exceeded 9%, and acid detergent fiber concentrations were less than 32% (table 3). The nutritional value of yellow starthistle in early stages thus appears to be acceptable as a component of a ruminant's diet. Toxicity is not a problem with ruminants but is well known with horses. Ruminants should never be encouraged to graze yellow starthistle after it produces spines; the stout, sharp, 1-inch spines can injure grazing animals.

Conclusion

Our preliminary results show that both herbicide plus grazing applications and grazing alone provide some measure of success in managing yellow starthistle. The herbicide applications substantially decreased yellow starthistle densities. However, they also eliminated all other broadleaved plants within the sprayed strips and reduced total biomass production.

Intensive grazing in late May and June had little effect on yellow starthistle densities, but it reduced plant height, canopy size, and seed production in the unsprayed areas. This late-season grazing occurred after annual grasses, legumes, and most other resident annuals had matured, allowing for seed bank replenishment and leaving appreciable amounts of plant residue on the ground.

As with all of California's annual range vegetation, rainfall had a major influence on yellow starthistle's density, plant size, and productivity at the two sites.

While we have achieved some management success, we expect some starthistle reestablishment. We therefore intend to apply greater grazing pressure during the critical control period with the objective of further reducing seed output. We are also establishing a site on the UC Davis campus to test sheep as biocontrol agents for yellow starthistle management.

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Orchard floor treatments, at midseason, included clean cultivation (foreground), planted annual grass killed with an herbicide application (background), and mowed, planted annual grass (distant background). Permanent cover was also tested.

Improving orchard soil structure and water penetration

Daniel C. Moore ❑ Michael J. Singer ❑ William H. Olson

Soil surface crusts can severely limit water infiltration and tree crop production. Vegetative cover and gypsum treatments in an orchard increased soil structural stability and may reduce crust formation in the long term. Tillage improved short-term water penetration by temporarily breaking up the crust.

Slow water penetration is a major factor limiting crop production in California's orchards. Causes of this problem include surface crusts, tillage-induced compacted layers, and restrictive soil layers such as clay-rich subsoil horizons. Low water intake rates are associated with reduced yield, increased disease susceptibility, and poor water use efficiency (increased runoff and evaporation losses).

Surface crusts result from structural deterioration of surface soil and its organization into a dense, restrictive layer at the soil surface. Management practices, soil properties, and irrigation water quality each may contribute to structural deficiencies that can lead to crust formation.

Cultivation contributes to structural deterioration of soil in several ways. Removal of the protective plant cover from between orchard tree rows makes these areas susceptible to mechanical disturbance by raindrops and overland water flow. Raindrop impact and overland flow are the energy inputs that form structural and depositional crusts, respectively. Cultivation also accelerates the decomposition of soil organic matter, the depletion of which is usually accompanied by a decrease in soil aggregate stability. Finally, cultivation reduces structural stability directly by physically compacting and destroying soil aggregates. Poor soil structural stability increases both the likelihood and the severity of crusting problems.

The chemical dispersion of clay can also play a large role in structural deterioration. During irrigation, dispersed clays become mobile and may be washed into pores, blocking them, or they may be deposited and oriented on the soil surface as part of a depositional crust. Susceptibility to dispersion is related to the chemistry of both the soil and the infiltrating water. High levels of sodium in the soil promote clay dispersion. Low salt concentrations in the irrigation water further encourage dispersion. Even where soil properties are favorable, low-salt irrigation water may produce dispersion, depending on clay type.

Potential management solutions would reduce crusting problems by promoting soil structural stability and improving soil infiltration. Such strategies include the establishment of cover crops, modification of conventional tillage practices, and use of chemical amendments such as gypsum.

We are conducting a 5-year study to evaluate the long-term effects of vegetative cover, tillage, and gypsum in managing an orchard's depositional crusting problem. Now in its third year, the study is designed to achieve this objective by assessing soil structural stability and water penetration. This report presents information gathered during the 1988 growing season, after 2 years of treatment.

Experimental design

The experimental plots are in a Butte County prune orchard north of Gridley. The soil is a Gridley loam (exchangeable sodium percentage, 4.0), irrigated with Feather River water (soluble salt concentration, less than 1 milliequivalent per liter). Irrigation is by flooding north-south trending rows of the orchard every 18 to 20 days. The crust forms as water carries and subsequently deposits soil particles on the soil surface during irrigation sets. Transporting of material is particularly severe near the irrigation outlet valves, where water flow energy and turbulence are greatest.

