Precise Soil Moisture Testing For Irrigation Scheduling, Deficit Irrigation In Vineyards, And Water Conservation In Agriculture, Using A New Portable Field Test

by:

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Abstract:

One of the last frontiers for precision agriculture is precise soil moisture testing that can be performed quickly in the field. The HydroScout analyzer developed by Dexsil Corporation, is a precise, palm-sized analyzer that allows irrigation schedulers, farmers, viticulturists, water conservationists, irrigation districts and state and federal water agencies to analyze any soil horizon, or the whole rooting zone specifically for soil moisture content. This information can then be used for efficient irrigation management for any crop based on the crop's yield threshold, the soil's allowable soil moisture depletion percentage, or a predetermined soil moisture level as in a vineyard deficit irrigation program. The HydroScout® test results correlate with the standard "oven dry" laboratory method for determining soil moisture content without the 48-hour wait. The HydroScout method requires four minutes per sample. A total of 56 soil samples were collected and tested for moisture content using the HydroScout method during this study. The agreement with the oven dry method was excellent. The correlation coefficient for comparison data was 0.99 and the average RPD was 4%. Dexsil tested 24 spiked soil samples in triplicate by both methods and the correlation between methods was excellent (R^2=0.96). The results presented in this paper show that HydroScout has tremendous potential to promote the efficient use of water resources through good management based upon accurate results.

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Introduction:

The currently available methods used for monitoring soil moisture levels to ensure the efficient use of irrigation water in production agriculture fail to provide data that is **precise** or **specific** enough to adequately accomplish the task. As a result, irrigation scheduling and other water management programs that are based upon these imprecise methods do not represent the best method for determining the most efficient use of precious water resources. Single location moisture sensors, moisture tension devices and weather data fail to account for changes in soil type, topography and slope exposure and the effect each has on a soil's water supplying characteristics. Furthermore, because these methods do not measure water content directly, they are incapable of precisely determining the two most important soil characteristics, a soil's Field Capacity (FC)[1] which represents 100 percent of plant available water (PAW)[2] and the soil moisture levels at the Permanent Wilting Point (PWP)[3] which represents zero percent PAW. They also fail to provide specific soil moisture data at other conditions, such as, between irrigation events.

Nation wide, the increasing importance of water conservation cannot be ignored. In Agricultural regions that experience an annual dry season, the efficient management and use of winter-stored water is critical to ensuring that both the domestic water needs and agricultural water needs are satisfied through the entire dry season. An increase in irrigation efficiency based upon an irrigation program that is developed from actual soil moisture content would be a worthwhile approach to water conservation programs in general and could provide farmers an important economic benefit. A method of monitoring soil moisture that is accurate, practical and portable would contribute greatly to water conservation measures. Soil moisture levels would be monitored and when the soil moisture in the root zone reaches the crops allowable depletion level, which is based upon the crops yield threshold, an irrigation would be applied.[4] A big advantage to this type of field soil moisture testing is that irrigations are applied when they are needed by the crop, potentially saving on non-essential, luxury irrigation events. This precise,

[1] Field Capacity is the maximum amount of water a soil can hold, exclusive of free or gravitational water.
[2] Plant Available Water is the total amount of water available to the plant, depending on both the species of plant and the type of soil. It would be calculated as the difference between Field Capacity (FC) and Permanent Wilt Point (PWP). It can be approximated by the Wilt Point which is just short of the PWP.
[3] Permanent Wilt Point is the moisture level at which the specific plant type is observed to permanently wilt in the type of soil it is growing.
[4] Yield thresholds are crop specific and are based upon a soil moisture level that will result in lower yields or lower harvest quality if soil moisture in the crops root zone drops below this critical level.

soil moisture information driven irrigation scheduling method could result in significant water conservation measures nation wide.

