Overview of the Soil, Water, Plant System:

The research performed on the effect of high organic matter for various cultivars using both irrigation and non-irrigated systems continues to grow. What is evident from the research data to date, however, is that *the water holding capacity is greatly increased by adding organic matter*. This, in turn, translates into 2-2.5 times the plant available water compared to un-amended soils. This is significant for California growing applications (agriculture, landscape and irrigated working lands), which constitute over 80 percent of its managed lands, and 90% of California's human (i.e. non-environmental) water use. The opportunity to save water in agriculture and landscape, is therefore very significant, especially in drought years.

We derive these increased water holding capacity numbers by comparing organic matter content with available water content. Hudson (1994; Figure 1) demonstrated that as organic matter content increases, available water content also increases. As soil organic matter approaches five percent, available water content approaches 30 percent.

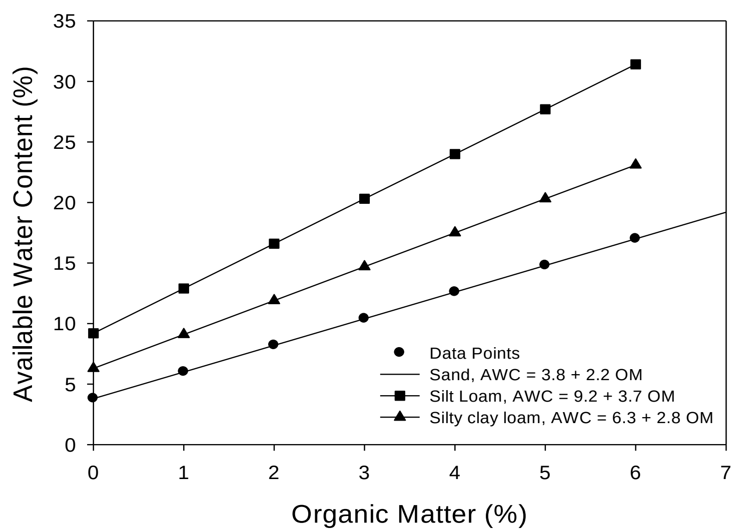

Figure 1. Available soil water content in sand, silt loam, and silty clay loam soils relative to organic matter content (Adapted from Hudson, 1994).[i]

In turn, plant available water increases with an increase in the soil organic carbon (Hudson, 1994; Figure 2). In fact, as the soil organic carbon (the carbon fraction of soil organic matter) increases by a factor of four, the plant available water increases by about 2.5 times.[ii]

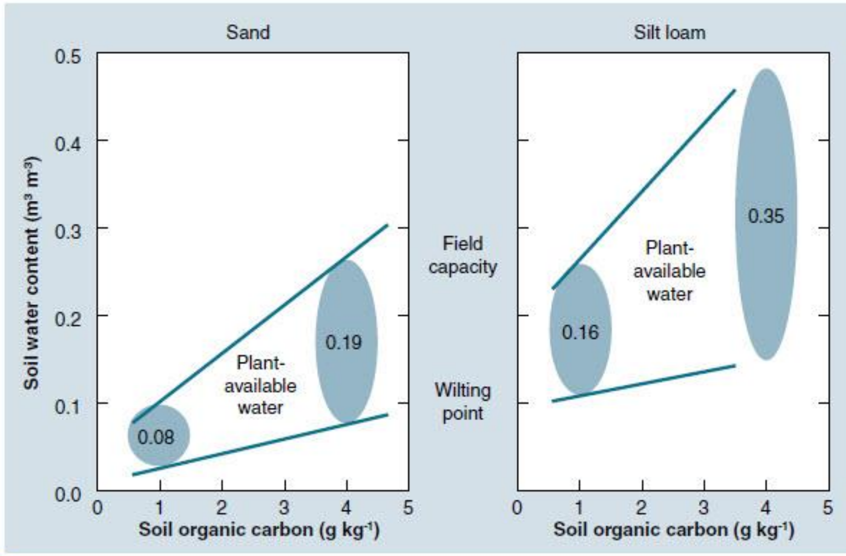

Figure 2. Plant-available water increases with increasing soil water content and organic carbon (Frankluebbers, 2010; Hudson, 1994; http://irrigatedag.wsu.edu/soil-organic-matter-boosts-water-holding-capacity/).

In a review of over 100 studies analyzing the ability of compost and mulch to conserve water either by reducing irrigation needs, increasing soil available water (SAW), or increasing water use efficiency (WUE), all of the studies demonstrated some increase in water conservation either quantitatively or qualitatively. Compost can be comprised of a number of different material types, such as yard trimmings, food, manure, straw, and biosolids. Mulch has similar variations in material types, such as shredded bark, redwood chips, and straw. Often in these studies uncomposted materials are applied as mulch. For the purposes of this analysis, compost will be considered to be any organic materials (organic in nature, not certified organic) that are incorporated into the soil, and mulch with be considered anything added topically to the soil. The average water savings from compost was 26 to 34 percent (Table 1; see References for list of studies), and from mulch was 19 to 39 percent. In general, the average water savings was 20 to 46 percent.[1]

When addressing water conservation in natural systems, there are many variables that play a role. Some of these variables are associated with the structure, flora, and fauna of the soil as well as external factors that affect these soil issues, such as air and water factors. These factors are outside of this analysis.

[1] All of the references are listed starting on page 8. There is a companion document, "WEGHG-3-Estimate Basis Reference Summary Final," that provides a brief summary of each of these references.

Table 1. Water savings by application type from water literature review.

