Soil properties necessitated a soil-specific calibration, which differed greatly from the instrument's standard calibration.

Soil water content increased with soil depth in all treatments (mean July SWC at 10 and 100 cm was 0.31 and 0.47 $m^3 \cdot m^{-3}$, respectively); within-treatment variability decreased with depth. The OM removal treatment did not influence SWC at depths between 10 and 100 cm. Soil water content was approximately 0.02 to 0.04 $m^3 \cdot m^{-3}$ greater between depths of 10 and 60 cm when competing vegetation was controlled. This effect was greatest from July to September during growing seasons 3 and 4. The effect of vegetation control on SWC was less in year 5 when water utilization by trees appeared to have increased relative to earlier years. Estimated soil water potential in August of years 3 and 4 was significantly lower without vegetation control (-348 to -262 kPa) than with vegetation control (-126 to -60 kPa) at depths of 30 and 40 cm. Soil water content was negatively correlated with percentage cover of competing vegetation and positively correlated with tree diameter growth across all treatments. On this highly productive site with high annual precipitation, SWC was greater through plantation age 5 when competing vegetation was controlled. Management of OM on similar sites should be based on factors other than its effects on soil water.

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Introduction

Water is transferred from the soil profile to the atmosphere via plant transpiration and evaporation from the soil surface. Under a forest canopy, plant transpiration is the dominant of these two processes (Blanken 1997, Tsujimura and Tanaka 1999, Wilson et al. 2001), but prior to canopy closure, both processes may be important. Silvicultural practices that affect evapotranspiration rates subsequently influence the amount of plant-available soil water. Site preparation practices such as chemical or mechanical removal of competing vegetation reduce soil water loss, thus increasing the amount of water available to plantation trees (Flint and Childs 1987, Nambiar and Sands 1993, Powers and Reynolds 1999). Management of organic matter (OM) in the form of logging residues or legacy logs prior to regeneration can also increase soil water availability. When residue is distributed over the soil surface, it creates a vapor barrier between the soil and the atmosphere. Although this barrier may intercept some precipitation, it also may reduce soil temperature and evaporative water loss (Powers 2002, Troncoso 1997). Reducing soil water loss may alleviate water stress among young trees, and thus, prevent associated reductions in photosynthesis and growth (Brix 1979, Cienciala et al. 1994, Pabst et al. 1990, Petersen et al. 1988).

In young forest stands where sunlight is abundant and soil water is growth-limiting (Drever and Lertzman 2001), control of competing vegetation may lead to greater soil water availability for trees, increasing stomatal conductance and transpiration rates (Fleming et al. 1996). Control of competing vegetation in 3- to 10-year-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands resulted in reduced water stress and increased growth of trees (Pabst et al. 1990, Petersen et al. 1988). Similarly, summer water stress has been reduced by vegetation control in other species including loblolly pine (*Pinus taeda* L.) (Morris et al. 1993), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) (Petersen and Maxwell 1987), and radiata pine (*Pinus radiata* D. Don) (Sands and Nambiar 1984).

Although many options exist for managing logging residue after harvest, leaving the residue dispersed on site may improve nutrient retention (Aber et al. 1978), and, in some cases, result in higher soil water content (SWC). Few data on the latter subject are available from the Pacific Northwest, but retention of logging slash significantly increased the summer SWC of a sandy soil in California (Troncoso 1997). In Australian *Eucalyptus globulus* (Labill.) plantations on sandy and red earth soils, retention of harvest residue onsite resulted in greater soil water for 5 years relative to removal of residue (O'Connell et al. 2004). Other studies, however, showed no differences in SWC after conventional and whole-tree harvest treatments (Hendrickson et al. 1985, Piatek and Allen 1999).

We examined the influences of vegetation control and OM removal on SWC in a young Douglas-fir plantation on a highly productive site in southwestern Washington, USA. A previous study on the same site (Roberts et al. 2005) examined plot-level treatment effects on SWC, soil temperature, nitrogen (N) availability, and tree growth through age 3. Because trees were relatively small, the study measured SWC at a depth of 0 to 20 cm. Roberts et al. (2005) found that both vegetation control and retention of OM positively influenced SWC during the second and third growing seasons after stand establishment. In the present study, our primary objective was to evaluate the effects of vegetation control and OM removal on SWC at six depths from 10 to 100 cm during growing seasons 3 through 5. Secondary objectives were to assess relationships between SWC, cover of competing vegetation, and annual growth of young Douglas-fir on a microsite basis.

Materials and Methods

Study Site

The study is located in Pacific County, in the Coast Range of southwestern Washington (46° 43’ N; 123° 24’ W). The site is gently sloping (10 percent) with a westerly aspect; elevation is 300 m above mean sea level. Mean annual temperature is 9.2 °C; mean minimum temperature in January is -0.1 °C, and mean maximum temperature in August is 23.1 °C (USDA, NWCC, and OSU 2006). Mean annual precipitation is 2260 mm, but an average of only 241 mm occurs from 1 June through 30 September (USDA, NWCC, and OSU 2006). Total precipitation measured on site from 1 June to 30 September was 112, 120, and 322 mm in 2002, 2003, and 2004, respectively (fig. 1). The soil, formed in basalt, is a medial over clayey, ferrihydritic over parasesquic, mesic Typic Fulvudand of the Boistfort series, with a silt loam A horizon (0 to 16 cm) underlain by a silt loam AB horizon (16 to 45 cm), both with andic influence. Beneath these layers are silty clay loam Bw1 (45 to 88 cm) and Bw2 (88 to 140+ cm) horizons. The soil is well drained and low in bulk density (0.59, 0.72, 0.99, and 1.14 $g \cdot cm^{-3}$ in the A, AB, Bw1, and Bw2 horizons, respectively). At four locations across the study site, 68-cm^3 soil samples were collected from each soil horizon to develop a soil water retention curve. Soil water content at saturation and at tensions of 6, 10, 80, 200, and 1500 kPa was determined for each sample at the Oregon State University Soil Science Physical Characterization Laboratory, Corvallis (fig. 2).

The study site was formerly occupied by an old-growth conifer stand that was clearcut in 1952–53. After a broadcast burn in 1953, the site was planted with Douglas-fir seedlings. The stand, consisting of planted Douglas-fir and naturally

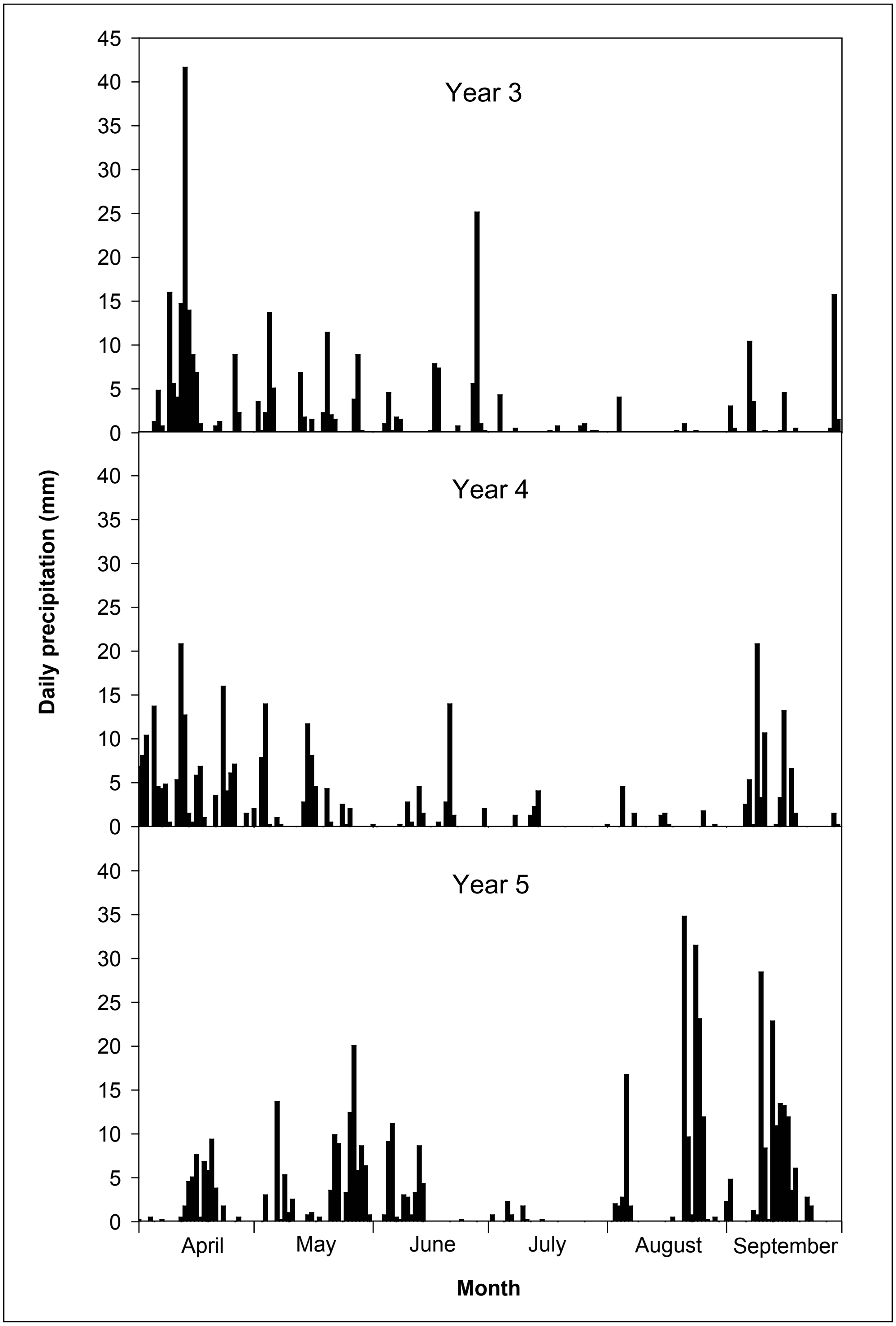

Figure 1—Daily precipitation (mm) for 1 April through 30 September at the Fall River Long-Term Site Productivity study, Washington, in years 3 through 5 (2002, 2003, and 2004).