Furthermore, the practice of deficit irrigation as employed in premium wine grape production for canopy management, or in citrus orchards, to improve fruit quality while reducing water use, demands knowledge of site-specific soil moisture conditions for irrigation scheduling. Deficit irrigation programs, for any crop, require accurate soil moisture information, that can be quickly acquired in the field, to verify exactly when the allowable soil moisture depletion level (deficit level) has been reached and to calculate how much water to apply to keep the over-all soil moisture levels at or above the predetermined depletion or deficit level.

The purpose of this study was to evaluate a new field soil moisture test kit, the HydroScout® (Dexsil Corporation, Hamden, CT, USA) to determine if, **precise**, **specific**, and **useful** soil moisture information could in fact be obtained directly in the field and used to develop efficient irrigation practices in vineyards and for agriculture in general. Data published by Dexsil, indicated that the HydroScout system was capable of accurately quantifying the water content in soils ranging from sand to sea sediment with a typical CV of 2% or less. (HydroScout Manual, November 2001) This degree of accuracy and precision, in a direct water measurement, should prove more than adequate to maintain an efficient irrigation scheduling program.

<u>Materials and Procedures:</u>

All of the field-testing was conducted at Sun Mountain Vineyard (Ntaba Langa) located in El Dorado County, California. The soil at this site is Aiken Loam (Afc2), and the vineyard is planted on an 11 percent westerly slope. Both the slope and the exposure are uniform for the whole vineyard. A rooting zone of 48 inches was used for this study. Field sample splits for lab analysis were analyzed in Placerville, CA. All soil samples were collected using a hand auger to get to each desired depth, and a small core sampler to extract the core from the boring. Soil samples were collected every 6 inches to a final depth of 48 inches. All of the soil samples that were tested using HydroScout, were tested in the field at the time they were collected. Soil samples that were oven dried were collected using a pre-weighed copper core sampler. The core samples for each oven dry test were weighed in the field, sealed with aluminum foil and stored in a cooler for transport to the laboratory before being oven dried.

In addition to the field-testing in California, Dexsil conducted a parallel set of experiments, in Connecticut, using spiked soils. Four types of soil were spiked at various water levels from 0-20% H_2Om. Each soil spike was analyzed in triplicate by the HydroScout method and once by the Oven Dry method. The sandy-loam, the sandy-clay-loam and the masonry sand were air dried prior to spiking. The sand-organic mater soil was spiked as found.

The HydroScout soil moisture test kit comes field ready with a palm sized digital meter, an analytical balance, and enough pre-measured reagents, pipettes, soil tubes and reaction test tubes for 40 tests. The complete test kit comes packaged in a portable, rugged case the size of a fishing tackle box. The easy to learn HydroScout method uses an extraction solvent that extracts the water out of the soil prior to analysis. An aliquot of the solvent is then removed using a disposable, calibrated pipette. The solvent is then dispensed from the pipette into the reaction test tube. The reaction test tube contains an ampulized water reactive chemical (calcium hydride). The reaction tube is squeezed to break the ampule and the tube is shaken so the reaction can proceed. The hydrogen gas produced is quantified using the HydroScout meter, which then displays the amount of water present in the soil sample. The step-by-step, five minute, procedure for testing a soil sample for soil moisture content using the HydroScout test kit is as follows:

1. Weigh 3 to 5 grams of soil into a soil tube (10 grams of soil can be used for dry soils; for wet soil, use 3 grams).
2. Add the pre-measured extraction solvent to the soil in the soil tube and shake to extract the water out of the soil and into the solvent. Allow soil to settle.
3. Remove an aliquot of the clear solvent using the preset pipette.
4. Add the solvent to the reaction tube.
5. Crush the reagent ampule inside the reaction tube and shake the tube for 30 seconds and allow to react for 2 minutes total.
6. Insert the reaction test tube into the meter and press the read button.
7. Read the meter, the results are displayed in milligrams of water in the sample.
8. Calculate the % water in the sample (see calculation on page 8).

