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In This Issue

- Estimating Bulk Density in California Soils
- Using partial budgeting to analyze farm business changes
- Foggy days in the Sacramento Valley

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Estimating Bulk Density in California Soils

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UC Cooperative Extension has developed a bulk density and soil carbon calculator. This tool can be used to estimate soil bulk density based on soil organic matter and saturation percentage. The calculator can then be used to calculate total soil carbon in pounds per acre using soil bulk density, percent total carbon, and sampling depth. The tool can be found at https://californiabulkdensitycalculator.com.

What is bulk density, why does it matter, and how is it measured?

Bulk density is the relationship between the weight of soil in a known volume. Soil is comprised of minerals (sand, silt, clay), organic matter, and open pore space that is filled with air and water. Bulk density depends on soil texture and soil organic matter content. It increases with soil compaction and reduces as soil structure improves due to increased aggregate stability and improved soil structure.

Bulk density is also important for understanding changes to soil chemical properties. Lab analyses often provide results as a percent or as parts per million (ppm). However, to interpret those results for a known soil depth, a measure of volume is needed. For example, if a soil is 1.06% carbon and has a bulk density of 1.4 g/cm^3, then there are 40,360 pounds of carbon per acre in the top foot. In soil with the same percent carbon (1.06%) and a bulk density of 1.3 g/cm^3, there are 37,470 pounds of carbon in the top foot, while a soil with a bulk density of 1.5 g/cm^3 would have 43,240 pounds of carbon in the top foot.

Bulk density is measured by collecting intact soil cores of a known volume. Samples are collected in the field, dried in a drying oven, and weighed. Bulk density is commonly expressed in grams of soil per cubic centimeter. One challenge with bulk density measurements is that they require specialized equipment (Picture 1). A second challenge is that sample collection is tedious, and it is important to be very precise to get an accurate measurement. It is challenging to remove an intact soil core (Picture 2).

Picture 2

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Web soil survey (https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) is USDA Natural Resources Conservation Service soil database that maps soils in the United States. This valuable resource has information about soil properties and is a good way to get baseline information about a field. Web soil survey has bulk density values for soils. However, field management can change bulk density over time and database values do not always correspond to present field conditions.

Can bulk density be estimated?

UC Cooperative Extension research evaluated a way to estimate bulk density based on field measurements. Fields were sampled for bulk density and other soil measurements including soil texture, saturation percentage, soil organic carbon, and soil organic matter. These field soil measurements were then included in 14 different models. The models were compared using statistical methods that assess the strength of different models. The final step was to check the model's accuracy by running a subset of our own field data into the model to see how the bulk density estimates compared to the actual bulk density measurements. One model emerged as the best for predicting bulk density. This model uses percent organic matter and saturation percentage to estimate bulk density based on current field conditions.

When organic matter is consumed by soil microbes different compounds are released into the soil, some of which are sticky and hold soil particles together into clumps of soil. These clumps are called soil aggregates (Picture 3). Aggregates are related to macropores, or larger pores in soil and aggregate production and stability is closely tied to organic matter. Saturation percentage measures soil water content of a saturated soil. Saturation percentage is measured on air-dried pulverized soil that has been sieved. Since the soil is pulverized, saturation percentage is related to micropores, or smaller pores in soil. Both organic matter and saturation percentage can be quantified at some commercial soil laboratories.

The University of California Bulk Density and Soil Carbon Calculator (californiabulkdensitycalculator.com) is an online calculator based on the research model. It can be used to estimate soil bulk density using only soil organic matter and saturation percentage as inputs. The calculator can then be used to calculate total soil carbon in pounds per acre using soil bulk density, percent total carbon, and sampling depth. If the user wants to calculate soil carbon in pounds per acre, they will need lab values for percent soil carbon which can be measured at some commercial labs.

Questions about this tool can be sent to Sarah Light, Agronomy Advisor, selight@ucanr.edu.

Using partial budgeting to analyze farm business changes

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Growers and farm managers are continually looking for ways to make their operations more efficient and improve profitability, whether deciding between a new technology and the current system, substituting one crop for another, adjusting input levels relative to existing practices, or choosing between owning equipment and hiring custom services. Making a sound choice among such alternatives requires a systematic evaluation of the positives and negatives of the proposed change. Partial budgeting provides an organized framework to help compare the costs and benefits of specific changes in farm operations. It focuses only on the revenue and expenses that are expected to change if the alternative is adopted. You do not need a complete farm budget.