The study has a split-split plot design. Two main plot treatments each contain four subplot treatments, giving a total of eight. The main plots are: gypsum amended to the soil surface at 2 tons per acre in mid-spring; and no gypsum. The subplot treatments are: permanent cover (ryegrass and berseem clover) mowed when necessary; fall tillage followed by a planted annual grass (barley or wheat) mowed when necessary; fall tillage followed by a planted annual grass (barley or wheat) killed with herbicide in the spring; and clean cultivation, including fall and mid-season disking. Treatments are replicated three times giving a total of 24 plots.

We evaluated soil structure by a wet-sieving procedure to determine aggregate stability. Determinations were done on surface aggregates collected in the spring (after application of gypsum) and again in the fall (after harvest). We assessed water penetration by using a neutron hydroprobe to measure soil moisture at depths of 8, 20, and 40 inches from a pair of access tubes in each plot. We took measurements before and after individual irrigations, and subtracted "pre-" from "post-" irrigation moisture measurements to obtain the change in soil moisture at each depth due to the irrigation.

Results and discussion

Aggregate stability results suggest that soil structure has improved in the vegetative cover and gypsum treatments (table 1). Several individual treatments performed particularly well. Soil aggregate stabilities under the gypsum-amended mowed and killed annual grass plots (GYP BM and GYP BK) were significantly higher than in several other treatments in the spring. The gypsum-amended killed annual grass remained significantly higher than most treatments in the fall. Based on the composited spring-plus-fall data, this treatment showed a significantly higher aggregate stability than all others.

TABLE 1. Comparisons of soil aggregate stability values for spring, fall, and composited surface samples, in three treatment groupings

Treatment*	Aggregate stability◊ Spring + fall	Spring	Fall
	.... %		
INDIVIDUAL:	(n = 30)	(n = 15)	(n = 15)
GYP BK	95.6 a	96.2 a	95.1 a
NO GYP BM	93.9 b	93.8 b	94.0 ab
GYP PC	93.8 b	94.7 ab	92.9 bc
GYP BM	93.7 b	96.2 a	91.3 c
GYP CC	93.6 b	94.9 ab	92.3 bc
NO GYP PC	93.1 b	95.0 ab	91.3 c
NO GYP BK	92.8 b	94.4 ab	91.2 c
NO GYP CC	92.4 b	93.5 b	91.4 c
COVER:	(n = 60)	(n = 30)	(n = 30)
BK	94.2 a	95.3 a	93.2 a
BM	93.8 ab	95.0 a	92.7 a
PC	93.5 ab	94.9 a	92.1 a
CC	93.0 b	94.2 a	91.8 a
GYPSUM:	(n = 120)	(n = 60)	(n = 60)
GYP	94.2 a	95.5 a	92.9 a
NO GYP	93.1 b	94.2 b	92.0 a

* Treatments: Main plots = GYP, gypsum; NO GYP, no gypsum. Subplots = BK, fall tillage followed by planted annual grass (barley or wheat) killed with herbicide in spring; BM, fall tillage, then planted barley or wheat, mowed when necessary; PC, permanent cover (reygrass and berseem clover) mowed when necessary; CC, clean cultivation, including fall and midseason disking.

◊ Means followed in a column by the same letter are not significantly different at $P = 0.05$.

The three vegetative cover treatments were intended to promote soil structure by increasing levels of soil organic matter. Shading of the soil surface may also enhance structural stability by lowering soil temperatures and promoting earthworm activity. In addition, a dense stand of vegetation can reduce irrigation flow energy, minimizing the disruptive forces on surface aggregates. Comparison of cover treatments shows no significant differences under either the individual spring or the fall samplings, but trends for both cases are the same. When results are combined over the entire season, the soil shows a significantly higher stability under killed annual grass than under the clean cultivated treatment. With time, these differences may be further accentuated with buildup of organic matter under the vegetative cover treatments.

The effect of gypsum on aggregate stability is evident in the spring measurements, made one irrigation after the gypsum addition. Here, surface soils in the gypsum-treated plots show significantly higher aggregate stabilities than those in non-treated plots. The fall measurements indicate a decrease in the effectiveness of the gypsum. The gypsum-treated soil is still higher in aggregate stability, but not significantly so. When composited over the season, the gypsum effect remains statistically significant.

The decrease between spring and fall aggregate stability suggests that soil structural stability varies with time. The effects of organic binding agents, such as polysaccharides, in promoting soil structure may be transient (weeks in duration) because of their rapid decomposition by microorganisms. Roots and hyphae may produce a longer but still only temporary positive effect (months in duration). The effects of gypsum are similarly expected to be short-lived, as is indicated by the loss of significance in the difference between the fall gypsum and nongypsum plots. Because gypsum improves structural deficiencies by chemical means, the effect of the material mostly dissipates with its dissolution and leaching.