® HydroScout is a registered trademark of Dexsil Corporation

Because the HydroScout system measures water directly, the only suitable reference method would be the laboratory Oven Dry method. Therefore, all comparisons in this study are made with oven dry results. In the oven dry method for determining soil moisture, the water content is determined by drying a weighed soil sample of suitable size for 48 hours in an oven at 105°C. The difference between the wet and dry weight is the water content. Typically, the water content is expressed as a percentage by taking 100 times the water content divided by the dry weight of the sample. For comparison purposes, the HydroScout results were calculated as percent water based on the calculated dry weight of the sample, i.e., the dry weight of the sample would be the wet weight of the sample minus the weight of the water present.

Field Testing:

The field-testing in California started May 23rd, 2002 with preliminary soil samples taken to determine the Field Capacity. This was 2 days after a storm that produced over three inches of rainfall at the site. Testing after a significant rainfall provided an excellent opportunity to test the soil by both the Hydroscout method and the Oven Dry laboratory method at Field Capacity. A sample was collected at a depth of 12 inches and the water content was determined by both methods. Because the samples were taken two days after a significant rainfall, the water remaining in the soil represents the Field Capacity. The results of the two methods were compared and the agreement between the two methods was excellent, with the HydroScout test result at 37.48 percent water on a mass basis (%$H_2$0m) and the Oven Dry result at 38.23% $H_2$0m. Field Capacity for this site based upon these representative samples was set at 38% $H_2$0m. This agrees well with the data published in *Water Holding Characteristics of California Soils,* 1989. As it turned out, this rainfall was the final rainfall experienced in the region for 170 days. Had it rained after May 23rd, Hydroscout would have been used two days following the rain to determine on a percent water basis, how much extra water had been added to the root zone, the irrigation schedule would then have been adjusted to account for the additional water added and stored in the root zone.

A total of 56 soil samples were collected and tested for percent moisture content during this study. Four soil samples (1 - 4) were oven dried, and spiked with water to Field Capacity (38% $H_2$0m). These soil samples were collected from four random locations within the vineyard. The sampling depth was 24 inches at each location. Each of the four samples was tested using both HydroScout and the Oven Dry methods. At two of the locations the soil borings were continued to the 48-inch depth, composited and oven dried. From this composite sample, two samples (5 – 6) were spiked to Field Capacity (38% H_20m) as before and additional samples (7-8) spiked to below field capacity (30% and 25% H_20m respectively). Seven soil samples (16, 22, 30, 39, 44, 50 and 56) were collected as quality control (QC) samples to be tested by the Oven Dry method. These samples were collected as core samples in copper tubes of known weight. The samples were sealed to prevent evaporation and stored in a cooler until they could be placed in the oven, approximately two hours after they were collected. The companion samples (15, 21, 29, 38, 43, 49 and 55) were analyzed by HydroScout as part of the soil moisture measurements in the field. Two "Soil Moisture Profiles" were developed by testing the soil at six-inch intervals with the first sample collected at 6 inches and the final sample collected at 48 inches. These profiles are important to understanding soil moisture in the root zone. One soil moisture profile was developed when the grapevine was observed to be wilting to determine the soil moisture levels at the wilt point. A second profile was measured at a soil moisture level that would be typical prior to irrigation.

Sample Calculations

Percent Water by The Oven Dry Method:

The weight of the Moist Soil + Container weight = 100 grams.

The Container weight = 10 grams.

100 grams – 10 grams = 90 grams moist soil.

The weight of the Oven Dry Soil + Container wt. = 80 grams.

80 grams –10 grams Container weight = 70 grams oven dried soil.

90 grams Moist Soil – 70 grams Oven Dry Soil = 20 grams water

20 grams Water / 70 grams Oven Dry Soil = 28.57 % water on a mass basis (H_20m).

The Oven Dried Method requires 48 hours to get a result.

Percent Water by The HydroScout Method:

4.8 grams of moist soil yields a HydroScout meter reading of 995mg water.