A partial budget has four sections and asks four main questions:

Added revenue: What will be the new or added revenue? Identify any new revenue that would be generated only if the proposed change is adopted. For example, if you are considering changing fertilizer type and expect yields to increase, the additional revenue from the higher yield should be included as added revenue. Similarly, if you plan to replace barley with beans, the expected revenue from the beans becomes added revenue.

Reduced revenue: What revenue will be reduced or lost? Identify any revenue that you currently receive but would no longer receive if the proposed change is adopted. For example, if you adopt a no-till system for crop production and yields are expected to decrease, estimate the lost revenue from lower yields and include it as reduced revenue. Likewise, if you reduce barley acres to plant beans, the revenue that would have been generated from the removed barley acres becomes reduced revenue.

Reduced costs: What costs will be reduced or eliminated? Identify any expenses you currently pay that would be reduced or eliminated if you make the proposed change. For example, if you replace part of your barley acres with beans, the input costs for the removed barley acres would become reduced costs because you would no longer pay them.

Added costs: What will be the new or added costs? Identify any expenses you do not currently but would have to pay if you make the proposed change. Any new or increased expense resulting from the change should be included here. For example, if switching from barley to beans requires extra fertilizer, count that increased fertilizer cost as added costs.

How does partial budgeting work?

The four components are usually presented in two columns: the positives (added revenue + reduced costs) on one side, and the negatives (added costs + reduced revenue) on the other. To determine whether the change would be beneficial, subtract the total negative effects from the total positive effects like this:

Change in Profit = (Added Revenue + Reduced Costs) – (Added Costs + Reduced Revenue)

A positive result indicates the proposed change is expected to increase profit. Conversely, a negative result indicates profit is expected to decline if the change is implemented.

A simple example

Suppose you are considering reducing your beans acreage by 100 acres and planting those acres in corn because you anticipate that corn prices and yields will be more attractive in the coming crop year compared to beans. You expect differences in variable costs such as fertilizer, labor, pesticide, and other operating expenses between the two crops. Because you already own the equipment needed to produce either crop, you do not anticipate any changes in fixed costs. Table 1 reports your expected price, yield, and variable costs.

Table 1. Expected price, yield, and cost estimates for beans and corn

Item	Beans	Corn
Yield	20 cwt /acre	180 bu/acre
Price	$60/cwt	$7/bu
Fertilizer	$150/acre	$190/acre
Labor	$200/acre	$240/acre
Pesticide	$120/acre	$180/acre
Other stuff	$200/acre	$150/acre

Beans are expected to generate $1,200/acre (20cwt × $60) in revenue, with variable costs of $670/acre ($150 + $200 + $120 + $200). Corn is expected to generate $1,260/acre (180bu × $7/bu) in revenue, with variable costs of $760/acre ($190 + $240 + $180 + $150). Switching 100 acres from beans to corn would add new revenue from the new corn crop while eliminating bean revenue. Some input costs would increase under corn production, while input costs associated with beans production would be avoided. Organizing these changes in a partial budget framework (Table 2) shows a negative projected net change of $3,000, indicating that it would be more profitable to continue producing beans.

Table 2. Partial budget for a proposed change of converting 100 acres of beans to corn

Added Revenue		Added Costs	
Revenue from producing 100 acres of corn		*Cost for producing 100 acres of corn*	
$7/bu × 180 bu/acre × 100 acres	$126,000	Fertilizer	$19,000
		Labor	$24,000
		Pesticide	$18,000
		Other stuff	$15,000
Reduced Costs		**Reduced Revenue**	
Cost eliminated for not producing 100 acres of beans		*Revenue lost for not producing 100 acres of beans*	
Fertilizer	$15,000	$60/cwt × 20cwt /acre × 100 acres	$120,000
Labor	$20,000		
Pesticide	$12,000		
Other stuff	$20,000		
Total added revenue and reduced costs	$193,000	Total added costs and reduced revenue	$196,000

Net change in profit = $193,000 - $196, 000
= -$3,000

Some important considerations

Both added costs and reduced costs may include variable and fixed costs. If the proposed change is expected to increase the use of variable inputs, such as labor or fertilizer, the additional costs associated with these inputs should be included as added costs. Similarly, if the change requires an investment in new equipment, the annual fixed costs of that equipment, such as depreciation, interest, and insurance should also be included as added costs. Conversely, if you anticipate selling equipment that will no longer be used under the proposed change, the eliminated depreciation, interest, and insurance costs should be reported as reduced costs. Do not record the full proceeds from the sale of the equipment as added revenue. Instead, include the annual returns you could earn by investing the sale proceeds elsewhere (sale proceeds × realistic interest rate) as added revenue.

