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Nitrogen Fertility in Common Beans following Whole Orchard Recycling

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Introduction:

Whole Orchard Recycling (WOR) occurs after the productive life of an orchard and is the process of grinding or chipping trees, spreading the wood chips evenly over the soil surface, and then incorporating the biomass into the soil. WOR has become more common in recent years because air quality regulations restrict growers' ability to manage biomass by burning. Additionally, half of California's biomass power generation plants have closed, and those that still operate are no longer paying for wood chips.

While the process of WOR came about due to biomass management restrictions, researchers have been evaluating the potential benefits it may have for resource management, including soil health and water management. This is because the practice incorporates large quantities of organic carbon (C) into the soil, and soil C influences other soil properties. Over the short term, WOR has been found to reduce soil compaction, improve water holding capacity and infiltration, and enhance nutrient cycling. Over the long term, the benefits have additionally included higher soil carbon, nitrogen (N), and microbial activity (UC ANR, 2019). The California Department of Food and Agriculture (CDFA) Healthy Soils Program (HSP) now recognizes the practice in their incentives program and provides growers with up to $800 per acre for WOR. The San Joaquin Valley Air Pollution Control District also supports growers who recycle orchards with up to $600 per acre.

While there are benefits associated with incorporating large quantities of C into the soil, there are also tradeoffs. The woody biomass of the trees has a high carbon to nitrogen (C:N) ratio. The C:N ratio is the mass of C relative to the mass of N. It is an important characteristic of soil amendments because it influences soil biological activity. Microbial metabolism is balanced when soil amendments have a C:N of 24:1 (USDA-NRCS, 2011). This ratio is approximately the ratio of alfalfa hay. When the C:N is higher, the N is primarily used for microbial energy and maintenance. In other words, the N is 'tied up' by the microbes and not available for plants.

Our understanding of nutrient cycling and availability is most advanced in almond WOR sites replanted back to almond. Previous research at WOR sites that were replanted back to almond found that extra N was needed in the first year to avoid reduced growth. The UC recommendation is to double the N application in the first year after replanting, applying it gradually over the year (Holtz, 2019).

We established this trial because more research is needed on WOR in other orchard systems, and when annual crops are subsequently planted rather than orchards. The trial involved recycling walnut trees instead of almond, was followed by a winter cover crop, and then was planted with light red kidney beans. Our objectives were to evaluate soil properties and bean yield following WOR compared to a non-WOR control, and to evaluate two N fertilizer rates. We hypothesized that bean yield might be compromised following WOR due to N immobilization but that higher fertilizer N might overcome the yield gap.

Methods:

The trial took place in 2020 on an approximately 35-acre site near Linden, following the June 2019 walnut orchard recycling that incorporated approximately 70 tons of wood chips per acre (Figure 1). At that time, three approximately 0.5-acre plots were kept without wood chips, as 'untreated controls'. We then identified three 0.5-acre WOR plots adjacent to each control plot.

Figure 1. Recycled orchard site showing wood chips spread over the field and the depth of wood chips applied.

Following recycling, the grower planted a mixed brassica winter cover crop that grew vigorously and was over 5 feet tall by spring. In early-April, we observed that the wood chips had been colonized by saprophytic fungi (Figure 2). In late-April the cover crop was mowed, disked twice, and plowed to 16 inches to bury the residue.

Figure 2. After the June 2019 WOR, a winter brassica cover crop was planted. In early-April 2020, prior to cover crop termination, soil microorganisms were observed to have colonized the wood chips.

In late-May, we took soil samples from across the field – not discriminating between WOR and control plots – to quantify the residual soil nitrate for the purpose of informing our sidedress N rates. Soils were analyzed by a commercial lab. There was approximately 6 ppm nitrate-N in the top 6 inches and 3 ppm from 6-12 inches, for a total residual nitrate level of approximately 18 pounds per acre in the top foot of soil.

In June, we soil sampled from the WOR and control plots, in 0-6 and 6-12-inch depth increments. The field was bedded up into 60-in beds, and the grower applied herbicides and pre-irrigated the field. Due to the large amount of organic amendments (wood chips and cover crop), the field took longer than expected to irrigate and dry down.

Bean seed inoculated with *Rhizobium* was planted on July 10th. Two rows of beans were planted per bed. A starter fertilizer of 4-10-10 was applied at 25 gpa, for an approximate at-planting N input of 10 pounds per acre. In August, beans were treated for worms and mites and were cultivated.

