Importance and Problems of Disposal of Crop Residues Containing Pathogens of Plant Diseases

By SHOSHIRO TAKEUCHI

Department of Plant Protection and Soil Science, National Research Institute of V egetables, Ornamental Plants and Tea
(Ano, Mie, 514-23 Japan)

Introduction

At the time of crop harvest, plant portions not to be harvested or plants unsuitable to be harvested are left on the field. The amount of such crop residues often reaches that of harvested crop or even more than that, and at least a part of them are generally plowed into the soil. In case of rice, wheat, and barley, their culms are utilized. However, residues of vegetables, particularly of leaf- and root-vegetables are mostly left on the field or plowed into the soil, except that only a few of them are used as livestock feed. An example is shown in Table 1[15].

It must be noticed that these crop residues play an important role as the primary infection source of many diseases for succeeding crops, because the crop residues contain diseased plants or diseased plant portions, on which pathogenic agents have multiplied to a large extent. In case of annual crops, air-borne diseases become epidemic when the formation and dispersal of spores of pathogens and the secondary infection occur within a short period. On the contrary, soil-borne diseases come to be epidemic when their pathogens, which continue to survive in the soil in the form of dormant propagules, are increased to a high level of their density by consecutive planting of susceptible crops for several years. Therefore, effect of residues containing pathogens (hereafter referred to RCP) on disease occurrence is more remarkable for soil-borne diseases than for air-borne diseases: the occurrence of the former is closely and directly influenced by the density of primary infection source (inoculum density) in the soil before

Table 1. Methods of disposal of vegetable residues after harvest* (modified)[15]

Crops	Utilization of residues		Methods of disposal practiced at present					
	Utilized	Not	Burning	Burying	Plowing	Composting	Removal	Others
Solanaceous vegetables	2	31	27	0	3	0	26	0
Cucurbit vegetables	5	33	23	2	7	1	28	0
Crucifer vegetables	16	26	0	4	41	4	18	5
Liliaceous vegetables	6	24	2	1	19	0	19	0
Strawberry	3	9	8	1	2	1	9	1
Lettuce, spinach, & garland chrysanthemum	8	15	3	1	22	0	10	0
The other vegetables	16	42	9	1	24	4	38	1
Total	56	180	72	10	118	10	148	7

* Answers to questionnaires distributed to 12 Agricultural Experimental Stations in 11 prefectures of Kinki-Chugoku District were compiled.
The numerals in the table show the number of positive answers given by the Experimental Stations to each item for each group of vegetables.

cropping.

Importance of the proper disposal of RCP as a method of disease control has been known for long together with the usefulness of crop residues as organic materials. However, the disposal of RCP has hardly been practiced. The reason for that may be listed as follows[19]:

1) Examples showing concrete effectiveness of RCP disposal are not available in plenty.

2) Since it is impossible to select out only RCP for the disposal from the bulk of crop residues, the whole bulk has to be treated. In other words, the practical method of disposal has not been established yet.

Regarding soil-borne diseases of vegetables, effectiveness of RCP disposal in decreasing disease occurrence and crop damage due to diseases, present situation of RCP disposal, and problems involved will be presented in this paper.

Effectiveness of RCP removal

After the inoculation of the pathogen of radish yellows, *Fusarium oxysporum* f. sp. *raphani*, to a central point of a small experimental field, Japanese radish was cultivated two times a year (in spring and autumn) for two years. Although the distribution of areas infested with radish yellows

