WEED CONTROL IN RICE: WHERE HAVE WE BEEN? WHERE ARE WE GOING?

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California yields have more than tripled since rice was introduced in 1912. Improved varieties, more efficient fertilizer management, laser-directed leveling and herbicides have all contributed to advancing yields. In California as in most of the other highly mechanized rice cropping areas of the world, rice is direct-seeded. However, the vast majority of the world's rice area, principally in Asia, is still transplanted. Most rice historians believe that the ancient practice of transplanting was adopted not only to shorten the growing season, but more importantly to control weeds. Three to five week old transplant seedlings have a head start on newly germinating weeds as well as the advantage of tolerating a continuous flood which further suppresses weed growth. It is interesting to note that the increasing wealth of Asian nations is rapidly leading to direct-seeded rice to offset higher labor costs.

In California, rice was initially dry-seeded, but the rapid buildup of barnyardgrass all but rendered much of the land useless for production after three years of continuous rice. Following the lead that continuous flooding greatly suppressed many weeds, especially barnyard grass and sprangletop and to a large extent the watergrasses (*Echinochloa* and *Leptichloa* species), water seeding of pregerminated seed was introduced in California. With regard to continuous flooding, water-seeding followed the ancient practice of transplanted rice systems for weed suppression. Although water seeding adequately controlled many small-seeded grass weeds, aquatic weeds such as ricefield bulrush, smallflower umbrella sedge, California arrowhead, water hyssop, ducksalad and others flourished in the aquatic system. Furthermore, the grass complex shifted to the large-seeded *Echinochloa* species of watergrass, capable of surviving continuous floodwater. The post World War II introduction of the phenoxy herbicides 2,4-D, 2,4,5-T and MCPA greatly improved the control of aquatic broadleaf and sedge weeds. These herbicides were followed in succession by bentazon (1979) and bensulfuron (1989) as the major herbicides for broadleaf weed control. Grass herbicides were also introduced: First propanil (1964), which also controlled some broadleaf and sedge species; then molinate (1973), an *Echinochloa* herbicide, followed by thiobencarb (1981) a grass herbicide with good activity on smallflower umbrella sedge and suppression of a few broadleaf aquatic weeds. Each of these herbicides contributed significantly to good weed control and the unprecedented high rice yields of the 1990s. Their introduction and use patterns are shown in figure 1. But herbicide resistance, weed species shifts, water pollution and drift to sensitive crops have taken their toll on herbicide registrations and use patterns in California rice. Furthermore, the difficulty of herbicide registration in a relatively small rice market and in an aquatic environment has limited the growers choices for herbicide rotation to avoid these problems. Hence, weeds remain as the primary pest problem of California rice growers.