4.8 grams of moist soil – 0.995 grams water = 3.805 Calculated Dry Weight.

0.995grams water / 3.805 = 26.15% H_20m

The HydroScout Test Method requires 5 minutes per sample to get a result.

Calculations for Total and Plant Available Water:

Tables 1 through 5 utilized the above calculations. Field Capacity for this soil (Aiken Afc2) was determined to be 38% H_20m. Wilting Point (not PWP) for this soil was determined to be 21% H_20m. For this study, a 48-inch deep rooting depth was selected for this site. To determine the total amount of water held in the 48-inch root zone at Field Capacity[5] is calculated as follows:

Total Soil Water Calculation At Field Capacity:

48 inches (rooting depth) of Soil x 38% H_20m @ F.C. = 18.25 inches of total water in the 48 inch root zone.

Total Soil Water Calculation At Wilting Point:

48 inches of Soil x 21% H_20m @ Wilting Point = 10.00 inches of total water in the 48-inch root zone.

Total Plant Available Water Calculation:

18.25 inches of water at F.C. – 10.00 inches of water at W.P. = 8.25 inches of PAW.

Total Soil Water and Total PAW Calculation From %H_2Om:

If the HydroScout test result is 32% H_2Om, then the Total Soil Water is:
0.32 x 48in. = 15.36 inches total soil water. The actual PAW at 32%H_20m by HydroScout is:
15.36 – 10.00 = 5.36 inches PAW.

Results and Discussion:

There were two objectives to this study. The first was to confirm that the HydroScout test kit is comparable to laboratory methods for determining moisture levels in soil. This was accomplished through the soil spiking experiments conducted at Dexsil and in the vineyard in California. The east coast experiments demonstrate that not only is the HydroScout method comparable to the Oven Dry method but also that the response of the HydroScout is linear over the full range of moisture contents tested. (See Table 1.) A regression analysis of the data indicated an excellent correlation between the two methods with a correlation coefficient of 0.96 and a slope of 0.99. Note the low CV for the HydroScout data (Average CV=0.04) and the low RPD for most of the samples (Average RPD=11). Note that because the sand-organic mater soil was spiked as found. This resulted in an over-range result on the HydroScout for the 10, 15 and

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[5] If the Bulk Density of a soil is known, then the percent water can be calculated on a volume basis (H_20v).

20% spiked samples when run using a 10-gram sample. Because the soils were not rerun using a smaller sample, these data points were not included in the final data analysis

The comparison data from the 24-inch depth core samples spiked at Field Capacity also confirm the comparability of the two methods. (See Table 2.) The additional data comparing the 48-inch core samples spiked at water levels from 25% H_2Om up to Field Capacity also show excellent agreement with a maximum RPD of only 8.4%. (See Table 3)

Table 4 showing all of the comparison data collected at the California site, both spiked and unspiked, summarizes the agreement between the laboratory method and the HydroScout method. The maximum RPD was only 13% with and average RPD of 4.4%. A regression analysis, performed on all the comparison data, indicated excellent correlation between the methods with a correlation coefficient of 0.989 and a regression slope of 0.993. A slope effectively of one, indicates that the HydroScout is also unbiased relative to the Oven Dry method. Samples 1-8 were the spiked samples from Tables 2 and 3. The remaining samples were collected as pairs one sample of each pair was analyzed in the field using the HydroScout at the time of sampling and the other was collected for the Oven Dry quality control testing. Despite the fact that these samples were not split samples, the agreement between the field and lab results was excellent.

The data presented in Tables 1-4 indicated that the two methods were statistically identical for both sets of soils, the east coast and the west coast. This was the first objective of the study. The second was to demonstrate the usefulness of the HydroScout test for field measurements necessary as part of a controlled irrigation program. Once the equivalence has been demonstrated, all further soil moisture measurements can be made using the HydroScout alone with out the necessity of laboratory conformation. Laboratory conformation samples were in fact taken to confirm the method comparability.