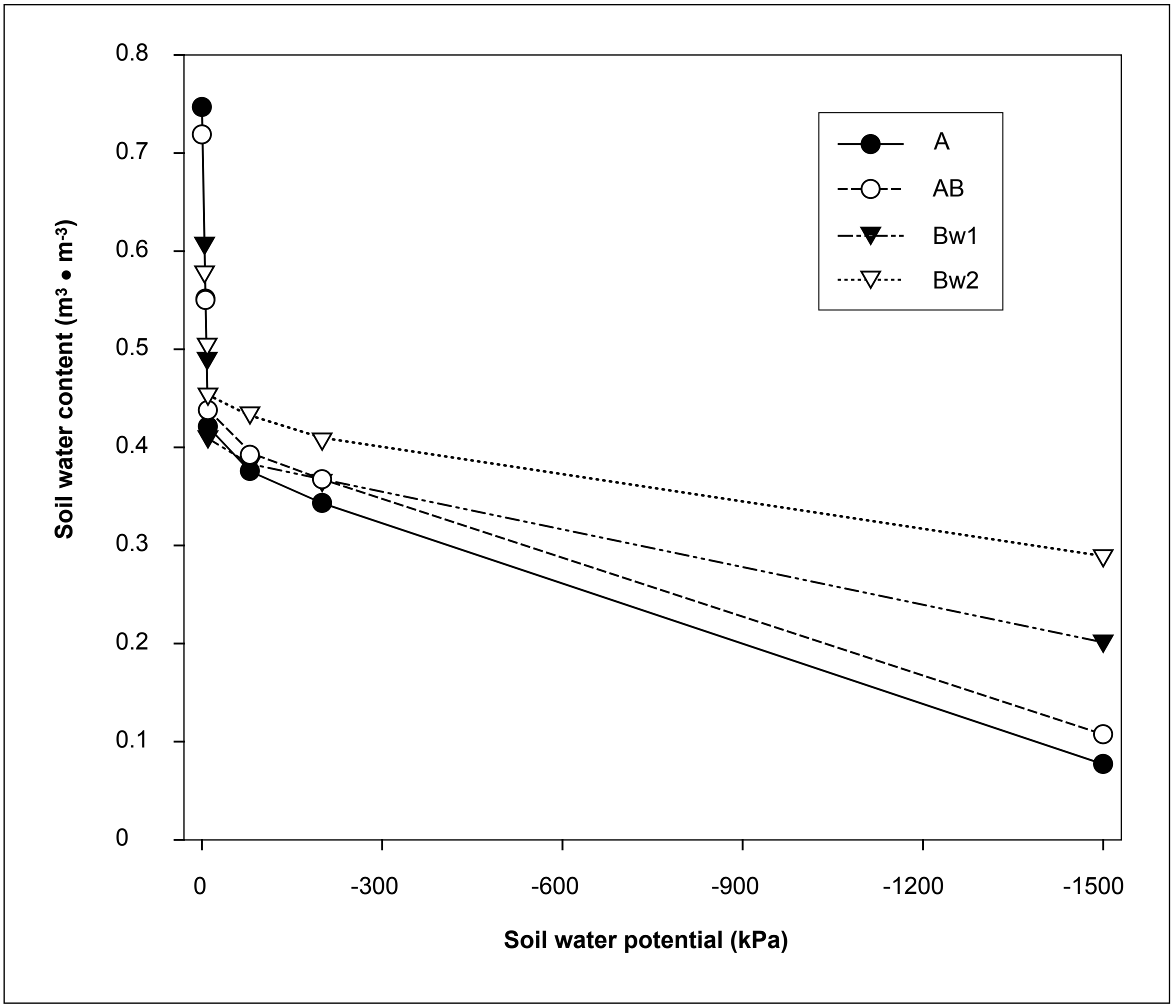

Figure 2—Soil water retention curves for four soil horizons at the Fall River Long-Term Site Productivity study, Washington.

regenerated western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), was thinned in 1971. At the time of harvest in April-July 1999, stand basal area was 69 $m^2 \cdot ha^{-1}$ (Terry et al. 2001). Douglas-fir site index at age 50 is 41 to 43 m (King 1966).

The study area is within the western hemlock vegetation zone (Franklin and Dyrness 1973). Prior to the study, the plant association was identified as *Tsuga heterophylla* (Raf.) Sarg./*Polystichum munitum* (Kaulfuss) K. Presl-*Oxalis oregana* Nutt. (Franklin and Dyrness 1973). In 2004, the most prevalent vascular plant species in the young plantation were common velvetgrass (*Holcus lanatus* L.), fireweed (*Epilobium angustifolium* L.), hairy cat's-ear (*Hypochaeris radicata* L.), western pearly everlasting (*Anaphalis margaritacea* (L.) Benth.), and California blackberry (*Rubus ursinus* Cham. & Schlecht.).

Design and Treatments

This study is part of the Fall River Long-Term Site Productivity study (LTSP), which examines the effects of silvicultural treatments on soil resources and processes and on planted Douglas-fir growth. The LTSP study was installed in 1999 following harvest of the previous stand. The study follows a randomized block design including 12 treatment combinations of OM removal, vegetation control, fertilization, soil compaction, and soil tillage. Some of the treatments are more intensive than operational treatments because the study was designed to isolate treatment effects to determine their influences on site productivity. The present study uses 3 of the 12 treatment combinations:

1. Bole-only harvest without vegetation control (BO - VC). Merchantable stems to a diameter of approximately 10 cm were removed, and logging slash was scattered on site. No herbicide was applied.
2. Bole-only harvest with vegetation control (BO + VC). Merchantable stems to a diameter of approximately 10 cm were removed, and logging slash was scattered on site. Competing vegetation was treated with herbicides during each of the first 5 years of the study (2000–2004). Two weeks before planting, Oust® (DuPont Crop Protection)[1] and Accord Concentrate® (Dow AgroSciences LLC) were broadcast by using backpack sprayers. In years 2 and 3, Atrazine® (Syngenta Crop Protection) and Oust® were broadcast in March and followed in April and May by spot application of Accord Concentrate® or Transline® (Dow AgroSciences LLC). In years 4 and 5, a directed band of Velpar® (DuPont Crop Protection) was applied between rows and followed by spot application of Transline® and Accord Concentrate® during April to June.
3. Total-tree harvest plus removal of legacy coarse woody material, with vegetation control (TTP + VC). Entire trees, including needles and limbs plus all remaining dead limbs > 0.6 cm diameter, old-growth logs, and intact decaying wood were removed from the site. Competing vegetation was treated with herbicides as in treatment 2.

Each of the three treatments was applied to two plots (each 30 by 85 m) within each of four blocks (see Terry et al. [2001] for additional treatment information). In March 2000, all plots were planted with 1 + 1 Douglas-fir seedlings at 2.5- by 2.5-m spacing, and the entire study area was fenced to eliminate potential deer and elk damage to seedlings.

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Data Collection

We measured SWC at 3- to 4-week intervals between May and October in years 3, 4, and 5 following study establishment (2002 to 2004) by using a 100-cm Profile Probe® type PR1 soil water probe with an HH2 moisture meter (Delta-T Devices, Ltd.). The probe has six capacitance sensors, mounted at 10-, 20-, 30-, 40-, 60-, and 100-cm positions, that simultaneously take readings at these soil depths. Data collected with the Profile Probe were recorded in volts and subsequently converted to SWC by using a soil-specific calibration (app. A). Several times during the course of the study, we tested the six probe sensors on reference soil samples of known SWC to verify that all six sensors were functioning similarly (app. B).

Prior to using the Profile Probe, 100-cm fiberglass access tubes were installed vertically in the soil profile to allow insertion of the probe. In April of year 3, we installed an access tube near the center of each study plot (3 treatments x 2 replications x 4 blocks = 24 plots), equidistant from four nearest trees. In December of year 4, we installed a second tube in each plot, approximately 5 to 6 meters from the first but also equidistant from four nearest trees. At each measurement, we made three readings, rotating the probe 120° between each reading. Readings were not taken less than 48 hr after rain events greater than 10 mm.