Some items may be difficult to measure precisely. For example, suppose you are considering hiring a custom harvester instead of using your own equipment. The custom fee is usually known in advance and can be included with a high degree of certainty. However, there may be uncertainty regarding whether the custom operator will be available at the optimal time for harvest. If harvest is delayed, yields or crop quality could decline, resulting in reduced revenue. The exact amount of such potential loss can be hard to estimate in advance.

To improve accuracy, use realistic estimates. Talking with other growers who have adopted the change you are considering can provide valuable insights and help you fine-tune your numbers. Reviewing your own farm records can further improve the accuracy of your estimates. The University of California Cooperative Extension (UCCE) cost studies webpage provides cost information on several field crops, some of which are accompanied by downloadable spreadsheets that can be used to track your expenses and returns. You can also consult your local UCCE Farm Advisor to discuss the change you are considering. Finally, repeating the calculation under alternative assumptions and scenarios can help you better understand the risks and opportunities of each decision and plan accordingly to protect or improve profitability.

If you would like to talk through partial budgeting for your specific operation, you can contact me at dagyeman@ucanr.edu or 859-913-1354.

Foggy days in the Sacramento Valley

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The current winter in California has brought an unusually high number of foggy days (Figure 1). Research indicates that dense valley fog in California has declined by roughly 70–80% since the mid-20th century. This decline is attributed to a combination of factors, including warming winter temperatures and reductions in air pollution that previously contributed particles needed for (fog) droplet formation.

Figure 1. Delta corn field in the afternoon of December 20, 2025

A wetter landscape provides more surface water available for evaporation, which adds moisture to the air. Under certain environmental conditions, fog can form. Fog develops when water vapor condenses into tiny liquid droplets around microscopic particles in the air, such as dust or pollutants. For condensation to occur, the air must cool to its "dew point", the temperature at which it becomes saturated with water vapor and condensation begins to exceed evaporation. Wind conditions also play an important role. Calm or light winds favor fog formation because strong air movement typically prevents saturation by mixing drier air into the moist layer.

So why did we have so much fog in the valley this winter? The first part of the 2025-2026 season delivered abundant rainfall. This rainfall replenished reservoirs, increased river levels, and significantly improved soil moisture. In the atmosphere, a high-pressure system was built that acted as an invisible lid to trap the soil moisture closer to the ground. The lack of stormy air movement enabled this high-pressure system to persist over the Valley and the Tule fog conditions kept recurring.

Although fog can create hazardous driving conditions, it can be beneficial for California's agricultural landscapes. When fog covers large areas, it reduces incoming solar radiation, which lowers evapotranspiration rates from soil and plant surfaces. In addition, saturated air limits further evaporation.

For example, if a rainy day is followed by several clear, sunny days, much of the moisture gained from rainfall may evaporate from the surface soil. However, if fog persists between rain events, evaporation slows, allowing more time for water to infiltrate deeper into the soil profile. This stored soil moisture can serve as an important reservoir for the next growing season. Of course, this is a simplified illustration. Rainfall intensity, duration of fog, air temperature, soil type, and many other variables influence how much water ultimately remains in the soil.

One downside of heavy winter rains is rapid runoff. When rainfall intensity exceeds the soil's infiltration capacity, excess water flows as a runoff, which can overwhelm infrastructure and cause downstream flooding. In some years, this amount of water available for groundwater recharge would be better used by being captured down the soil profile, particularly important in regions with overdrafted aquifers.

Unfortunately, forecasting complex weather patterns involving rainfall, snowfall, humidity, temperature, and fog becomes increasingly uncertain beyond 10–14 days. The farther into the future a forecast extends, the lower its reliability.
Weather patterns can appear stable over long periods, but the climate is changing in ways that increase water loss through evapotranspiration and runoff compared to precipitation gains in many regions. Short-term weather is difficult to predict because the atmosphere is complex and chaotic. Even with modern satellites, models, and data systems, reliable detailed forecasts generally extend only about 10 days into the future, sometimes up to 14 days with decreasing accuracy. Predicting the balance between local evapotranspiration and rainfall is also challenging. Evapotranspiration is strongly influenced by local factors such as temperature, vegetation, soil moisture, and wind. In contrast, rainfall patterns are often driven by large-scale atmospheric systems.