The first and most important soil characteristic that is essential to develop for any soil for irrigation management is Field Capacity (FC), which represents 100% of Plant Available Water (PAW). Field capacity can be determined by spiking dry soil, or can usually be obtained by collecting a sample two days after a significant rainfall. The FC for this site was determined in the preliminary phase to be 38% H_2Om. The second most important soil characteristic is Permanent Wilting Point, (PWP) which represents 0% PAW. In order to determine the PWP a plant would have to be deprived of water until it wilted beyond recovery. A good approximation to the PWP would be to go only to the Wilting Point, just short of permanent damage, and measure the water content in the root zone. To accomplish this, one grapevine in the vineyard was intentionally deprived of water so that a soil moisture profile could be done at the wilting point, but not at PWP (no grapevines were sacrificed for this paper). The Wilting Point for this soil was set at 21% H_20m based on this testing, i.e., the average water content over the root zone, from 12" to 48". (See Table 5.) Once the Field Capacity and the Wilting Point have been established, it is a simple matter to calculate the Plant Available Water (See Sample Calculations above.) The PAW for each sample was calculated and added as the last column in Tables 5 and 6.

To illustrate how the HydroScout test should be used to schedule when and how much to irrigate, a soil moisture profile was developed at a moisture content that would be typical prior to an irrigation event. (See Table 6) If the allowable depletion level or deficit level for the vineyard was set at an average of 23% H_20m by HydroScout over the 48 inch root zone, then based upon this data, it is time to irrigate because the average water content is 22.42 % H_20m or 0.76 inches PAW per inch of soil. Based upon this profile, it would require 7.49 inches of irrigation water to bring the soil moisture content up to Field Capacity. Adding any more water would be wasting water and if you know the irrigation systems water application rate, then you can calculate how long the irrigation system needs to be on to add a specific amount of water back into the soil. Tables 5 and 6 demonstrate the advantages of being able to use the HydroScout test kit to quickly and precisely determine the water supplying power of the soil for the crop, at any place in the field and at anytime.

A standard reference table can be created relating the measured water content in weight percent (%H_2Om) to both the "Total Soil Water" and the PAW in inches based on the Field Capacity determination and the Wilt Point determinations for the site. After this data is compiled into a **"Plant Available Water Reference Table"** (See Table 7) for a specific soil at a specific site, then truly meaningful HydroScout testing can be performed anywhere, and the results interpreted immediately to determine the actual soil moisture status at the time of the sampling. An irrigation schedule can then be made to determine when to irrigate and how much water to apply based upon the actual soil moisture content. If between irrigations, a rainfall event occurred, additional HydroScout testing would be used to account for the additional soil moisture. The irrigation schedule would then be adjusted to account for this additional soil moisture.

At large vineyards that are topographically diverse, same day soil moisture profile testing, using the HydroScout, may reveal that the soil at the top of a hill contains less moisture than the soil in the valley below. Different irrigation schedules would then be required for each location within the vineyard. If the vineyard is planted in several different soil types, each soil type will need to be tested to determine its Field Capacity, Wilting Point and a **Plant Available Water Reference Table** will have to be developed for each soil type. Any HydroScout soil moisture determination can be cross referenced using Table 7 to find either the total water content of the soil in inches of water or the amount of plant available water present in the soil at the time of the testing.

Summary and Conclusions:

The HydroScout Method was evaluated as a stand-alone soil moisture testing method by comparing the HydroScout test results to the Oven Dry Method test results performed on comparable soil samples in the laboratory. Tables 1 – 3 show that the agreement between the two methods at a variety of soil moisture levels for a number of soil types is very good on both the spiked samples and the actual field samples. The correlation coefficient for the method comparison data collected at Dexsil was 0.96 and 0.99 for the data collected in California.