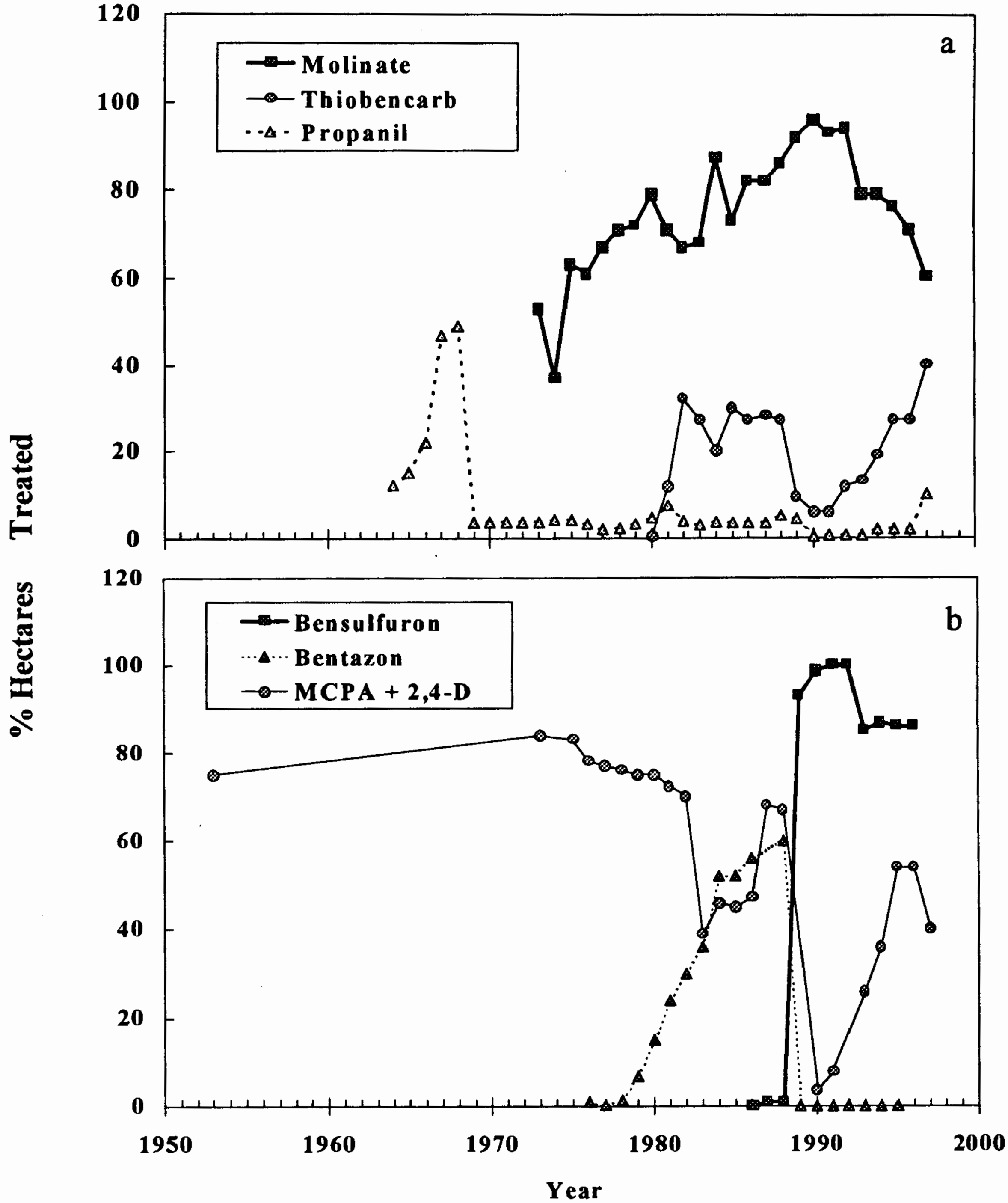

Figure 1. Herbicide use patterns over time: (a) California grass herbicides; (b) California broadleaf herbicides.

Weed Resistance: Weed resistance is caused by a genetic shift rendering a species once normally controlled by a herbicide the ability to survive treatment. Bensulfuron was introduced in 1989 to California rice and by 1993 four aquatic broadleaf and sedge species had develop resistance. The single gene mechanism for ALS inhibitors such as bensulfuron was highly vulnerable to selection for resistance, but even herbicides with more complex mechanisms of action used continuously may eventually allow selection for resistance. It took many years of use for barnyardgrass and junglerice to develop resistance to propanil in the southern United States and South America, respectively. It appears now that resistance of late watergrass to molinate, thiobencarb and fenoxaprop has developed in California rice . Resistance is most often the result of continuous use (every rice crop) or overuse (higher rates or more applications than needed) of a single herbicide. Herbicide resistance is best solved by rotating or combining herbicides with different mechanisms of action or with crop rotations (limited in rice) or targeting rates to the dominant weed species if less than the label rate will provide control. The early identification of resistance is important to begin management strategies before seed banks of resistant biotypes build up to levels that ensure a continuous source of seed for future recruitment. The recent removal of phenoxy labels for rice will exacerbate the problem of herbicide resistance in California rice.

Weed Species Shifts: Weed shifts are caused by increases in weed species that are not controlled by the principal herbicides used in the rice cropping system. For example, the widespread use of bensulfuron which effectively controlled annual species, allowed many of the perennial species such as Greg's arrowhead to expand. Similarly, the adoption of early drainage or the so-called pin-point flood has increased the abundance and incidence of sprangletop as a problem weed. Solutions to weed species shifts are similar to those for weed resistance--rotation of crops, herbicides and management practices to break weed cycles.

Water Pollution: The aquatic environment for rice is unusual among crops and provides special challenges to prevent off-site pollution of downstream waterways with fertilizers and pesticides used in production. Although in-field water movement may actually be detrimental to weed control by dilution of the herbicide, the primary problem is water pollution from off-site movement to surface or groundwater. Weed control is affected indirectly through restricted use or the deregistrations of herbicides. In California, much has been accomplished in the management of rice irrigation and tailwaters to mitigate problems of surface water pollution.. The extensive use of recirculating irrigation systems, static irrigation systems, gravity recapture irrigation systems and just plain good water management in conventional systems has reduced off-site herbicide movement by over 95%. However, political and regulatory pressure continues to rachet down on water pollution. Perhaps the most difficult herbicide loss to good weed control and resistance management was the deregistration of bentazon use in 1989 due to very low residues found in well water.

Drift to Sensitive Crops: Herbicide drift has been a long-standing problem for rice producers. The flooded environment has favored aerial application for speed and timing, but aerially applied herbicides are more difficult to keep on target compared to those applied by ground. In California, the phenoxy herbicides have long been excluded from most areas of the San Joaquin Valley after March. Similar regulations are now being enacted for the Sacramento Valley. Thus, after 50 years of mostly successful use, the phenoxy herbicides will be severely restricted, if at all available in 1998 for California rice growers. Drift to sensitive deciduous orchards, particularly prunes, caused propanil to be restricted to a very limited acreage in 1969. More recently the acreage has been expanded due to improved formulations and restrictions to ground-only application where sensitive crops are nearby. Liability issues from drift often limit the manufacturer's interest in product registration, particularly in California where agriculture is highly diversified and rice is a relatively minor crop. The principal solution to drift problems will be from improved formulations, herbicides with less potential for drift damage, better application methods (such as the direct-dry application pioneered by DuPont for bensulfuron) and with precision ground equipment guided by global positioning systems (GPS) and operated in concert with geographic information systems (GIS) to provide historical records (and perhaps "smart" weed identification systems).

Summary: California rice farmers have taken great strides in improving field infrastructure in ways that provide good cultural and chemical management of weeds. Two of the most important are precision leveling for water management and the development of irrigation systems to control water movement within the field and to prevent water pollution from tailwaters. It will be critical to diversify weed management by coupling cultural control strategies with those new and few remaining "old" herbicides available for use. Fortunately, a few new herbicides are on the horizon such as V-10029 and carfentrazone, as well as the advent of rice genetically engineered for glufosinate and glyphosate resistance. Additionally, the expansion of currently registered herbicides such as propanil and the labeling of older products such as trichlopyr will help immensely in maintaining the diversification necessary to minimize drift, water pollution, weed shifts and resistance as previously described. At least for the near term, based on the foliar activity of both new and expanded herbicides, ground applications will increase driven by both regulations and stewardship. The old strategy of market dominance with herbicides (get there first and with the most) will have to change to one of partnerships to ensure that diversity in weed management systems is maintained.