We surveyed vegetative cover in the vicinity of each access tube on 10 July 2002, 21 August 2003, and 28 July 2004. We visually estimated percentage cover of herbaceous and woody vegetation on circular plots (radius = 1.0 m) centered on each access tube. Cover estimates between 10 and 90 percent were in 5-percent categories, and estimates above and below this range were in 1-percent categories. After each growing season from year 3 to year 5, we measured diameter (at a height of 0.15 m after years 2 and 3; at breast height [d.b.h.; 1.30 m] after years 3 through 5) of the four trees closest to each access tube (n = 96 in years 2 and 3; n = 192 in years 4 and 5). We used these data to relate annual tree growth increment to SWC on a microsite basis.

Data Analysis

For each growing season, we normalized SWC based on the SWC value at each sensor location at the beginning of the growing season. The resulting value (SWC at a given date subtracted from the first value of the season) was the relative SWC (RSWC; $m^3 \bullet m^{-3}$), or the change since the beginning of that growing season. A preliminary analysis of true SWC revealed the same significant results as the RSWC analysis; however, trends in RSWC data are better defined owing to removal of initial variation among sensor locations. Treatment effects on RSWC may be slightly underestimated because they are normalized on initial readings from early May of each year, and thus, any treatment effect on SWC already present in early May is excluded. Analyses of year 5 data were performed both with and without data from the additional 24 access tubes installed prior to that year; treatment means were similar for both analyses, and data presented here are from all access tubes.

Within each year, RSWC was analyzed by using repeated measures analysis of variance (ANOVA) (Proc Mixed; SAS Institute, Inc. 2005). The effects of vegetation control (BO - VC vs. BO + VC and TTP + VC) and OM removal (BO + VC vs. TTP + VC) were tested by using orthogonal contrasts. We also used ANOVA to analyze treatment effects on estimated late-growing-season soil water potential. We estimated soil water potential at each sensor depth by using the laboratory soil water retention data for the soil horizon at that depth, with linear interpolation between data points on the soil water retention curve. We made protected, post-ANOVA mean separations by using Fisher's Least Significant Difference test.

We used correlation analysis to examine relationships between SWC and percentage cover of vegetation around each access tube (Proc Corr; SAS Institute, Inc. 2005). To assess relationships between SWC and annual tree diameter growth increment, we correlated SWC at specified dates at individual tube locations with the current year's average growth increment of the four nearest trees. An alpha value of 0.05 was used to determine significance in all analyses.

Results

Soil Water Content by Depth

Soil water content increased consistently with increasing soil depth. Average SWC across all treatments and years in mid- to late-July was 0.31, 0.35, 0.38, 0.39, 0.43, and 0.47 $m^3 \cdot m^{-3}$ for soil depths of 10, 20, 30, 40, 60, and 100 cm, respectively. Variation in SWC within treatment decreased with increasing soil depth. In April of year 5 (prior to treatment effects associated with summer water depletion) within-treatment coefficients of variation (CV) for soil depths from 10 to 30 cm averaged 35 percent. At 40, 60, and 100 cm, average CVs were 26, 14, and 4 percent, respectively. Within each sample depth, the amount of variation in SWC among sample locations was similar for the three treatments and the four experimental blocks.

Treatment Effects

In year 3, vegetation control resulted in significantly greater RSWC at all soil depths, although the magnitude of the effect was much less at 100 cm than at other depths (fig. 3). This treatment effect was greatest from July through the final measurement of the year on 17 October. In year 4, vegetation control resulted in

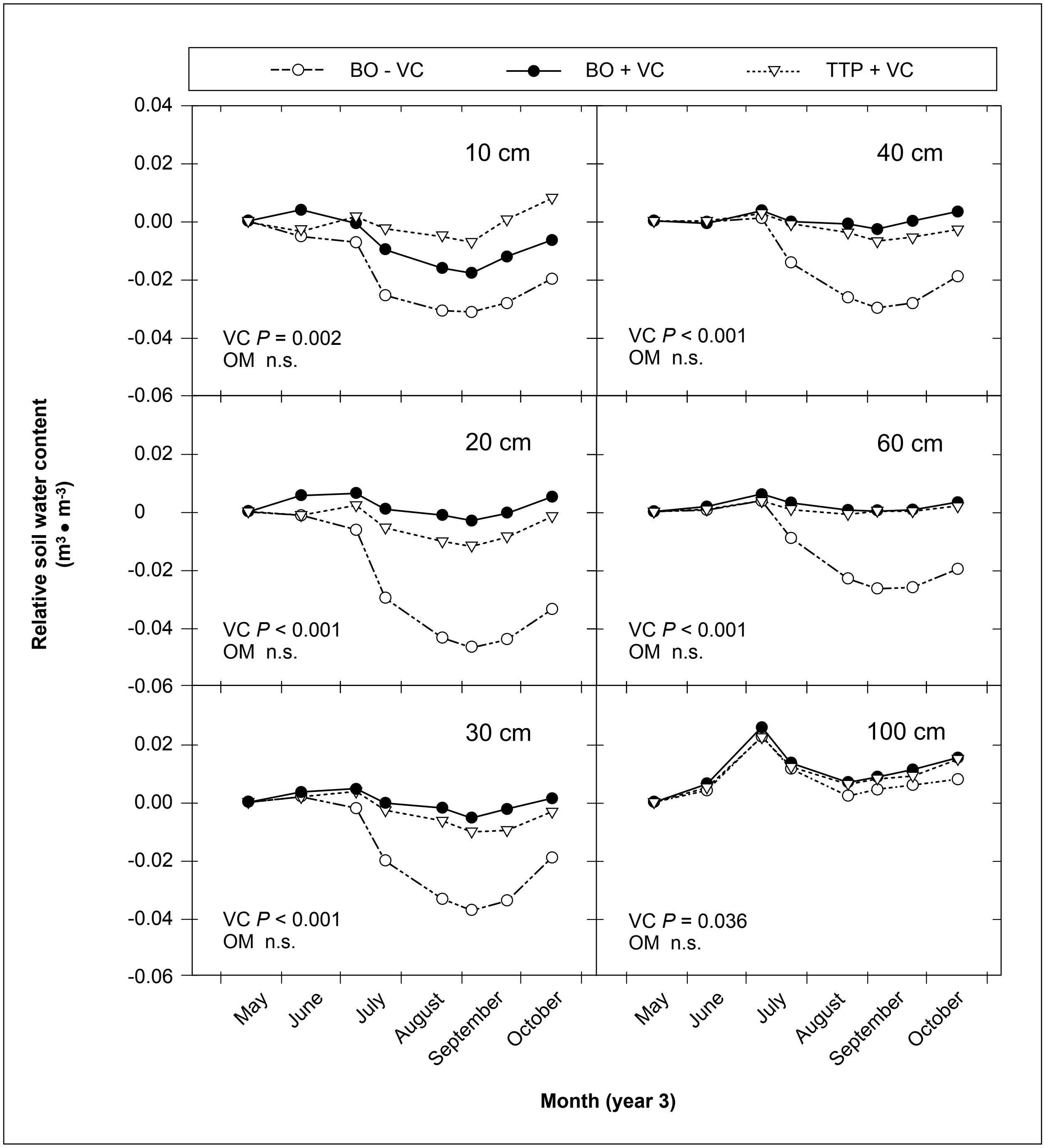

Figure 3—Relative soil water content under vegetation control (VC) and organic matter removal (OM) treatments, measured at six soil depths, during year 3 (2002). Significance of contrasts for vegetation control (bole only without vegetation control [BO – VC] vs. bole only with vegetation control [BO + VC] and total tree “plus” with vegetation control [TTP + VC]) and for organic matter removal (BO + VC vs. TTP + VC) are shown.

significantly greater RSWC at soil depths from 10 to 60 cm (fig. 4); effects were greatest from July through early September. In year 5, RSWC at soil depths of 40 and 60 cm was significantly greater under vegetation control (fig. 5). The effect of OM removal (BO + VC vs. TTP + VC) on RSWC was not significant except at the 100 cm depth in year 4. True SWC values ($m^3 \bullet m^{-3}$) appear in appendix 3.

Over the course of the study, treatments with vegetation control showed a progressively greater decline in late summer RSWC each year. This effectively reduced the magnitude of the vegetation control treatment effect in year 4 and again, to a greater extent, in year 5. In year 3, RSWC in the BO + VC and TTP + VC treatments remained relatively constant throughout the growing season; however, in year 5 the same treatments showed obvious depletions in RSWC in midsummer.

Estimated soil water potential differed significantly among treatments in late summer at depths of 30 and 40 cm, with the BO - VC treatment more negative than the treatments with vegetation control (fig. 6). At 10- and 20-cm soil depths, there was a nonsignificant trend in which the BO - VC treatment had more negative water potentials than the other treatments.

Relationships Between SWC, Vegetation, and Tree Growth

Vegetation control resulted in a dramatic reduction in vegetative cover. Treatments that included vegetation control averaged less than 10 percent vegetative cover, whereas those without vegetation control averaged greater than 80 percent vegetative cover (table 1). Late summer SWC was significantly and negatively correlated with vegetative cover in all 3 years of the study (table 2). The strengths of the correlations were similar for herbaceous or herbaceous plus woody vegetation. In years 3 and 4, correlations between vegetative cover and SWC were significant at soil depths of 10 through 60 cm. In year 5, significant correlations occurred primarily at soil depths of 40 and 60 cm.