In terms of water penetration, no vegetative cover treatment had any advantage over the clean cultivated plots (fig. 1). Before the midseason disking of the clean cultivated plots (irrigations 1 and 2), there were no significant differences among any of the treatments at any depth. Immediately following the disking of the clean cultivated plots (irrigation 3), significant differences

Surface structure of clean cultivated treatment (midseason) deteriorated after one irrigation. (Lens cap is 55 mm diameter.)

appeared between the clean cultivated and the killed annual grass treatments at the 8-inch depth, and between the clean cultivated and both permanent cover and mowed annual grass treatments at the 20-inch depth. These significant increases in moisture change for the clean cultivated plots indicate a positive effect of the disking in physically destroying the crust.

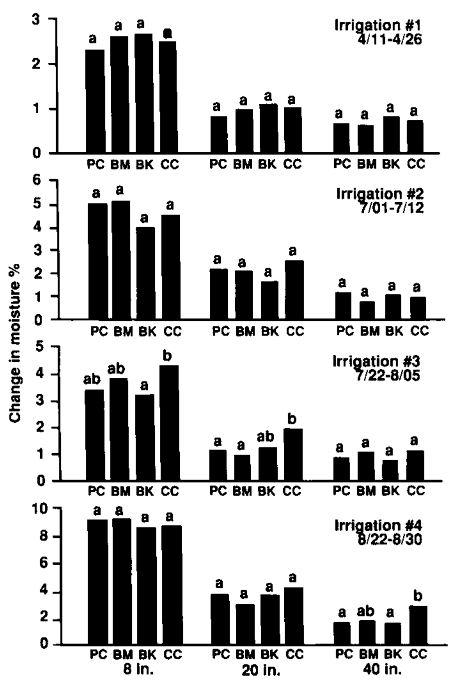

Fig. 1. Moisture percentages at three depths showed similar water penetration in all treatments at first. After midseason disking, cultivated plots (CC) were significantly better ($p=0.05$). (See table 1 footnote for explanation of treatments.)

For the final irrigation, significant differences appeared between the clean cultivated and both permanent cover and killed annual grass treatments at the 40-inch depth. However, the final irrigation again showed no significant differences in moisture change at the 8- and 20-inch depths, suggesting that the beneficial effect of disking was temporary and that the crust reformed quickly.

Conclusions

Treatments selected for this experiment were designed to combat surface crusting problems. Only the clean cultivated treatment showed a significant increase in water penetration over any of the irrigations, and therefore it may appear to be the superior management practice here. In soils of poor structural stability where crusting is pronounced, shallow tillage to break up the crust may markedly improve infiltration rates. The effect is temporary, however, and frequent tillage is required. For such a system, an optimum tillage intensity is needed that breaks up the crust without contributing to additional structural deterioration or compaction of the subsoil to form a plow pan. Such pans may eventually become as limiting to water penetration as the surface crusts themselves.

Despite the lack of water penetration benefits in the vegetative cover treatments after two years, trends in aggregate stability data suggest that soil structure under these treatments is improving. Because organic matter has temporary effects in improving soil structure, annual additions must be part of a management system. Where soils have been cultivated, several years of continuous vegetative cover may be necessary to build up organic matter levels to a point where structure and infiltration are significantly improved. Therefore, the lack of a demonstrated positive effect on water penetration after only 2 years of vegetative cover is expected.

The gypsum-treated plots had higher aggregate stabilities than did the nontreated plots. Gypsum has a two-fold effect in promoting structure and infiltration. First, the addition of gypsum to the soil may replace sodium with calcium in the soil exchange complex, which may improve soil structure by decreasing the swelling of soil particles. Second, the dissolving of gypsum during irrigation increases the salt concentration of the infiltrating water, retarding dispersion. Gypsum is most effective where irrigation water is low in salts.

Two treatments investigated here attempt to combine the positive attributes of tillage and nontillage management systems. The mowed and killed annual grass vegetative treatments add organic matter to the soil by incorporation, decomposition, or both. Annual disking can break up any restrictive surface layers that may form despite the presence of the vegetative cover. Also, these treatments do not provide a year-round environment for pests as does a permanent cover.

Variability in soils, irrigation water quality, and cropping histories prohibit any "blanket solutions" for water penetration problems in California orchards. Management of such problems may be highly site-specific. In the test orchard, water infiltration is largely limited by poor surface and near-surface soil structure and the formation of a depositional crust. Potential solutions should therefore focus on improving and maintaining soil structure and on reducing the picking up and deposition of sediment. Based on data presented here, structural improvements resulted from the buildup of soil organic matter under vegetative cover and from the promotion of a more stable, less dispersive soil environment through the amendment of gypsum. The treatments did not reduce depositional crusting.

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