Type	No. Studies	Average minimum water savings	Average maximum water savings
Compost (Quantitative)	28	26%	34%
Compost (Qualitative)	19	All showed increase	All showed increase
Compost/Mulch (Quantitative)	1	15%	64%
Compost/Mulch (Qualitative)	1	All showed increase	All showed increase
Mulch (Quantitative)	28	19%	39%
Mulch (Qualitative)	27	All showed increase	All showed increase
Total	**104**	**20%**	**46%**

We further analyzed the water savings ability by landscape type (agriculture, urban farming, and native landscapes). Associated with erosion control for native landscapes, five studies demonstrated increases in soil available water. The one using mulch demonstrated water savings of less than ten percent (three to seven percent; Bhatt and Khera, 2006). The ones using compost demonstrated upwards of 100 percent increase in plant available water when incorporated into the soil (Curtis and Claassen, 2005; Greb et al, 1967; Illera et al, 1999; Bresson et al, 2001).

The two vineyard studies using compost as mulch (surface application), netted an increase in water savings of between 4 and 34 percent (Pinamonte, 1998; Buckerfield and Webster, 1995).

In landscape beds, incorporation of compost resulted in water savings of between 65 and 71 percent (Cogger et al, 2008).

The number of studies related to growing vegetables is significantly more extensive. There are a total of 18 studies with quantitative results (Adamtey et al, 2010; Adetunji, 1990; Ahmad et al, 2008; Bahadur et al, 2009; Edwards et al, 2000; El-Shaikh, 2008; Foley and Cooperband, 2002; Khurshid et al, 2006; Lal, 1974; Lal, 1978; Maynard and Hill, 1994; Mamo et al, 2000; Naeini and Cook, 2000; Nguyen et al, 2012; Ngoundo et al. 2007; Pervaiz et al, 2009; Sarkar et al, 2007; and Tolk et al, 1999). In general, the average water savings ranges from 39 to 46 percent (Table 2). Half of these studies are associated with growing corn using either compost or mulch applications. Greater water savings are demonstrated in the compost usage with corn with an average of 37 to 49 percent water savings versus 9 to 16 percent in the mulched systems.

Table 2. Water savings by crop type from water literature review.

Crops	No. Studies	Minimum water savings	Maximum water savings
Corn (Compost)	4	37%	49%
Cabbage (Compost)	1	65%	71%
Tomatoes (Compost)	1	22%	26%
Vegetables (General; Compost)	2	19%	41%
Corn (Mulch)	5	9%	16%
Cucumbers (Mulch)	1	63%	73%
Lettuce (Mulch)	1	100%	100%
Okra (Mulch)	1	30%	30%
Potatoes (Mulch)	1	7%	10%
Rapeseed (Mulch)	1	37%	45%
Total/average (Compost):	8	36%	46.7%
Total/ average (Mulch):	10	41%	45.7%
Total/Total average (All):	18	39%	46%

While these data are suggestive of the ability of compost and mulch to save significant amounts of water by greatly increasing the PAW with increasing soil organic matter (OM) from less than one percent to greater than five percent by mass (g OM/kg total soil mass), it is not prescriptive of how much water can be saved for all cultivation applications and variables. It follows from this reduced need for water that both reduced irrigation needs and increased aquifer recharge can be achieved on California's managed lands through the use of compost and mulch.

In turn, significant energy savings, and reduction of greenhouse gas emissions can be achieved. Energy can be saved in terms of reducing irrigation and transportation of water needs, which in turn can reduce greenhouse gas emissions from fossil fuels used to power the transportation of water. When applied to rangelands, which comprise over 60 percent of California's approximately 100 million acres (http://www.caenvirothon.com/?page_id=859), it has also been demonstrated that carbon dioxide can be sequestered. In studies conducted by the Marin Carbon Project in conjunction with UC Berkeley, they determined for rangelands where cattle are able to graze native grasses post-application of compost that: "Conservatively, one tonne of carbon (3.67 tonnes of CO_2e) is sequestered per hectare per year for each of 20 years following the initial compost application, assuming good grazing practices. This is 1.5 tons of CO2e per acre, per year for 20 years, or 30 tons/acre over that time frame." (Ryals and Silver, 2013; DeLonge et al., 2013).

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[i] From Berman (1994), "For the last 50 years, the consensus view among researchers has been that organic matter (OM) has little or no effect on the available water capacity (AWC) of soil. The historical development of this viewpoint is traced. It is argued that the literature on this subject has been misconstrued and that the consensus view is wrong. In addition to a critical review of the literature, published data were evaluated to assess the effect of OM content on the AWC of surface soil within three textural groups. Within each group, as OM content increased, the volume of water held at field capacity increased at a much greater rate (average slope = 3.6) than that held at the permanent wilting point (average slope = 0.72). As a result, highly significant positive correlations were found between OM content and AWC for sand (r^2 = 0.79***), silt loam (r^2 = 0.58***) and silty clay loam (r^2 = 0.7G***) texture groups. In all texture groups, as OM content increased from 0.5 to 3%, AWC of the soil more than doubled. Soil OM is an important determinant of AWC because, on a volume basis, it is a significant soil component. In this study, one to 6% OM by weight was equivalent to approximately 5 to 25% by volume."

[ii] Using the above data, combined with other information it is found that: "As the soil carbon (or organic matter) increases by four times [one to four percent OM, or soil organic carbon 1g/kg to 4g/kg soil], the plant available water increases by 2.2 to 2.5 times. [Depending on the starting soil type, from sands or silt loams]." (http://irrigatedag.wsu.edu/soil-organic-matter-boosts-water-holding-capacity/)