Annual tree diameter-growth increment (mean of the four trees closest to each access tube) was significantly correlated with SWC at 40- and 60-cm depths in summer of year 3 (mean $r = 0.46$ for SWC measurements in August and September) and at 30-, 40-, and 60-cm depths in year 4 (mean $r = 0.60$ for SWC measurements in August and September). For example, year 4 d.b.h. growth increment was significantly correlated ($r = 0.66$; $P < 0.001$) with SWC on 21 August 2003 at a soil depth of 30 cm (fig. 7).

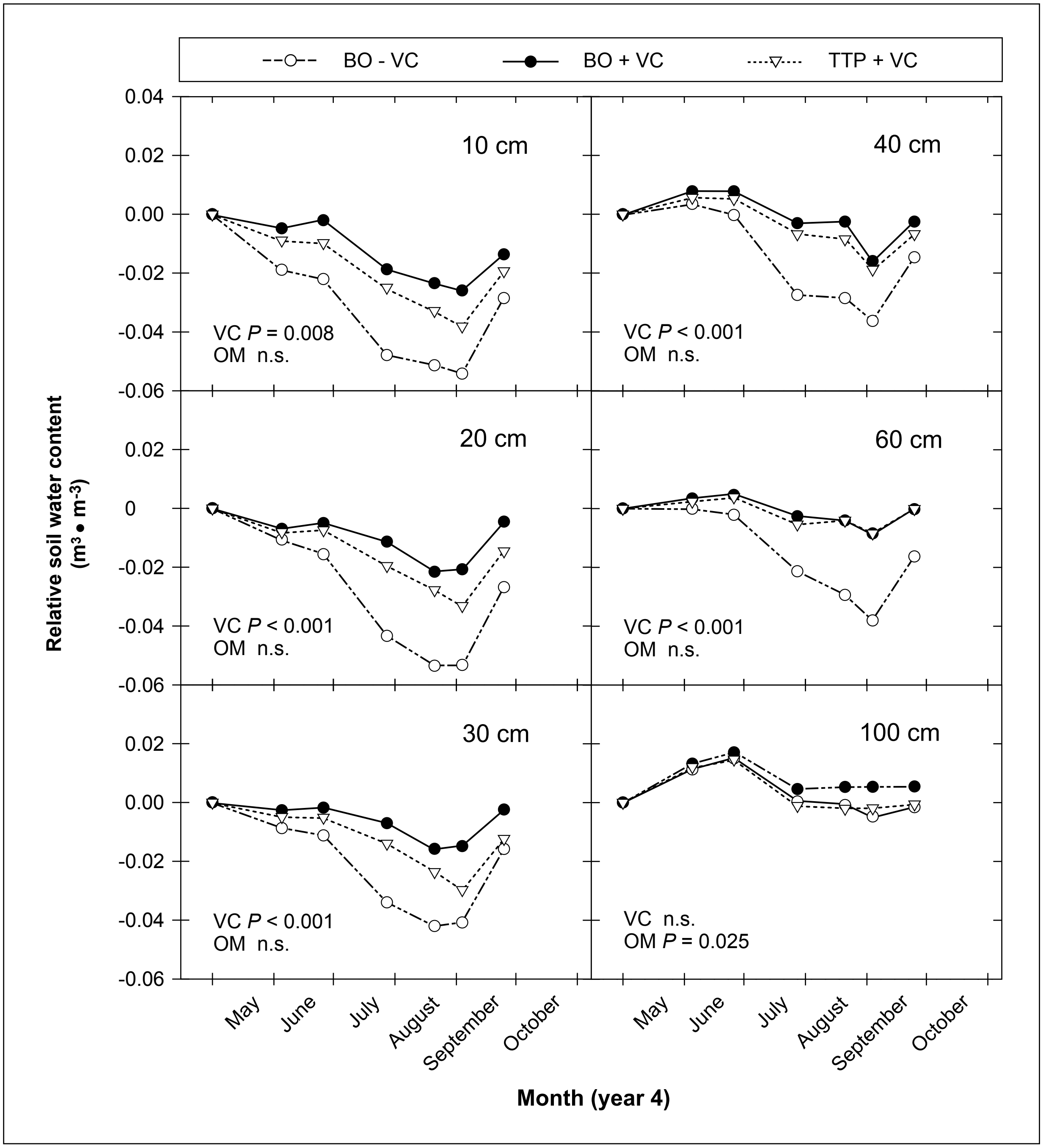

Figure 4—Relative soil water content under vegetation control (VC) and organic matter removal (OM) treatments, measured at six soil depths, during year 4 (2003). Significance of contrasts for vegetation control (bole only without vegetation control [BO – VC] vs. bole only with vegetation control [BO + VC] and total tree "plus" with vegetation control [TTP + VC]) and for organic matter removal (BO + VC vs. TTP + VC) are shown.

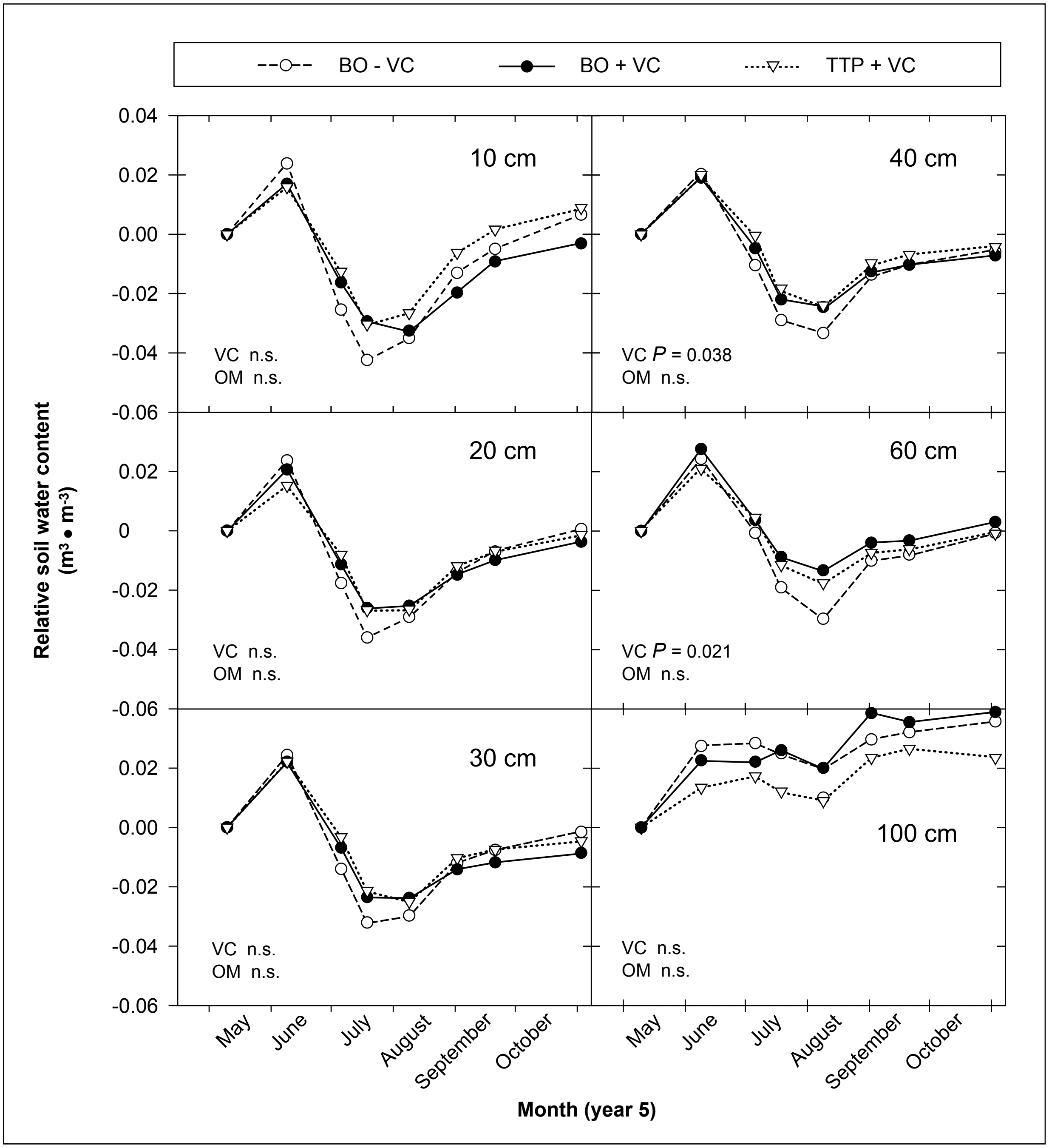

Figure 5—Relative soil water content under vegetation control (VC) and organic matter removal (OM) treatments, measured at six soil depths, during year 5 (2004). Significance of contrasts for vegetation control (bole only without vegetation control [BO – VC] vs. bole only with vegetation control [BO + VC] and total tree "plus" with vegetation control [TTP + VC]) and for organic matter removal (BO + VC vs. TTP + VC) are shown.