The ability to walk out into the vineyard and test the soil anywhere and at anytime and immediately use the data to assess the soils water supplying power based upon the actual percent soil moisture content is unique and informative and quite satisfying. Using the site and soil specific **Plant Available Water Reference Table** (Table 7), the HydroScout soil moisture profiles developed at each sampling event were immediately useful in determining the actual soil moisture status and water supplying power for the vines.

The HydroScout Method is well suited for soil moisture research work and for establishing yield thresholds for crops that do not have a yield threshold as of yet. The HydroScout Method can be used to determine the infiltration rate of rainwater into soil and the depth of soil wetted after a rainfall or irrigation event. It can be used to evaluate whether a site is suitable for planting a crop that requires good soil drainage. HydroScout can also be used to determine the actual volume of soil wetted (lateral and vertical extent) by a particular type of irrigation method at a set application rate. The timing of irrigation applications can be determined using good soil moisture data generated from the HydroScout Method. Individual soil horizons can be tested for their water holding capacities.

The HydroScout soil moisture field-test kit proved to be a precise, specific and useful, stand-alone soil moisture testing method. A deficit irrigation program will be established at the vineyard for the growing season of 2003. The irrigation program will be monitored using the HydroScout field test kit and irrigation will be scheduled based upon "Soil Moisture Profiles" as they approach the predetermined deficit level. Table 7, the **Plant Available Water Reference Table** will be re-made in 0.5 % point increments (i.e. 20%, 20.5%, 21%, 21.5% etc to 38%) in an effort to become more precise with soil moisture levels. Areas with newly planted vines (1-3years old) will have irrigation schedules developed that will provide for higher soil moisture levels in the top 24 inches of the soil through-out the growing season.

The HydroScout test kit, if utilized in production Agriculture properly, has a tremendous potential to promote the efficient use of precious water resources through good management based upon good information.

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Table 1 Laboratory Spike Data						
Nominal Spike ($\% H_2Om$)	Sample Size (g)	HydroScout mg H_2O	HydroScout Ave. ($\% H_2Om$)	CV	Oven Dry ($\% H_2Om$)	RPD
Sandy Loam						
0	10	641	6.303	0.022	6.4	1.5
2	10	821	8.108	0.016	9	10
5	10	1125	9.999	0.158	11.9	17
10	10	1490	14.558	0.022	15.5	6.3
15	10	1878	18.637	0.024	20.4	9.0
20	5	1298	24.483	0.027	25.4	3.7
Sandy Clay Loam						
0	10	186	1.860	0.021	2.16	15
2	10	411	4.225	0.031	4.09	3.2
5	10	720	7.441	0.030	6.34	16
10	10	1221	12.279	0.010	11.41	7.3
15	10	1577	16.080	0.033	16.85	4.7
20	5	1163	22.361	0.025	20.54	8.5
Masonry Sand						
0	10	21	0.284	0.218	0.37	26
2	10	251	2.469	0.034	1.75	34
5	10	560	5.495	0.033	4.61	17
10	10	1072	10.971	0.051	9.72	12
15	10	1593	15.336	0.019	14.89	2.9
20	5	1104	22.488	0.020	18.49	20
Undried Sand With Organic Mater						
0	10	1075	10.723	0.019	10.5	2.1
2	10	1210	12.549	0.018	12.7	1.2
5	10	1384	14.298	0.022	14.2	0.7
			Average	0.040		11

Table 1: Laboratory Spiked Soil Comparison Data (Connecticut)

Four types of soil were spiked at various water levels from 0-20%m. Each soil spike was analyzed in triplicate by the HydroScout method and once by the Oven Dry method. The sandy-loam, the sandy-clay-loam and the masonry sand were air dried prior to spiking. The sand-organic mater soil was spiked as found. This resulted in an over-range result on the HydroScout for the 10, 15 and 20% spiked samples when run using a 10-gram sample. Because the soils were not rerun using a smaller sample, these data points were not included in the final data analysis. A regression analysis on the data indicated an excellent correlation between the two methods with a correlation coefficient of 0.96 and a slope of 0.99. Note the low CV for the

HydroScout data (Average CV=0.04) and the low RPD for most of the samples (Average RPD=11).