The UC production manual for dry beans indicates that a bean crop that yields 2000 lb/acre needs approximately 80-120 lb of N to grow the crop. While beans are a legume and can fix atmospheric N and turn it into plant-available N, they do not fix enough to satisfy their own N requirement. They fix about 20-40 percent of their need. The grower decided on an N rate within the recommended range, and we evaluated a doubled sidedress rate since previous research has shown that plant-available N can be limited the first year after WOR. The sidedress application was made in August, and we applied the doubled rate to nine beds (i.e. 18 bean rows) per replicated block. The grower rate was 25 gpa of UN32, and the doubled rate was 50 gpa. Total available N from soil and fertilizer is shown in Table 1.

Table 1. Nitrogen inputs in 2020 trial.

Source	Grower rate	Doubled rate
Soil residual	18 lb	18 lb
At-planting fertilizer	10 lb	10 lb
Sidedress fertilizer	88 lb	176 lb
Total	116 lb N/ac	204 lb N/ac

On October 12th, we soil sampled across all treatments from 0-6 and 6-12 inches. We harvested the beans shortly after, on October 19th. We harvested 2250 sq-ft per plot (i.e. three beds wide by 150 ft long), avoiding edge beds of the N treatments.

The trial was a split-plot experimental design with three replicated blocks (Figure 3). We treated the WOR treatment as the main effect, nesting N rate as the sub plot effect. Data were analyzed by ANOVA with means separated by Student's t test or by Tukey's range test (α = 0.05). Yield data were transformed for analysis to satisfy the statistical assumptions for normality.

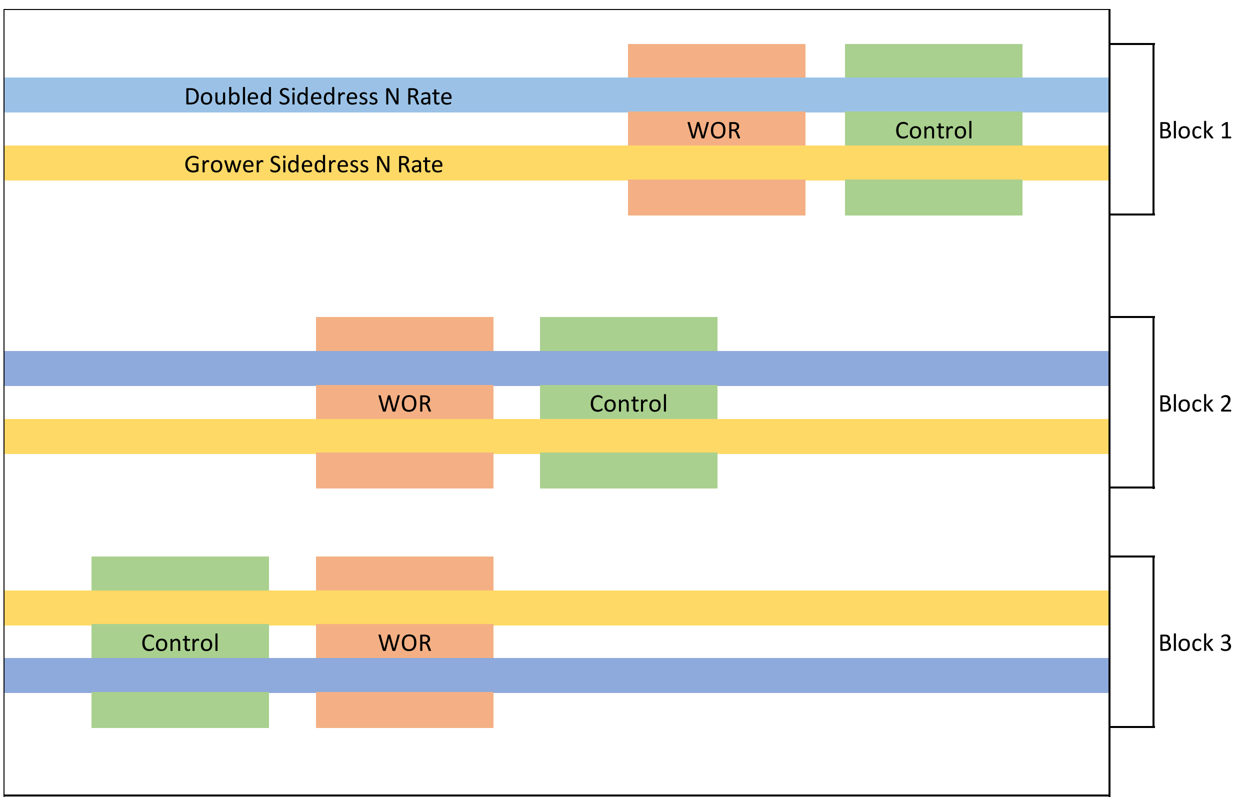

Figure 3. The trial was a split-plot experimental design, where the recycling treatment was the main effect, and the fertilizer rate was the sub plot effect. The WOR and control plots were approximately 0.5 acres each, and the fertilizer treatments were 45 feet wide. The figure is not drawn to scale.

