

# Chemical Control of Clubroot

results from cooperative work between California Extension

chemicals applied in setting water  
controlled soil-borne fungus disease

W. C. Snyder, L. D. Leach, and R. H. Sciaroni

**San Mateo County producers** of cabbage, broccoli, and Brussels sprouts have incurred large financial losses—in the past several years—because of the clubroot disease of crucifer plants.

The clubroot disease caused by the soil-borne fungus — *Plasmodiophora brassicae*—has not been found in California, outside of San Francisco and San Mateo counties.

However, clubroot disease has been known in Europe for more than a century and in the United States for many years, where it is a major problem in certain areas, particularly in the Pacific Northwest. In 1938, the disease was found—for the first time in California—infesting large acreages of cabbage and cauliflower in southern San Francisco County and northern San Mateo County in the vicinity of Colma and Daly City.

During 1945 and 1946, clubroot was introduced into the Half Moon Bay area, probably on diseased transplants brought in from near Colma.

A young Brussels sprout plant infected with clubroot disease is at the left. A healthy plant is on the right.



There is concern among Brussels sprout growers in the central coastal counties of Santa Cruz, southern San Mateo, Monterey, and San Luis Obispo, because of the ease with which the disease is spread.

The clubroot fungus can persist in the soil for many years as resting spores. During favorable periods of temperature, moisture, and soil conditions, the resting spore germinates and produces a motile swarm spore. These motile spores invade a plant through root hairs, young roots, or wounded tissue. Infection may take place on seedlings in seedbeds or transplants in the field. Large, swollen growths—clubs—develop in the root system as a result of root cell invasion. These clubbed roots soon rot and the root system is destroyed. As a result of root infection, the tops of plants wilt and droop. Wilting of the tops of the plant is particularly noticeable on warm days. Early infection may cause death of the plant before a crop is produced. Later infection generally leads to reduced growth, lowered quality, and poor yields.

The rotting and breaking down of infected clubs releases enormous numbers of spores into the soil. A spectacular spread of the disease was observed in a Brussels sprouts planting in Half Moon Bay, where only a few diseased plants were found in a 20-acre field one season and—two years later—almost the entire planting was infected.

Because each spore is capable of initiating infection, the causal fungus can be introduced easily into clean soil by diseased plants from infested seedbeds or fields; by the movement of soil by water or wind; on plants, farm equipment, hoofs of animals, and so forth.

Where infection has occurred, a 3-to-5-year rotation interval out of susceptible crucifer crops—such as broccoli, cabbage, cauliflower, Brussels sprouts—has been of benefit but will not free the soil of fungus; it will only reduce the amount of the fungus. A satisfactory crop might possibly be obtained after such a rotation.

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**Clubroot**, a soil-borne fungus disease, threatens industry. Control was achieved on 250 acres in a

grated three-phase research program carried out by the University of California Extension Service of combining for instance, members of the University of California, Agricultural Engineering, and Vegetable co-ordinated effort toward development of an equipment, and adaptation of equipment to apply chemical strain of seed.

Paul F. Sharp  
J. Earl Coke,

resistance to clubroot  
of breeding project in

## Development

of a strain of Brussels sprouts resistant to the fungus causing clubroot disease was started because the use of chemical treatments at the time of transplanting does not provide a permanent solution for the problem.

Applications of  $HgCl_2$ —mercuric chloride — and PCNB — pentachloronitrobenzene—have been spectacularly successful in restraining the clubroot organism sufficiently to permit the growing of a good crop, but if acceptable lines of resistant sprouts could be bred, the problem could be solved without the need for such treatments. The breeding program necessary for this objective requires a number of years because the plants must be bred for several successive generations. The chemical treatments therefore have great value in providing an immediate and effective stop-gap control. Furthermore, it is of the utmost importance that the problem be attacked from both angles and that the work on both aspects be carefully integrated.

Work on the breeding of resistant Brussels sprouts was initiated in 1952,



Roots of plants grown on soil in  
Left: resistant plant of the bad  
Brussels sprouts; not

# Disease of Brussels Sprouts

Extension Service and Experiment Station in San Mateo County

California's 4-5 million dollar Brussels sprouts in Mateo County in 1954 as a result of an inter- under actual field conditions within the county. ed are an example of the policy of the Experiment es in an effort to solve county problems. In this ia Experiment Station departments of Plant Pa- Crops joined with the Extension Service in a nomical chemical control procedure, improve- nicals and a breeding program to develop a re-

Director of California Agricultural Experiment Station  
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## disease is goal Brussels sprouts

Charles M. Rick and Donald Y. Perkins



Infested with the clubroot organism.  
Left: resistant generation. Right: susceptible  
clublike malformations.

when various lines of sprouts and related crops of the cabbage species — *Brassica oleracea* — were tested for resistance in heavily infested soil at Half Moon Bay. One of the lines of cabbage tested completely remained free of the disease throughout the season despite severe damage to adjacent plant-

ings of susceptible lines.