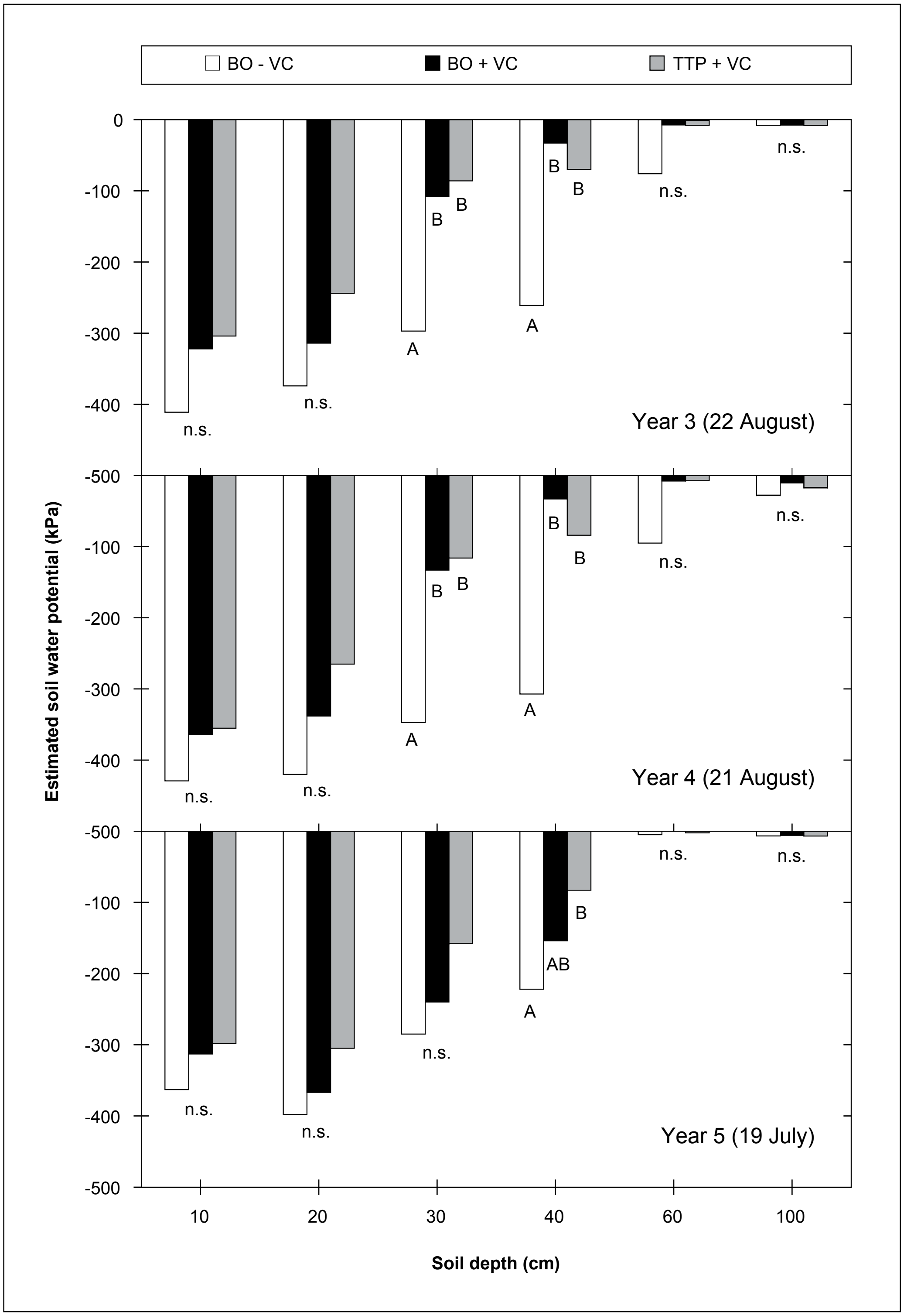

Figure 6—Estimated soil water potential (kPa) in late summer (22 August 2002, 21 August 2003, and 19 July 2004, years 3, 4, and 5) under vegetation control and organic matter removal treatments. The earlier date for year 5 is because of early August rain that year. Same letter denotes no significant difference ($P \geq 0.05$) within year and depth.

Table 1—Mean coverage (and standard deviation) of herbaceous and woody vegetation present on circular plots (radius = 1.0 m) centered on each access tube in three treatments (*n* = 8 in years 3 and 4; *n* = 16 in year 5)

		Treatment					
Year	Cover type	BO - VC		BO + VC		TTP + VC	
				Percent			
3	Herbaceous	83.8	(10.5)	1.4	(1.8)	15.6	(21.8)
	Herbaceous and woody	90.3	(21.9)	1.6	(2.1)	16.1	(21.7)
4	Herbaceous	85.8	(27.9)	4.3	(8.4)	2.4	(2.9)
	Herbaceous and woody	95.8	(38.8)	4.3	(8.4)	3.0	(3.3)
5	Herbaceous	95.5	(5.1)	4.6	(4.9)	5.0	(6.9)
	Herbaceous and woody	107.1	(16.7)	4.6	(4.9)	5.4	(7.1)

BO – VC = Bole-only harvest without vegetation control.
BO + VC = Bole-only harvest with vegetation control.
TTP + VC = Total-tree harvest with vegetation control.

Table 2—Significant (*P* < 0.05) correlation coefficients for the relationship between late summer (year 3 = 22 August 2002, year 4 = 21 August 2003, year 5 = 19 July 2004) soil water content at six soil depths and herbaceous and woody vegetation coverage on circular plots (radius = 1.0 m) centered on each access tube (*n* = 24 in years 3 and 4; *n* = 48 in year 5)

		Soil depth (cm)					
Year	Cover type	10	20	30	40	60	100
3	Herbaceous	-0.44	-0.38	-0.68	-0.39	-0.64	--[a]
	Herbaceous and woody	-.48	-.38	-.60	-.63	-.59	--
4	Herbaceous	-.40	-.39	-.59	-.67	-.58	--
	Herbaceous and woody	-.42	-.39	-.52	-.60	-.53	--
5	Herbaceous	--	--	--	-.38	-.47	--
	Herbaceous and woody	-.30	--	--	-.35	-.40	--

[a]Cells with no value had correlation coefficients that were not statistically significant.

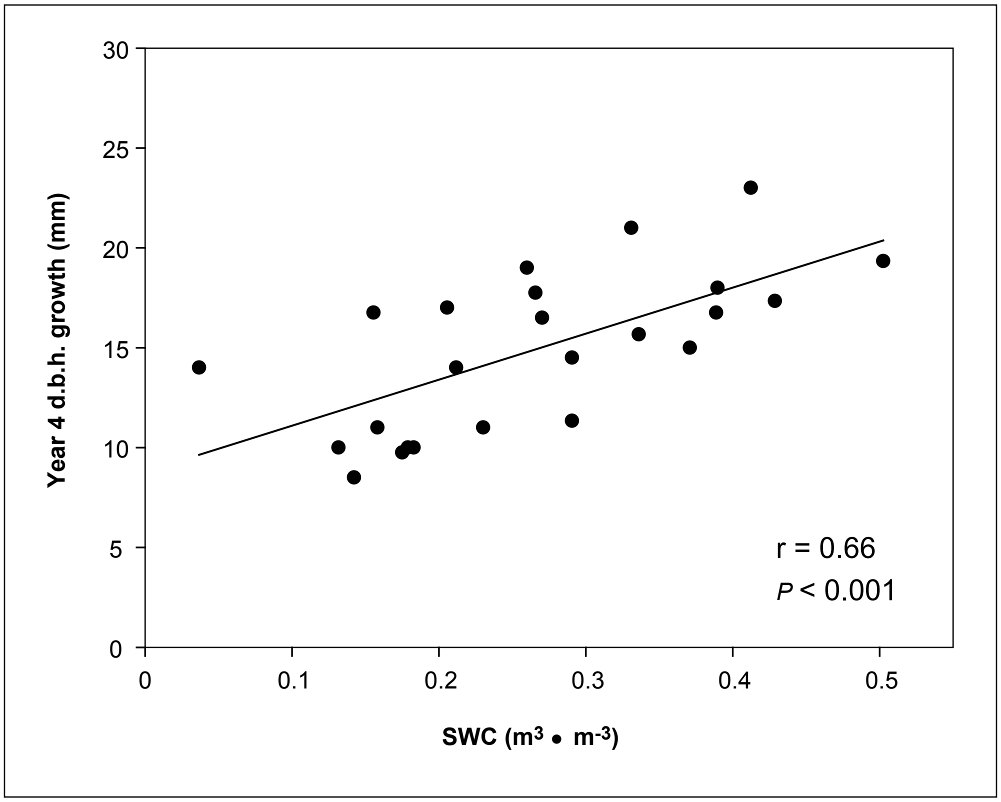

Figure 7—Relationship between year 4 diameter at breast height (d.b.h.) growth increment and soil water content (SWC) on 21 August at a soil depth of 30 cm. Each point represents SWC at one access tube and mean year-4 d.b.h. growth of four nearest trees.