Table 2 Soil Spiked at Field Capacity				
Sample #	HydroScout % H_2Om	Oven Dry % H_2Om	RPD	Water Spiked In Dry Soil (%)
1	37.52	38.64	2.9	38
2	38.22	40.91	6.8	38
3	37.20	38.24	2.8	38
4	38.72	39.45	1.9	38
Average	37.91	39.31	3.6	
CV	0.018	0.03		

Table 2: Soil Moisture Determination on Selected Soil Samples Spiked at Field Capacity.

Soil samples collected at four random locations, at a dept of 24 inches, were oven dried and then spiked at Field Capacity. The water content was determined for each soil sample by both methods. Note the excellent agreement between the two methods; the average Relative Percent Difference (RPD) was only 3.6%. The Coefficient of Variation (CV) for both methods was 3% or better.

Percent Water by Mass (%H_2Om) by Oven Dry Method

%H_2Om = 100 x (Wet Weight – Dry Weight)/Dry Weight

Percent Water by Mass (%H_2Om) by Oven HydroScout Method

%H_2Om = 100 x Mass Water/(Wet Weight – Mass Water)

Table 3 Spiked 48 Inch Composite Samples				
Sample #	HydroScout % H_20m	Oven Dry % H_20m	RPD	Water Spiked In Dry Soil (%)
5	37.64	38.25	1.6	38
6	39.81	41.43	4.0	38
7	32.65	32.15	1.5	30
8	24.32	26.45	8.4	25

Table 3: Comparison Data for Spiked Soil Samples Taken at 48-Inch Depth (Root Zone)

At two of the sample sites used for the 24-inch soil samples, the soil profile was continued to a depth of 48 inches to cover the entire root zone. The samples at 48 inches were homogenized to form a composite, oven dried and split for spiking. Two samples were spiked with 38% water, one sample was spiked at 30% water and one sample was spiked at 25% water. The agreement between the field method and the lab method was excellent with a maximum RPD of only 8.4%.

Table 4 All Comparison Data				
Sample #	Sample Depth (in.)	HydroScout % H_20m	Oven Dry % H_20m	RPD
1	24	37.52	38.64	2.9
2	24	38.22	40.91	6.8
3	24	37.2	38.24	2.8
4	24	38.72	39.45	1.9
5	48	37.64	38.25	1.6
6	48	39.81	41.43	4
7	48	32.65	32.15	1.5
8	48	24.32	26.45	8.4
15,16	48	22.22	22.71	2.2
21,22	30	23.46	23.62	0.7
29,30	24	19.69	20.00	1.6
38,39	24	18.10	20.60	13
43,44	48	20.80	22.70	8.7
49,50	24	19.45	20.58	5.6
55,56	48	24.25	25.34	4.4

Table 4: All Soil Data Comparing HydroScout and Oven Dry (California Site)

In addition to the spiked soils, seven soil samples (15, 21, 29, 38, 43, 49, 55) were collected and tested immediately in the field by HydroScout. The seven corresponding correlation samples, collected for the Oven Dry quality control testing (16, 22, 30, 39, 44, 50, 56), were collected as core samples in copper tubes of known weight. These samples were sealed to prevent evaporation and stored in a cooler until they could be placed in the oven, approximately two hours after they were collected. Despite the fact that these samples were not split samples, the agreement between the field and lab results was excellent. The maximum RPD was only 13%. A regression analysis performed on all the comparison data indicated excellent correlation between the methods with a correlation coefficient of 0.989 and a regression slope of 0.993.