Crosses were attempted between the resistant cabbage and the best available strains of Brussels sprouts, and since these crops are interfertile, abundant seed was produced. The resulting hybrid — F<sub>1</sub> — generation was also grown under conditions of heavy infection in 1953 and, like its cabbage parent, was found to be completely free of clubroot symptoms. This hybrid is intermediate between the two parents in such vegetative characteristics as height of stalk, development of axillary buds, and size and shape of leaf.

Having gained this evidence of dominance of clubroot resistance, the F<sub>1</sub> hybrid was backcrossed to Brussels sprouts. These crosses were again successful in

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## liquid drop valve for transplanters conserves chemicals and setting water

Norman B. Akesson and Ralph R. Parks

**Experiments** in San Mateo County showed that a metered amount of a mercuric chloride solution applied—by hand—to the roots of Brussels sprouts at the time of transplanting would control the clubroot disease sufficiently for an economic crop return.

A mechanical transplanter that would meter the liquid carrying the chemical accurately and rapidly to the immediate vicinity of the plant root would conserve both chemical and water and make possible large-scale treatment at a reasonable cost, but most mechanical transplanters discharge a continuous stream of water in the plant row. However, one type of machine in use does have a simple interrupted drop valve system. Work was started with this machine to develop a transplanter liquid drop valve which would meter the setting water solution. A simulated transplanter with a drop valve setup—using the simple gravity flow system—was made to provide a maximum of one pint liquid drop per second, which—when planting on 36" intervals at about two miles per hour—is equivalent to 7.5 gallons per minute flow.

The source of gravity flow was a 55-gallon barrel lying on its side at about 30" above the valve. Thus when the barrel is full, the head is 51"—21" diameter—and when nearly empty, the head is 30".

The flow of liquid through a hose with the various couplings, adapters—from hose coupling to pipe—and valves is shown for three sizes of hose in the graph on page 11. The hose lengths plotted are for 10' plus the appropriate couplings to connect the hoses to ordinary pipe fittings. The couplings are the limiting orifice—smallest openings—in the system. Hose coupling to pipe adapters—nipple type—and gate-type valves of the same ID—inside diameter—as the hose, have little or no further flow restricting effect on the system. The table in the next column gives the ID sizes for various components to be used with the hose size specified. Connecting a 3/4" ID hose, for example, to a pipe by slipping the hose over a 1/2"—ID 1 1/32"—pipe

Component	Nominal or identifying size		
	3/8"	3/4"	1"
	Actual ID inches		
Hose . . . . .	20/32	24/32	32/32
Hose coupling .	18/32	21/32	28/32
Nipple type adapter, hose to pipe . . . use 3/4 size	21/32	30/32	
Pipe size to which adapter connects . . . use 3/4 size	26/32	33/32	

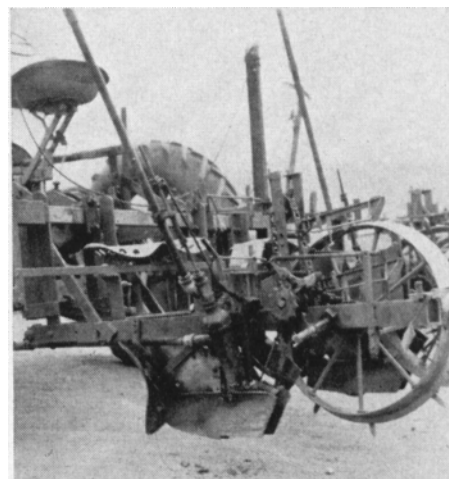
would cause a drop in the flow because of the wall thickness of the pipe. A 3/4" hose coupling—2 1/32" ID—should be used to maintain the flow.

The drop valve assembly was constructed with simple plumbing parts and a minimum of welded joints. No machining was necessary.

Rapid flowout properly timed to the transplanter is the essential aim of the system. This reduces the distance the material covers in the ground. For example, at two miles per hour, if the valve is open 0.53 second—equivalent to 1.5 pints of material flow—approximately 1.5' of ground is covered, or on 3' plantings one half of the row length is wetted. At 0.38-second valve timing—1.25 pints—about 1' is wetted or only

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Transplanter with drop valve installed.



# CLUBROOT DISEASE

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In San Mateo County, economic conditions are such that a long rotation out of Brussels sprouts would be difficult. Few other irrigated vegetables can be profitably raised in competition with other areas of the state. Sprouts are a specialty crop grown only in the central coast counties with the cool, moist climate necessary for high-quality sprouts.