Discussion

Vegetation control resulted in greater SWC during the third, fourth, and fifth growing seasons, although the magnitude of the treatment effect was less pronounced in year 5. This decreased treatment effect in year 5 may have been a result of increased utilization of water by trees relative to competing vegetation as trees became increasingly dominant on the site. In year 3, the summer decrease in RSWC without vegetation control (BO - VC) was likely due primarily to water utilization of competing vegetation, as RSWC remained relatively constant in treatments where trees were the primary form of vegetation (BO + VC and TTP + VC). In year 5, RSWC in treatments with vegetation control declined sharply in summer, closely paralleling the trend of the BO - VC treatment. Thus, the substantial increase in tree size from years 3 to 5 (mean height increased from 150 to 340 cm) was apparently accompanied by an increased influence of trees on soil water. The gross decline in RSWC in the BO - VC treatment in year 5 was somewhat greater than that of the treatments with vegetation control, but transpiration by trees in the BO - VC treatment was probably less than that of trees in the other treatments because they were, on average, smaller, and transpiration by competing vegetation was likely a substantial component of total transpiration in this treatment. In addition to the treatment effects, RSWC in year 5 was influenced by greater total precipitation from June through September (188 and 168 percent greater than in years 3 and 4, respectively). The increased year-5 precipitation is evident in all treatments in the early June RSWC spike and in higher September RSWC values relative to previous years.

Although the effect of vegetation control on estimated soil water potential was not statistically significant at 10- and 20-cm depths, treatment effects on RSWC and negative correlations between vegetative cover and SWC at these shallow soil depths indicate, as was shown by Roberts et al. (2005), an influence of vegetation on SWC near the soil surface. Using an intensive sampling protocol (324 to 432 sample points) on the same study site, Roberts et al. (2005) found that SWC was slightly greater with vegetation control in the 0- to 20 cm soil depth interval during years 2 and 3. The increased variability in SWC that we observed near the soil surface compared to greater depths was probably due, in part, to an increased number of decaying tree roots as well as other woody materials, such as tree limbs and fragments of decaying logs, that were embedded in the soil profile across all treatments. During instrument calibration in late summer, we observed that where these woody materials were present in the soil profile close to access tubes, SWC values were lower than where woody debris was not present.

The influence of the mostly herbaceous competing vegetation on SWC extended to a soil depth of at least 60 cm. In a young Douglas-fir plantation in western Oregon, shrub competition reduced SWC to a depth of 100 cm (Petersen et al. 1988), and in a 2-year-old loblolly pine plantation, competing vegetation reduced soil water to an 80-cm depth (Morris et al. 1993). Although the effect on SWC that we observed at 60 cm may indicate that roots of competing vegetation are present at this depth, it is also possible that shallow-rooted herbaceous plants may have intercepted percolating soil water during light growing-season rain events, thus influencing SWC below their rooting zone. Furthermore, a portion of this precipitation was intercepted aboveground by leaves and stems of competing vegetation. Particularly in the treatment without vegetation control, trees probably utilized an increasing amount of water from lower in the soil profile over the course of the growing season after trees and other vegetation had depleted shallow soil water. This transition of water uptake from shallow to deeper soils during the growing season was quantified in a 20-year-old Douglas-fir stand (Nnyamah and Black 1977). In a 50-year-old Douglas-fir stand adjacent to our study site, cumulative growing-season depletion of soil water at depths from 10 though 100 cm was similar in magnitude to that reported in this study (Devine et al. 2005).

In contrast to the results of previous research conducted at the same study site (Roberts et al. 2005), we detected no significant effect of OM removal on SWC. During years 2 and 3 after plantation establishment, SWC from 0 to 20 cm was approximately 0.015 $m^3 \cdot m^{-3}$ greater during the mid-to-late growing season in the BO + VC treatment relative to the TTP + VC treatment (Roberts et al. 2005). The authors concluded that this was caused by shading or mulching effects that reduced evaporation at the soil surface. A possible reason why we did not detect this treatment effect when sampling during the same year as the earlier study (year 3) is that the sensor used in the earlier study measured soil water in the entire 0- to 20-cm interval, including the soil near the surface, which we did not sample and which may have had the greatest evaporative loss. In contrast, our shallowest measurements were taken at a 10-cm soil depth.

Although our soil-specific instrument calibration and the PR1 Profile Probe's generalized mineral soil calibration did not result in different conclusions regarding the significance of treatment effects on SWC, the soil-specific calibration produced a much smaller overall range in SWC values than the generalized calibration. The Profile Probe User Manual states that the accuracy of the generalized calibration is poorest in heavy clay soils, organic soils, or soils that are extreme in any respect (Delta-T Devices, Ltd. 2001). The large difference between our soil-specific calibration and the generalized calibration indicates that soil-specific calibration is vital when using this instrument in soils such as those of our study site (i.e., low bulk density, andic properties). Similar soils are common in the coastal Pacific Northwest. The improved accuracy of soil-specific calibration is necessary for comparing SWC among sites and to values reported elsewhere.

Estimated soil water potentials generally remained above -400 kPa; however, significantly lower late-summer values in the BO - VC treatment (-348 to -262 kPa) versus treatments with vegetation control (-126 to -60 kPa) at 30- and 40-cm depths may have adversely affected tree growth rates. Haase and Rose (1993) reported significantly greater terminal growth of Douglas-fir seedlings at a soil water potential of -10 kPa than at -100 kPa. When SWC was progressively lowered, transpiration rates of 4-year-old Douglas fir began to decline when soil water potential reached -100 to -200 kPa (Lopushinsky and Klock 1974). Meinzer et al. (2004) found a sharp increase in soil water utilization by 24-year-old Douglas-fir when the soil water potential increased from -400 kPa to near zero at the soil depth interval of 20 to 60 cm. Therefore, it is possible that relatively small differences among treatments in volumetric SWC in our study influenced soil water potential sufficiently to affect water utilization by trees.

The negative correlation between competing vegetation cover and SWC suggests that water was depleted by this vegetation, and the positive correlation between tree d.b.h. growth and SWC suggests that tree growth may have been limited by water availability. Many studies have previously shown that growth of young Douglas-fir is increased when soil water availability is increased by control of woody and herbaceous vegetation (Cole and Newton 1986, Flint and Childs 1987, Pabst et al. 1990, Petersen et al. 1988, Rose and Ketchum 2002), although the influence of competing vegetation on SWC and tree growth diminishes over time as trees become larger and more deeply rooted (Nilsson and Örlander 1999, Sands and Nambiar 1984). In addition to soil water, competition for other resources may have influenced tree growth in this study. For example, foliar N concentration for Douglas-fir at the end of year 3 was significantly lower in the absence of vegetation control (Roberts et al. 2005). However, Roberts et al. (2005) concluded that because year-3 foliar N concentration in that treatment (BO - VC) was still within the range of sufficiency at 1.8 percent, reduced tree growth in the same treatment was probably not caused by N deficit, but more likely by competition for soil water. Foliar N concentration remained significantly lower in the BO - VC treatment at the end of year 4, but by the end of year 5, differences in foliar N between treatments were no longer significant.[2] Further study is necessary to separate the relative effects of water and N availability in this system.

Conclusions

Microsite variability in SWC within treatment, particularly in the top 40 cm of the soil profile, was greater than anticipated given the uniform appearance of the study site. By measuring SWC at permanent sample points, we were able to detect treatment differences despite the spatial variability. However, soil-specific calibration was necessary for accurate measurement of SWC with the PR1 Profile Probe.

Removal of OM at the time of harvest did not have a detectable influence on SWC during the 4th and 5th years after plantation establishment, although previous research at this site indicated that the presence of organic residues resulted in slightly greater SWC near the surface in years 2 and 3 (Roberts et al. 2005). Overall, the positive effect of OM retention on SWC was smaller in magnitude and briefer in duration than that of vegetation control. Although our study design did

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[2] Unpublished data and report. On file with: USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3625 93rd Avenue SW, Olympia, WA 98512.

not test the interactive effects of OM presence and vegetation control on soil water, we found no additive effect when the treatments were combined. Thus, on sites similar to Fall River, operational costs, nutrient cycling, wildlife, and long-term productivity are more important factors to consider when deciding how to manage OM than the mulching effect that OM has on soil surface drying.

On this highly productive site with high annual precipitation, control of competing vegetation resulted in greater SWC to a depth of 60 cm, particularly from July to September during years of below-average growing-season precipitation. This depletion of soil water occurred in the rooting zone of the young trees and may have had a negative impact on tree growth, although vegetation also may have negatively affected tree growth through competition for available soil N. Apparent increases in soil water utilization by trees from years 3 to 5 suggest rapid root growth during this interval and an improved ability to compete with vegetation for soil water. Increased tree growth associated with vegetation control treatments will likely result in earlier crown closure, at which point water losses through transpiration of competing vegetation and soil surface evaporation will decline.

Acknowledgments

We thank Thomas Terry, Weyerhaeuser Company, Centralia, Washington, for installing the study and allowing us access for data collection. We also thank Rodney Meade and Adrian Ares of Weyerhaeuser Company and our current and former coworkers at the Olympia Forestry Sciences Laboratory for their assistance, particularly Joseph Kraft, Bryan Wender, Bridget Korman, James Dollins, and Diana Livada. We thank David Peter for providing vegetation data and Douglas Waldren for instrument calibration.