Table 5 Soil Moisture Profile At Visual Wilting Point						
Sample #	Depth (in.)	Sample Wt. (g)	HydroScout mg H_20	HydroScout Dry Wt. (g)	HydroScout % H_20m	PAW* (in.)
26	6	5.2	749	4.45	16.83	0
27	12	5.0	814	4.19	19.43	0
28	18	5.0	786	4.21	18.67	0
29	24	5.0	823	4.18	19.69	0
31	30	5.1	818	4.28	19.11	0
32	36	5.2	855	4.35	19.66	0
33	42	5.1	923	4.18	22.10	0.56
34	48	5.0	974	4.03	24.17	1.60
				Average	20.5	
*PAW= Plant Available Water						

Table 5: Soil Moisture Profile at Visual Wilting Point

One grapevine in the vineyard was intentionally deprived of water so that a soil moisture profile could be done at the wilting point, but not at PWP (no grapevines were sacrificed for this paper). The Wilting Point for this soil was set at 21% H_20m based on this testing, i.e., the average water content over the root zone, from 12" to 48". Sample #30 (20% H_20m) is the Oven Dry quality control sample for this "Soil Moisture Profile". Sample #29 (19.69% H_20m) was tested by HydroScout and was collected at the same location as sample #30. See Table 4.

Table 6 Typical Soil Moisture Profile Prior To Irrigation						
Sample #	Depth (in.)	Sample Wt. (g)	HydroScout mg H_20	HydroScout Dry Wt. (g)	HydroScout % H_20m	PAW* (in.)
17	6	5.6	778	4.82	16.14	0
18	12	5.0	769	4.23	18.18	0
19	18	4.8	845	3.96	21.34	0.24
20	24	5.1	920	4.18	22.01	0.57
21	30	5.0	950	4.05	23.46	1.26
23	36	4.8	995	3.81	26.12	2.54
24	42	5.2	1033	4.17	24.77	1.89
25	48	4.7	1006	3.69	27.37	3.14
*PAW = Plant Available Water						

Table 6: Typical "Soil Moisture Profile"

This soil moisture profile demonstrates how the HydroScout test should be used to schedule when and how much to irrigate. If the allowable depletion level or deficit level for the vineyard was set at an average of 23% H_20m over the 48 inch root zone, then based upon this data, it is time to irrigate because the average PAW is 0.76 inches/inch of soil or 22.42 % H_20m. Based upon this profile, it would require 7.49 inches of irrigation water to bring the soil moisture content up to Field Capacity. If you know the irrigation systems water application rate, then you can calculate how long the irrigation system needs to be on to add a specific amount of water back into the soil. Sample #22 (23.62% H20m) is the Oven Dry quality control sample for this testing event. Sample #21 (23.46% H20m) was tested by HydroScout and was collected at the same location as sample #22. See Table 4.

Table 7 Plant Available Water Reference Table for the Sun Mountain Vineyard site		
% Water by HydroScout	**Total Soil Water In Inches**	**Inches of PAW (Plant Available Water)**
38	18.25	8.25
37	17.76	7.76
36	17.28	7.28
35	16.80	6.80
34	16.32	6.32
33	15.84	5.84
32	15.36	5.36
31	14.88	4.88
30	14.40	4.40
29.5	14.16	4.16
29	13.92	3.92
28	13.44	3.44
27	12.96	2.96
26	12.48	2.48
25	12.00	2.00
24	11.52	1.52
23	11.04	1.04
22	10.56	0.56
21	10.08	0.08
20	9.60	0
Wilting Point Established at 21% H20m for the Sun Mountain Vineyard Site.		

Table 7: "Plant Available Water Reference Table"

Generated from HydroScout testing, this Table is established for a specific soil at a specific site, then truly meaningful HydroScout testing can be performed anywhere, and the results interpreted immediately to determine the actual soil moisture status at the time of the sampling. An irrigation schedule can then be made to determine when to irrigate and how much water to apply based upon the actual soil moisture content. If between irrigations, a rainfall event occurred, additional HydroScout testing would be used to account for the additional soil moisture. The irrigation schedule would then be adjusted to account for this additional soil moisture.