A series of tests was initiated in 1951 to investigate possible chemical control in field plantings. After two years of trial and demonstration, seedbed fumigation with chloropicrin—tear gas—became a standard practice. Liming of soils was not found to be entirely satisfactory in San Mateo County soils.

Additional field experiments during 1951 and 1952 showed that a 1-to-2,000 HgCl<sub>2</sub>—mercuric chloride—solution, about four ounces to 55 gallons of water, used as the setting water at transplanting time gave good control when the solution was applied by hand at the rate of one-half to three-fourths pint per transplant. On the basis of results obtained in the hand-treated test plots, over 250 acres of Brussels sprouts were treated with mercuric chloride in 1953 and 1954.

Later, machine transplanters were developed to automatically set plants and inject a measured amount of the mercuric chloride solution into the soil around the stem and root.

Mercuric chloride treatment does not completely control clubroot disease but it will protect the main root and stem from attacks by the fungus. Therefore a satisfactory crop can be obtained where

Control of clubroot by chemical soil drench. The row of Brussels sprouts left of the center was treated with PCNB 1-400 in the transplanting solution while the row to the right of the center was nontreated and shows the loss due to clubroot infection.



## Chemical Soil Treatment Control of Clubroot on Brussels Sprouts, 1954

Chemical concentration*	Pure chemical per acre pounds	Infection rating 0-4	Yield	
			Per plot pounds**	Pounds per acre equivalent
1. Nontreated (water only)	..	2.14	14.83	5,980
2. HgCl <sub>2</sub> ..... 1-2000	1.2	0.54	24.25	9,770
3. PCNB ..... 1-1600	1.5	0.78	27.41	11,050
4. PCNB ..... 1- 400	6.0	0.35	28.05	11,300
5. Captan ..... 1-1600	1.5	1.36	20.67	8,330
6. Captan ..... 1- 400	6.0	0.51	23.95	9,650

\* Applied at the rate of 8 oz. per plant or 302.5 gal. per acre.

\*\* Each plot equivalent to 1/403 acre.

otherwise continued planting would not be possible.

Because mercuric chloride is very corrosive to equipment and extremely poisonous to humans, a series of tests was made during the 1954 season in an effort to find other—less hazardous—chemicals for control of clubroot.

In May 1954, an experimental plot was established near Half Moon Bay to compare the protective effects of mercuric chloride with two dosages each of captan and PCNB—pentachloronitrobenzene. Each plot consisted of 12 hand-planted and hand-treated plants, and the six treatments were each replicated six times in a Latin square arrangement. Observations were made throughout the season on the appearance and vigor of the plants. Yield was measured by three pickings at 3-to-4-week intervals.

Examination of the roots at the end of the experiment showed that most of the nontreated plants were severely infected with clubs and that the roots had been invaded by secondary organisms and completely destroyed. The captan-treated roots were severely clubbed, but secondary invasion of the main stem and root system had not occurred and the root systems were still intact. PCNB provided good control of infection on the main stem and root, although overgrowths were found on the branch roots some distance from the crown. The best protection was obtained with mercuric chloride, but some of the plants appeared less vigorous than those treated with PCNB.

All treatments significantly increased yield over that of nontreated plots, but the highest yield occurred with PCNB treatments.

Because PCNB provided club root control nearly equal to that from mercuric chloride but was less injurious to plants in dry soils—as well as being much less poisonous and noncorrosive to metals—it appears to offer advantages over the other fungicides tested and its use may soon supersede that of mercuric chloride.

In addition to the replicated hand-planted plots, several large field plantings were made with mechanical trans-

planters using a PCNB suspension as the setting water. All of the field plots were on land known to be infested with the clubroot disease. The 75% wettable powder of PCNB was used at a concentration of two, three, four, and eight pounds per 100 gallons of water, and each plant received three-fourths pint of the liquid. Clubroot disease control was obtained almost equally well at all concentrations. No injury was observed at higher levels except perhaps a slight stunting of plants early in the season.

On several plantings where PCNB and mercuric chloride solutions were used as the setting water, the soil had been treated with 2,000 to 3,000 pounds of Dolomite lime prior to planting. It was observed that the lime application in combination with PCNB and mercuric chloride treatment appeared to increase the degree of control. This will be investigated further.

Registration of PCNB has been recently completed by the Bureau of Chemistry, so it is expected that this chemical will be widely used for clubroot control in 1955.

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## RESISTANCE

Continued from preceding page

producing a large quantity of seed, which was planted in an infected seedbed in 1954 in the same fashion as in tests of the preceding years. Since conditions in the seedbed did not prove satisfactory for the development of clubroot symptoms, it was not possible to select plants for resistance there, but it was necessary to transplant all seedlings to the field without advance knowledge of their resistance. In the field, however, conditions for infection were satisfactory as judged by the clubroot symptoms on susceptible control lines.

