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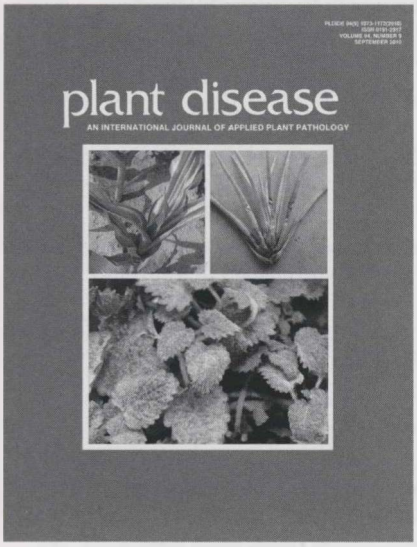

COVER

(*Clockwise from upper left*): Systemic Stewart's wilt, caused by *Pantoea stewartii* subsp. *stewartii*, on corn (courtesy M. D. Meyer et al., see page 1111); early symptom of leaf blight of the air plant *Tillandsia tenuifolia* caused by *Stachybotrys chartarum* (courtesy G.-H. Zhao et al., see page 1166); leaves and stems of lemon balm heavily infected with *Golovinomyces biocellatus* (courtesy E. Kassai-Jáger et al., see page 1169).

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FOCUS

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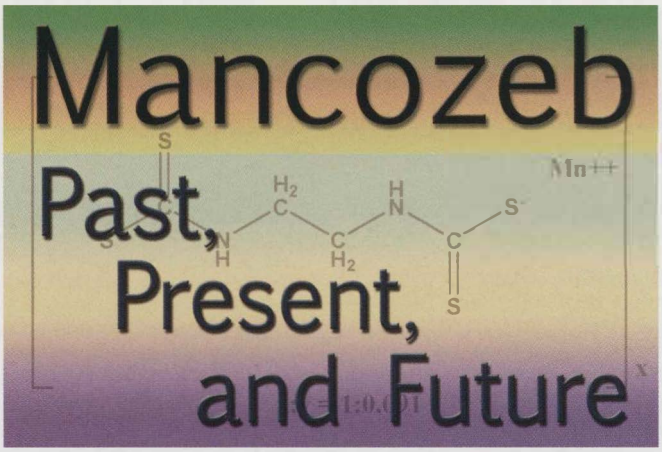
Mancozeb Past, Present, and Future



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This feature reviews the broad-spectrum fungicide mancozeb. Introduced in 1962, it still plays a significant role in the world fungicide market. Mancozeb possesses a number of key attributes that have contributed toward its development into a globally important tool in modern chemical-based plant disease management. These attributes are discussed from the perspective of both public and private research.

History and Role of Mancozeb in Disease Management

Dithiocarbamate development. For a review of the development of mancozeb, it is useful to review the history of the development of the dithiocarbamates as a group. McCallan (119) produced an excellent review of this class of products at a time when they were becoming established as key tools for the management of plant diseases. Dithiocarbamate-type compounds were originally used as accelerators in the rubber vulcanization process (119). The first derivative of a dithiocarbamate to achieve prominence as a fungicide was tetramethylthiuram disulfide, more commonly known as thiram, for which a patent was granted in 1934 (200). Thiram was demonstrated to be an effective seed dressing by Muskett and Colhoun (145), and Harrington (77) demonstrated thiram's utility for control of turf diseases. Thiram was not a particularly strong product when applied as a foliar spray, and the next generation of more active molecules based on metal salts of dithiocarbamic acid was soon to appear. Ferric dimethyl dithiocarbamate (ferbam) was first reported by Anderson (6) and independently by Kincaid (101). It gave good control of orchard diseases and gained wide acceptance as a spray for ornamentals due, in part, to the fact that its potential for phytotoxicity was significantly less than those of copper or sulfur sprays. Following ferbam was the closely related ziram (zinc dimethyldithiocarbamate), which was found to be more useful on vegetable crops (80,211).

The first dithiocarbamates were prepared from a monoamine and carbon disulfide. In 1940, W. F. Hester of Rohm and Haas, Inc., prepared a dithiocarbamate from a diamine. Hester's compound, disodium ethylene bisdithiocarbamate (nabam), can be considered the first true ethylene bisdithiocarbamate (EBDC). A patent was awarded on the compound in 1943, and the first published scientific report appeared in print in the same year (46). Nabam was unstable as a solid and had to be used in liquid form. Thirteen years after its introduction, it was demonstrated that nabam was not fungicidal in itself, and only when the compound was exposed to the air and converted into a fungitoxic active compound did it exhibit fungitoxicity. Nabam's high water solubility and relative instability meant that performance was somewhat variable (26). Heuberger and Manns (79) discovered that adding zinc sulfate to the spray tank had a stabilizing effect on the nabam. The new liquid product was commercialized in 1944 and given the trade name Dithane D-14 (26). From this point forward, utilization of the compound by growers accelerated rapidly, and it became widely adopted for management of many vegetable diseases and gained particular popularity with potato growers in the United States, where it rapidly replaced Bordeaux mixture. The reaction product that formed in the spray tank when zinc sulfate was added to nabam was zinc ethylene bisdithiocarbamate (zineb). Field tests in 1945 showed zineb to be a stable and superior fungicide, and it was rapidly commercialized under the trade name Dithane Z-78. In 1947, national cooperative potato fungicide trials were organized in the United States and tested over a 3-year period. In these studies, nabam and zineb consistently proved their efficacy for control of late blight caused by *Phytophthora infestans* and early blight caused by *Alternaria solani* on potato. In the following decade, nabam and zineb were rapidly adopted by growers in a wide range of crops. By 1953, the two products combined were being used on 75% of the total U.S. potato hectarage (26). Other significant U.S. uses were on tomatoes, onions, carrots, cucurbits, celery, hops, spinach, beets, beans, peppers, tobacco, cherries, sweet corn, and pecans. In Europe, zineb became well established for control of grape downy mildew (*Plasmopara viticola*) and apple scab (*Venturia inaequalis*). In 1952, Rohm and Haas started to operate a commercial plant in France for the manufacture of Dithane.

The development of new EBDCs continued apace, and DuPont was granted a patent for manganese ethylene bisdithiocarbamate (maneb) in 1950 (61). Maneb was more active than nabam or zineb and raised the bar for performance yet further. In 1962, Rohm and Haas registered the zinc ion complex of maneb (mancozeb), which was to become the most important and commercially significant of all the EBDCs. Two further alkylene bisdithiocarbamate fungicides were also developed at around the same time as mancozeb. Propineb was first reported in 1963, and metiram was first introduced into Germany by BASF around 1958 (201). By the mid-1960s, the EBDC fungicides were considered to be the most important and versatile group of organic fungicides yet discovered (119). This situation led to the development of mancozeb. In the intervening 46 years since commercialization, mancozeb has been developed in over 70 crops for the control of numerous fungal plant pathogens. Key representative uses for mancozeb spectrum and utility are found across a cosmopolitan range of plant groups and fungal diseases (Table 1). This theme will be discussed in more detail later in

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