Results and Discussion:

Soil samples were evaluated for organic C, total N, and nitrate-N. In June, there were no differences in organic C (P = 0.7491), total N (P 0.3375), or nitrate-N (P = 0.7028) between the WOR treatment and control. Total organic C averaged 1.2 percent across all plots, total N averaged 1052 ppm, and nitrate-N averaged 2.78 ppm. The only statistical difference that we observed was between soil depths for nitrate-N (P = 0.0146), with the 0-6-in layer averaging 3.4 ppm, and the 6-12-in layer averaging 2.2 ppm, but this difference has negligible agronomic significance.

In August, prior to sidedress N application, we observed differences in plant size, with plants in the WOR treatments being smaller than those in the control plots (Figure 4). We did not collect any data related to plant size.

Figure 4. Bean plants in August 2020, prior to sidedress N application, where plants in the WOR treatment were observably stunted compare to those in the control plots where no wood chips were previously incorporated. A) Plants to the right of the pink flag in the foreground are in a control plot. B) Bean plants in the foreground near the pink flag are in a control plot.

By October, soil organic C, total N, and nitrate-N differed among treatments but not between 0-6 and 6-12-in depths. Organic C was significantly higher in the WOR treatment compared to the control (Figure 5A). From June to October, organic C increased from 1.2 to 1.4 percent in the WOR treatment but did not measurably change in the control. There were no differences in organic C between N fertilizer treatments (P = 0.3140). Total N had similar results, with the WOR treatment having higher total N compared to the control (Figure 5B), and no differences between N fertilizer treatments (P = 0.2021). From June to October, total N increased by about 180 ppm in the WOR treatment but did not change in the control. Nitrate-N, however, had an opposite result. It was significantly higher in the control compared to the WOR treatment (Figure 6A), and there were differences between fertilizer rates. The grower N rate in the WOR treatment had statistically lower nitrate-N compared to both N rates in the WOR treatment (Figure 6B). The soil results suggest that, by October, the wood chips were decomposing and contributing to the soil organic C and N pools. The organic N, however, was not yet mineralizing to nitrate. Nitrate was limited in the WOR treatment, where it was possibly tied up by soil microbes, unless supplemented by the doubled rate sidedress fertilizer.