English Equivalents

When you know:	Multiply by:	To find:
Millimeters (mm)	0.0394	Inches
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Square meters per hectare (m^2/ha)	4.37	Square feet per acre
Degrees Celsius (C)	1.8 C + 32	Degrees Fahrenheit
Cubic meters (m^3)	1.308	Cubic yards
Grams per cubic centimeter (g/cm^3)	62.43	Pounds per cubic foot
Kilopascals (kPa)	0.145	Pounds per square inch

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Appendix A: Soil-Specific Calibration for the PR1 Profile Probe

Because soil properties influence readings from the Profile Probe (Delta-T Devices, Ltd. 2001)[1], we performed a soil-specific calibration to convert the recorded data from the Profile Probe (volts direct current) to soil water content (SWC; $m^3 \cdot m^{-3}$). Initial attempts at soil-specific calibration followed the laboratory procedure described by Delta-T Devices, Ltd. (2002). However, we found that this calibration procedure was not suitable for the soils in this study. The procedure resulted in disturbance of the soil structure, which consequently reduced water-holding capacity of the soil samples. Thus, the calibration equation that it produced was not applicable to soil under field conditions.

As an alternative to the laboratory calibration procedure, we performed a calibration based on probe readings and samples collected in the field. We took readings (n = 16) at two to six depths (10 to 100 cm) at six locations across the study site with the Profile Probe. We then collected two 348-cm^3 soil samples adjacent to the probe sensor where each of the readings were taken and dried the samples to constant weight at 105 °C to determine gravimetric and volumetric SWC. The relationship between Profile Probe readings and sample SWC (mean of two soil samples per reading) was the calibration equation that we used to convert volts (V) to SWC ($m^3 \cdot m^{-3}$):

$$SWC = (0.574V) + 0.217$$

The generalized mineral soil calibration that is provided with the Profile Probe is:

$$SWC = -0.113 + (1.62V) - (3.56V^2) + (8.63V^3)$$

Our soil-specific calibration produced SWC values that were higher than those produced by the generalized mineral soil calibration, except in very moist soil where the soil-specific calibration produced lower SWC values (fig. A-1). The SWC values calculated from our calibration equation were consistently within 0.05 $m^3 \cdot m^{-3}$ of values produced by frequency- and time-domain reflectometry sensors at the study site (CS616, CS620, and TDR100 (Campbell Scientific, Inc.)).

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

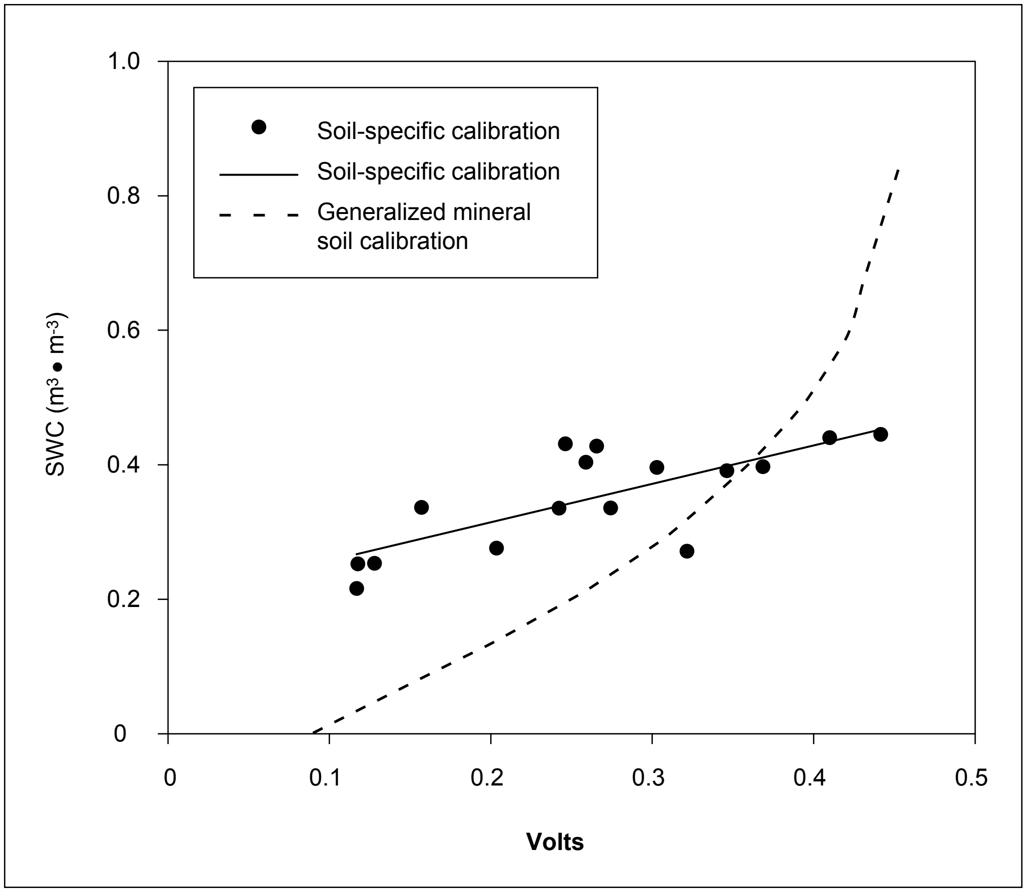

Figure A-1—Soil-specific and generalized mineral soil calibration curves based on equations used to convert output from the Profile Probe type PR1 (volts) to soil water content (SWC; $m^3 \bullet m^{-3}$).

Appendix B: Procedure for Checking Consistency Among the Six Sensors of the PR1 Profile Probe

1. We assembled two soil calibrators following the procedure described by Delta-T Devices, Ltd. (2002).[1 2] A calibrator is a sealed, 10-cm-diameter cylinder containing a soil sample with a known water content. An open-ended tube runs through the cylinder so that the calibrator may slide along the length of the probe, allowing readings from any of the six probe sensors. Our calibrators were filled with soil from the study site and had soil water contents (SWC) of 29 and 53 percent, allowing us to verify sensor consistency at the high and low ends of the SWC range in this study.
2. For each calibrator, we inserted the probe so that the sensor of interest was in the center of the calibrator cylinder.
3. We took three readings with the sensor, rotating the probe 120° between readings. We then averaged the three readings.
4. We repeated steps 2 and 3 for all six sensors on the probe.
5. We compared average readings among the six sensors. If any sensor returned readings that were different from the other sensors, given the instrument's specified level of precision (Delta-T Devices, Ltd. 2001), we returned the probe to the factory for recalibration of sensors.

Twice during our use of the Profile Probe, we found that, when tested on the same calibrator, the sensor at the 100-cm location was reporting readings 0.04 to 0.05 volts higher than the other five sensors on the same probe. This was an indication that the probe required factory recalibration of the sensors. Our Quality Assurance/Quality Control Guidelines require bimonthly checks for consistency among sensors as a part of all research involving this instrument.

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[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

[2]Because this check of sensor consistency was not part of a soil-specific calibration, the problems with the calibrators described in appendix A were not relevant to this procedure.

Appendix C: Soil Water Content at Six Depths in Years 3, 4, and 5

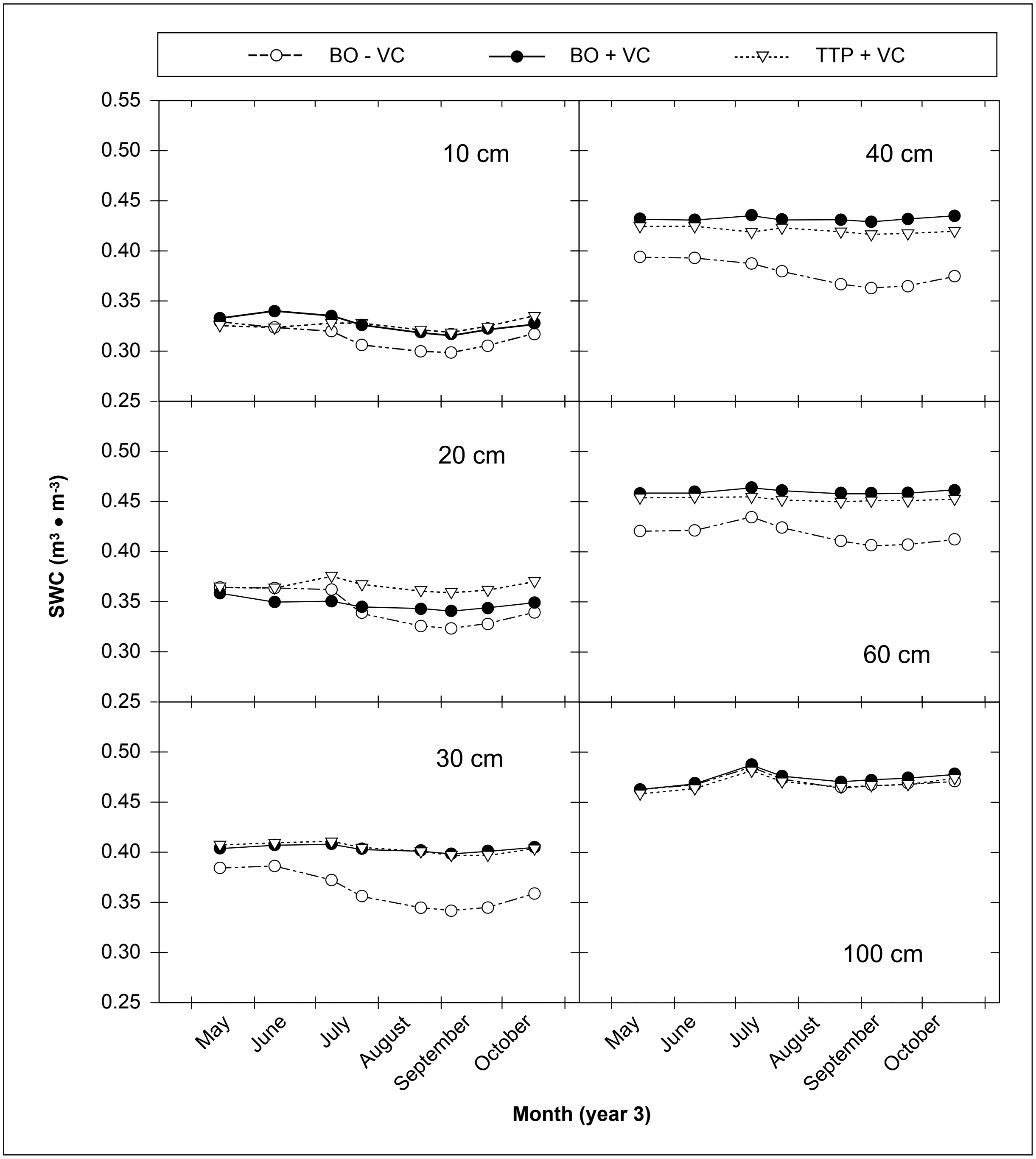

Figure C-1—Soil water content (SWC) under vegetation control and organic matter removal treatments measured at six soil depths, during year 3 (2002).