How does mountain snow impact our water storage? Snowpack in the mountains increases our water storage as long as it doesn't melt and run off with the river flows too soon in the beginning of the year. Many meteorologists and climate scientists project that in regions like California, precipitation may occur less frequently but in more intense events. Climate scientist Dr. Daniel Swain cleverly calls this new trend "Precipitation Whiplash". Figure 2. shows winter cumulative precipitation gains and evapotranspiration potential losses over vegetated surfaces near Davis, CA over a 30-year (1995-2026) period. We can observe that there used to be a pattern of rain being higher in volume than the evapotranspiration loss up until 2011 (except for one winter 2006-2007). Since the drought started in 2011, there have been 7 winters with water deficit when evapotranspiration was higher than the rain. It is also notable that out of the 4 wettest winters (cumulative rain was > 25 inches) in the past 30 years, 3 occurred in the last 8 years. Warmer winters are also causing a shift from snow to rain in some areas, and snow is melting earlier in the season with increase in evapotranspiration rates. Earlier snowmelt reduces natural water storage in mountain snowpack, which historically acts as a reservoir and is often called California's "frozen reservoir". According to the water managers at the state level (Department of Water Resources), on average, the Sierra snowpack can supply about 30 percent of California's water needs annually. It is also true that California's short distance between mountain watersheds and the coast allows rapid runoff of surplus water to the ocean. Evapotranspiration further removes water from the system, reducing the amount available for groundwater recharge and soil storage. As increasing climate variability adds uncertainty, the combined effects of these processes make water management more complex for farmers.

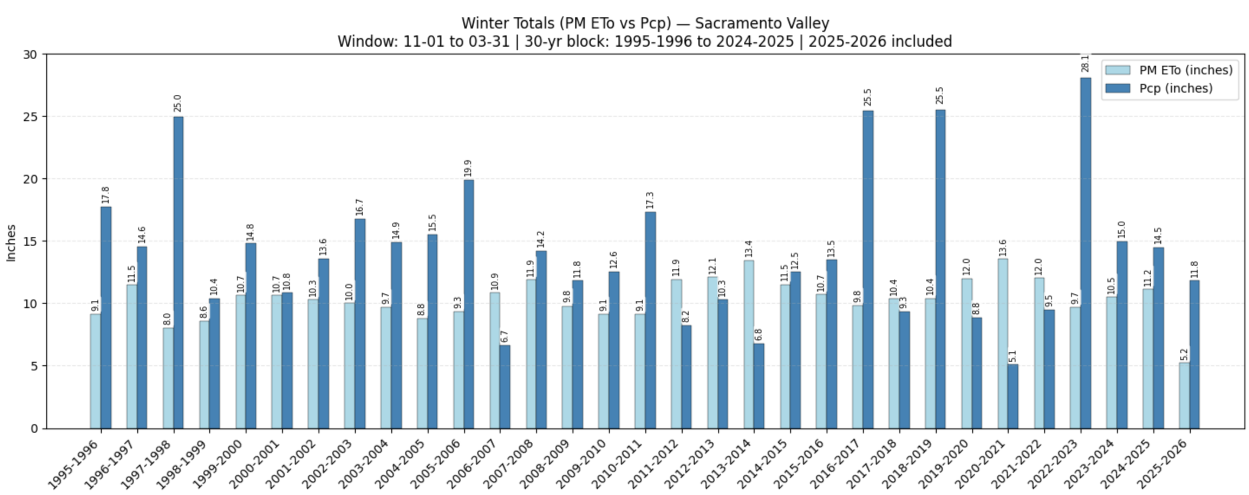

Figure 2. Comparison of cumulative winter (November - March) precipitation and Penman Monteith reference evapotranspiration (PM ETo) from CIMIS station over a 30-year period. The winter 2025-2026 is based on data November 1, 2025 - February 25, 2026, that was available at the time of this article preparation.

Because weather variability and climate shifts are increasing uncertainty, farmers face more complex decision-making. While we cannot control weather patterns, adaptation strategies, such as improved water storage, soil management, crop selection, and irrigation efficiency, can help reduce current risks. At the same time, State water managers are doing their best to help combine surface water with groundwater and snowpack for numerous water users.