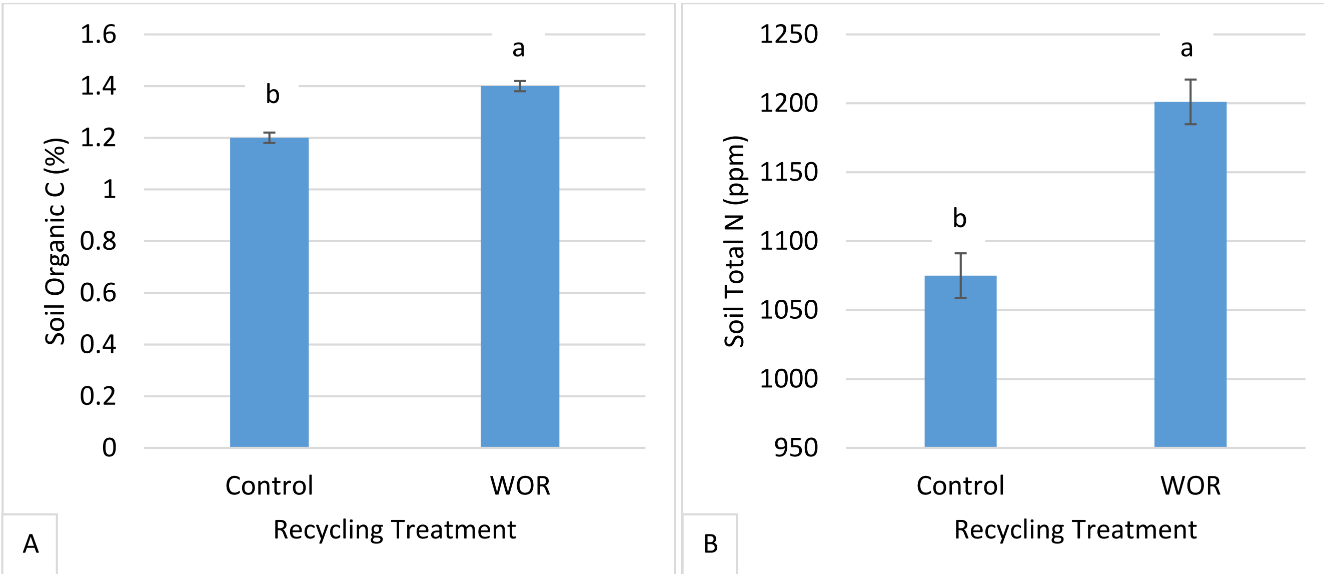

Figure 5. Soil properties in October 2020 averaged across three replicated blocks and two depth increments (i.e. 0-6 and 6-12 inches). A) Soil organic C was significantly greater in the WOR treatment compared to the control ($P < 0.0001$). B) Soil total N was also significantly greater in the WOR treatment compared to the control ($P < 0.0001$). The error bars represent the standard errors.

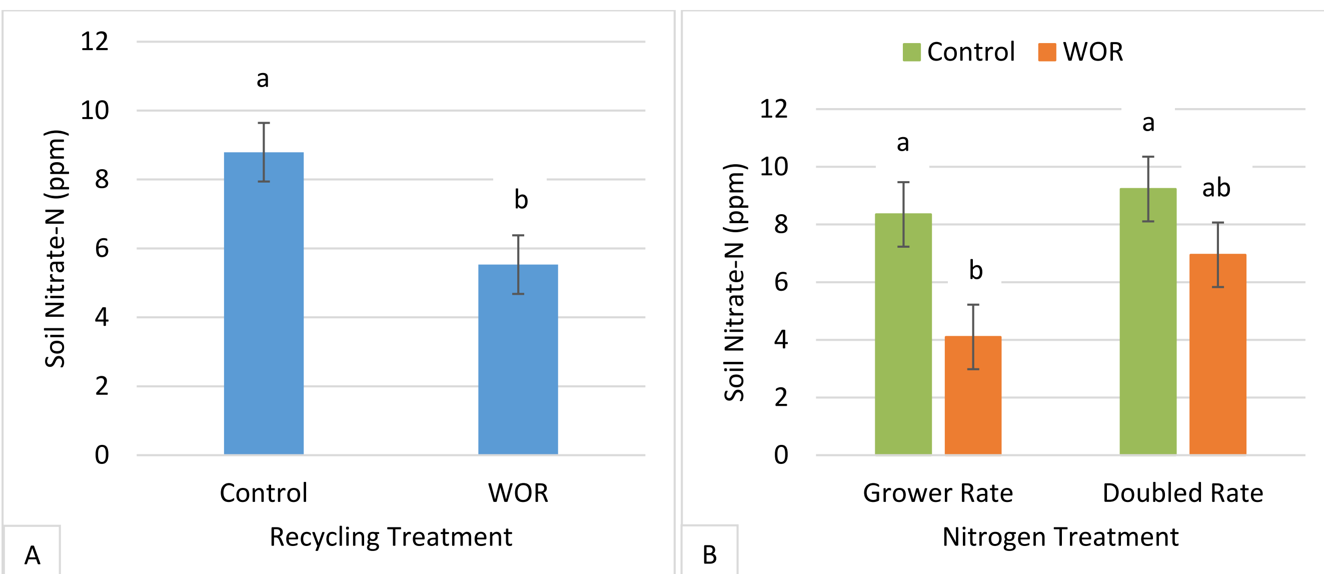

Figure 6. Soil nitrate-N in October 2020 averaged across three replicated blocks and two depth increments (i.e. 0-6 and 6-12 inches). A) Soil nitrate-N was significantly greater in the control compared to the WOR treatment ($P = 0.001$). B) Soil nitrate-N differed across N fertilizer treatments ($P = 0.0404$), with significantly less nitrate-N in the WOR grower N rate treatment compared to both N rates of the control. The error bars represent the standard errors.