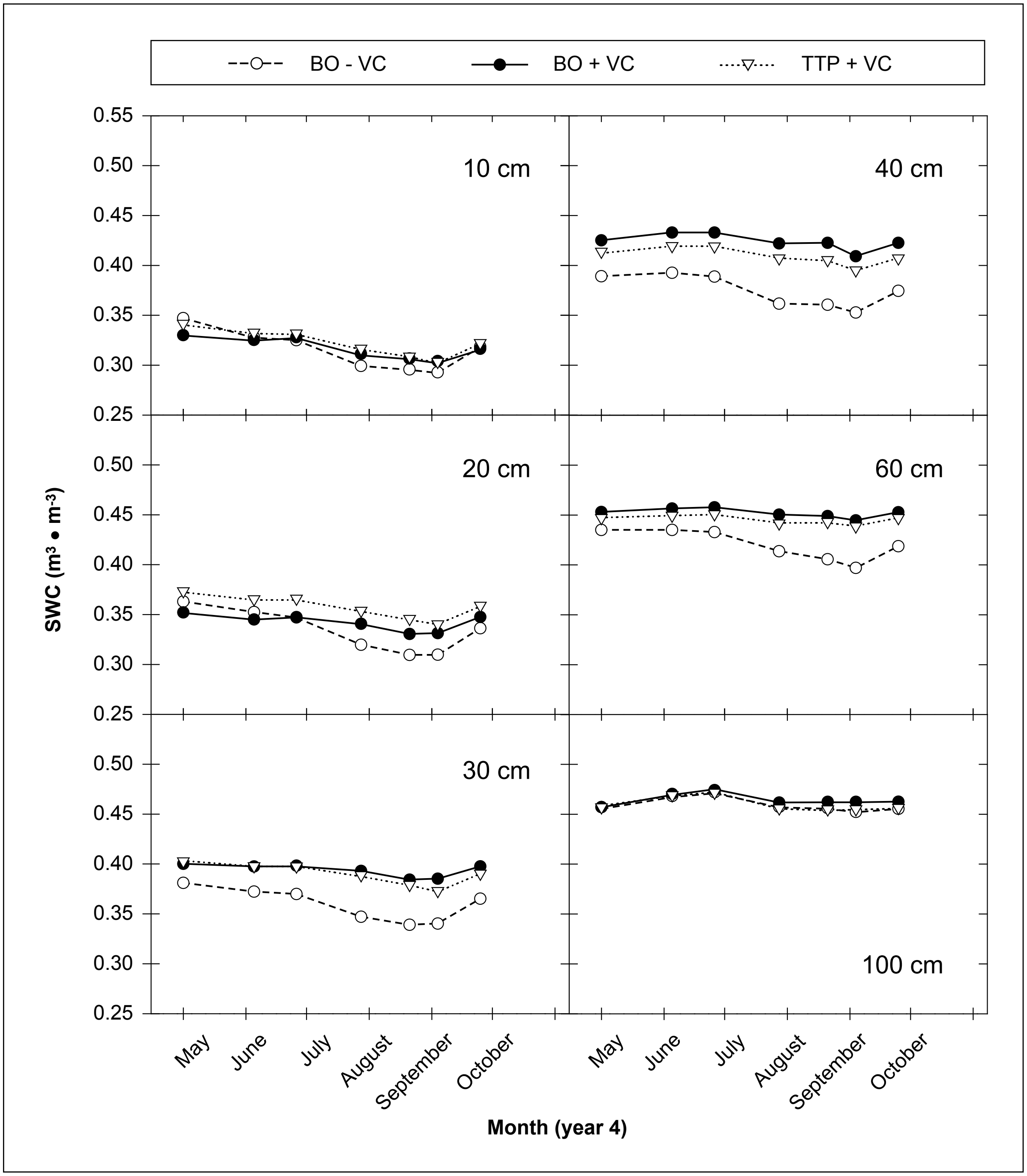

Figure C-2—Soil water content (SWC) under vegetation control and organic matter removal treatments measured at six soil depths, during year 4 (2003).

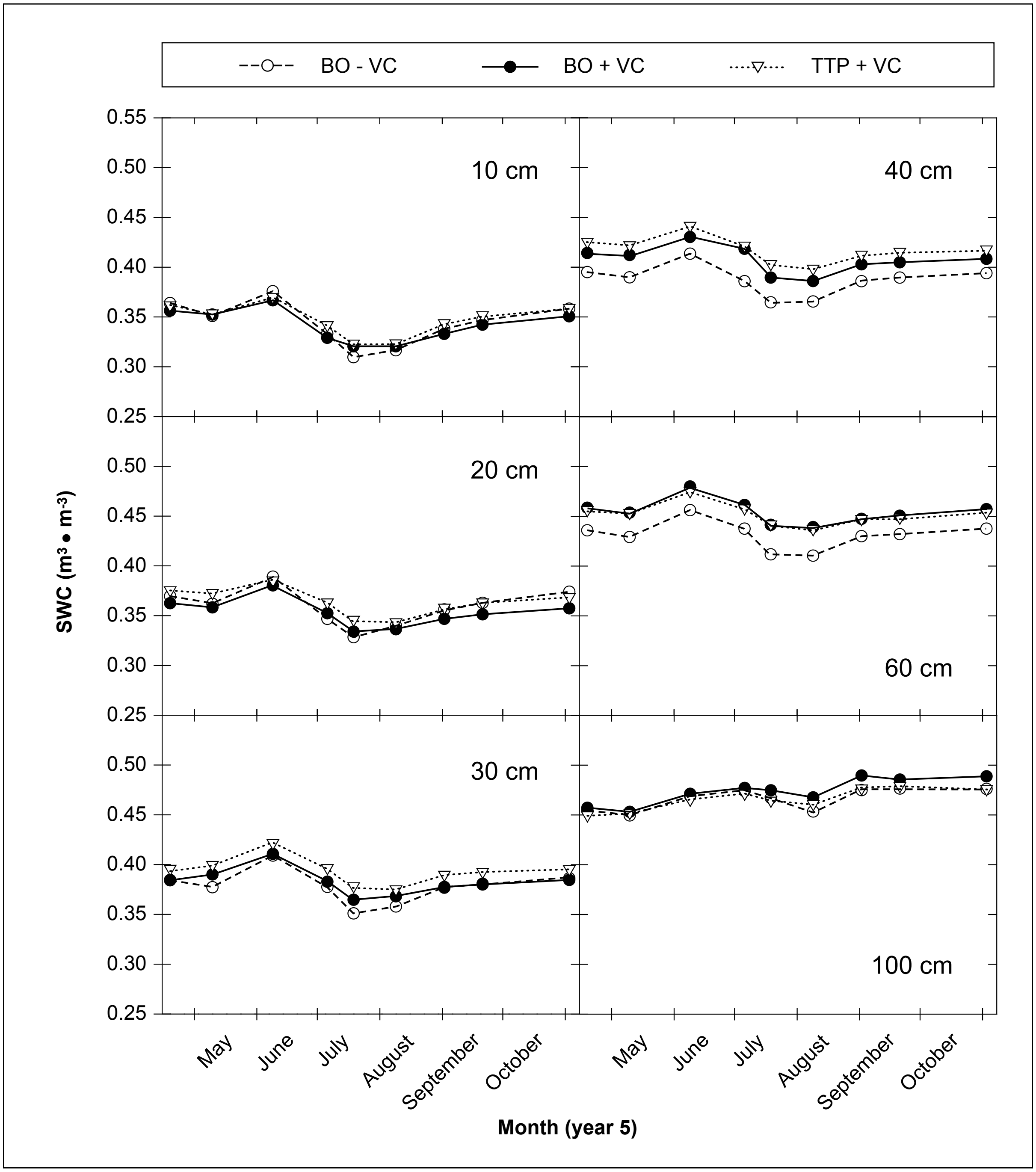

Figure C-3—Soil water content (SWC) under vegetation control and organic matter removal treatments measured at six soil depths, during year 5 (2004).

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