As expected, plants of this backcross generation segregated for resistance as

well as for the aforementioned horticultural characters, the latter varying between the extremes of Brussels sprouts and the F<sub>1</sub> hybrid. Approximately 1% of the plants was judged to be of excellent Brussels sprouts type, and 2% or 3% of acceptable type. Resistance seems to appear at random with respect to horticultural type, so that it was possible to select for further breeding certain symptomless plants that approached the Brussels sprouts type.

Simultaneous with this work on Brussels sprouts, the initial crosses were made to transfer clubroot resistance to broccoli and cauliflower. Outbreaks of clubroot in areas of production of these crops have not been observed, but hybrid seed has been produced and placed in optimum storage conditions preparatory to the possibility that a need for breeding resistance in these crops might arise in the near future.

Progress up to the present time in developing strains of Brussels sprouts resistant to clubroot has been encouraging; nevertheless, the work has only begun and further development will depend upon the nature of inheritance of resistance, the success in maintaining a high level of infection in test plots, and other factors.

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*Donald Y. Perkins was Junior Olericulturist, University of California, Davis, when these tests were conducted.*

*Dr. J. C. Walker, of the University of Wisconsin, provided the strain of cabbage that was the source of clubroot resistance in this work.*

*The above progress report was based on Research Project 906F.*

## DROP VALVE

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$\frac{1}{3}$  of the row length. The valve should have sufficient capacity to hold the maximum drop required. The 6" nipple, 2.5" in diameter, plus the bell reducer, adequately handles the one-pint maximum specified for this job. Adequate venting to prevent air lock is necessary. This vent should be separated from the liquid feed line and raised sufficiently high to prevent liquid slopping over the top. Venting of the discharge tube from the valve with a short piece of pipe was found desirable.

The flow path past the valve and seat should be of uniform area for maximum flow with minimum parts size. When the cylinder ID is taken at 2.5", the valve seat can be a 1.5" x 2" reducer bushing. This bushing has an ID of 1.75" and an OD of about 2.5". The rubber valve is cut to a scant 2" ID to seat in the 1.75" hole.

To check the entire system further, the complete mock-up, tank, hose, and valve were assembled and operated by means of an adjustable cam lift device. The cam was set to operate at 40 drops per minute—about two thirds of the original requirement of one drop per second—which at one pint per drop exacts a flow requirement of 5 gpm—gallons per minute. A  $\frac{3}{4}$ " hose system will allow a flow of about 6.2 gpm at 42" head and 4.9 gpm at 27.5" head. At this speed of one drop per 1.5 seconds—40 drops per minute—the flow was found to be about 1.25 pints per drop at 42" head, and one pint at 27.5", which is very close to the maximum flow rate of a  $\frac{3}{4}$ " system. A one-inch hose and connections would be needed for the original requirement of one drop per second—one pint per drop—7.5 gpm—at this head.

The cross guide should have  $\frac{1}{8}$ " clearance in the 2.5" nipple and should also be free on the valve rod. The cross guide is essential to permit accurate seating of the valve. The valve itself was made from a No. 10 $\frac{1}{2}$  rubber laboratory cork cut to shape by drilling and bolting it on a short rod and cutting with a powered sander or coarse emery wheel on a lathe. The 30° faces seem to give the best results, being steep enough to seat easily without undue jamming.

The tube from the bottom of the valve to the planting area should be as short as possible, vented and made of light gage metal or conduit. It should be welded to the outside of the valve and not threaded into the seat which would reduce the effective discharge opening.

The mercuric chloride solution—added to the transplant water—is more or less corrosive to all metals, but if the liquid valve drop is assembled with grease—or nonhardening pipe compound—it can be easily taken apart for checking and cleaning. The machine should be flushed with clean water after each day's use, and at the end of the season the valve should be disassembled and oiled.

The metered liquid applied by the valve drop conserves water and chemicals—when added for disease control—and increases the efficiency of the transplanting operation.

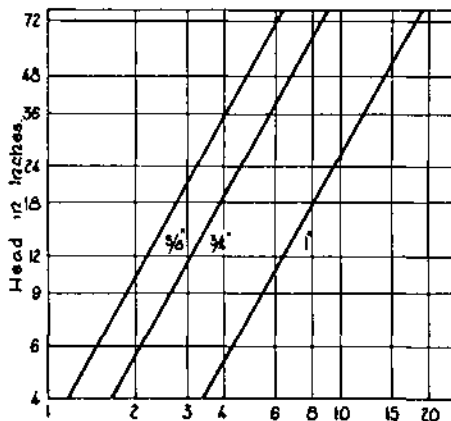
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*The above progress report is based on Research Project No. 1046.*

## Discharge

G.P.M. 10' of hose and couplings.



Cross-section view of an improved transplanter liquid drop valve.