Whole orchard recycling and nitrogen fertilizer rate impacted yield in this trial. Yield was statistically higher in the control plots, averaging 2652 lb/ac across replicates, compared to the WOR plots where the average was 1820 lb/ac (Figure 7A). There were also differences in yield among N fertilizer rates (Figure 7B). In the control, the grower N rate and the doubled N rate performed statistically similar. In other words, there was no benefit to applying the doubled sidedress rate in the control. Additionally, the grower rate in the control performed statistically similar to the doubled rate in the WOR treatment. This indicates that while WOR may tie up N – limiting its availability for plant growth and yield – doubling the recommended N rate overcame the yield penalty imposed by WOR. Thus, when coupled with additional N fertilizer, WOR can augment soil health properties, like organic C and N, without penalty to yield.

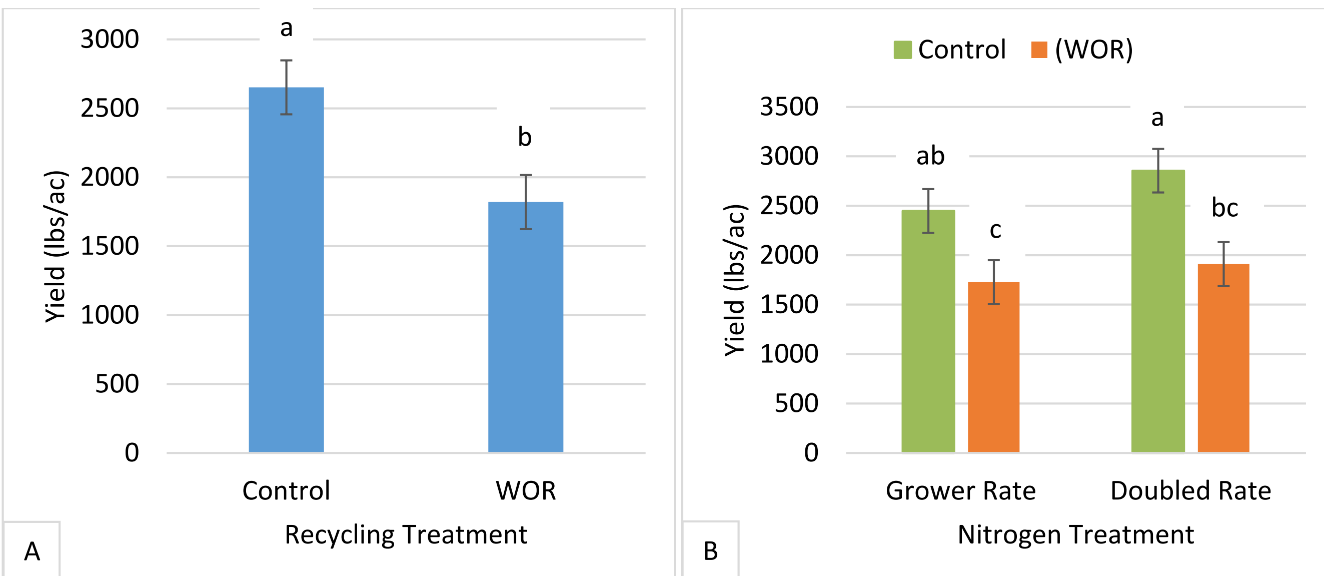

Figure 7. Bean yield in October 2020 averaged across three replicated blocks. A) Bean yield between WOR treatment and the control were statistically different ($P = 0.0004$). B) Bean yield for N fertilizer rates: while the ANOVA test indicated no statistical difference in treatments ($P = 0.0682$), the Tukey test detected differences. Bean moisture averaged 10.5 percent across all treatments.

Summary:

Whole orchard recycling is a practice for managing orchard biomass. By incorporating a large quantity of organic C into the soil, WOR has the potential to improve soil health properties, but a tradeoff may be that N becomes limiting for subsequent crops. This project evaluated soil properties and kidney bean yield following walnut WOR. We found organic C and N to increase with WOR from the beginning of the bean season to the end, but plant-available nitrate was limited by WOR. Bean yield suffered as a result of WOR, but doubling the fertilizer N recommendation mitigated the yield penalty. Under the circumstances of this trial, a total N rate of just over 200 lb/ac maintained bean yield where WOR had been implemented compared to the control plots with no wood chips. It does appear, however, that the yield in the WOR treatment might have benefitted from an even higher rate of N. To our knowledge, this trial was the first of its kind and more research will be needed to develop N fertility guidelines in dry beans following WOR. Other tree and annual crops should also be studied. We will continue this trial in 2021 to evaluate whether the impacts of WOR continue in the second season after recycling.

Acknowledgments:

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