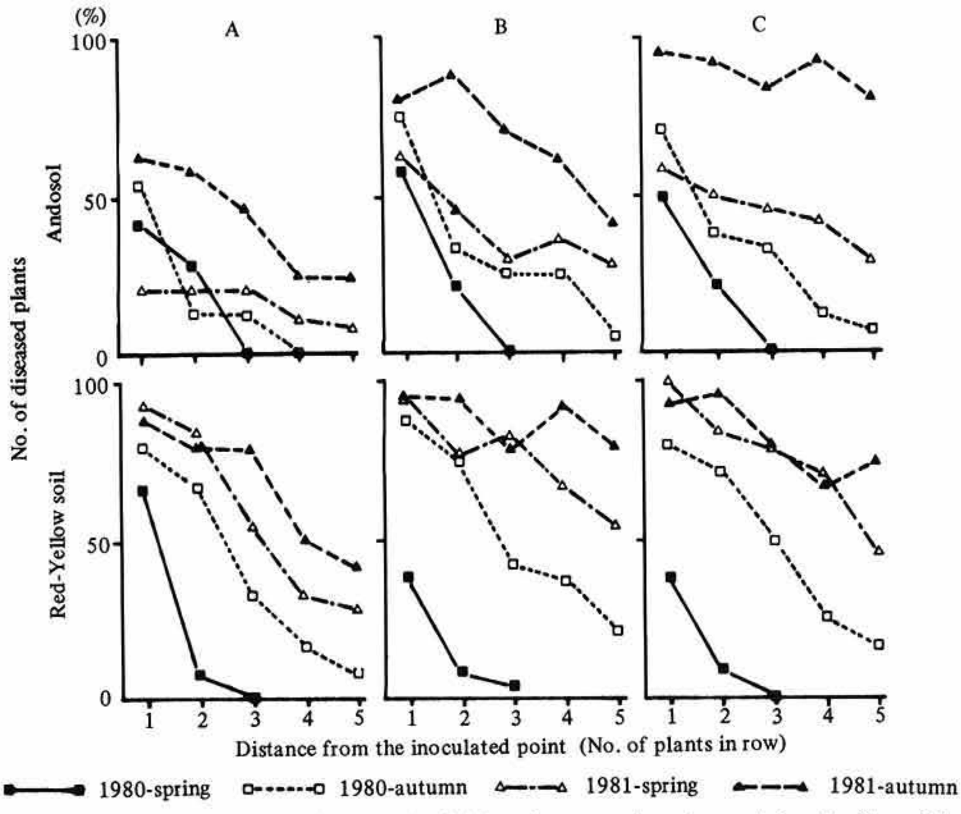

Fig. 1. Effect of removing RCP from the field on the expansion of area infested with radish yellows[8]

Fusarium oxysporum f. sp. *raphani* was inoculated to the center of a field in spring of 1980. Then, Japanese radish was cultivated in spring and autumn of 1980 and of 1981. Diseased plants (in %) at different distances from the inoculated site were counted. In plot A, the crop residue was removed from the field immediately at the end of each growing season. In plot B, the residue was plowed-in, and in the plot C residues obtained from plots A and C were plowed into the soil.

gradually expanded with the progress of repeated cropping, the rate of expansion was apparently slower in the plot where RCP was removed from the field than in the plot where RCP was plowed into the soil (Fig. 1)[8]. Effect of RCP removal in suppressing the spread of the disease was clearly demonstrated. The similar effect was reported with Verticillium wilt of potato[3,4] and hop[16].

The effect of RCP removal in reducing the density of pathogens seems not to be so high as compared with the effect of chemical control. However, there is an example of a considerable reduction of Verticillium wilt of Chinese cabbage due to RCP removal (Table 2)[2]. In addition, RCP removal, practiced continuously from year to year, showed the effect to reduce gradually the occurrence of club-

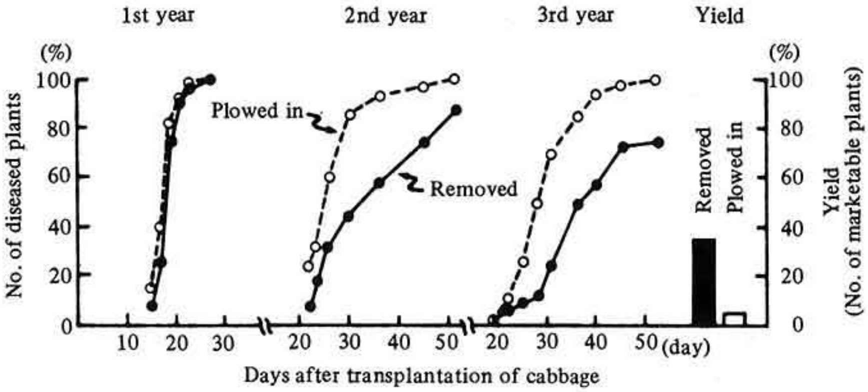

Fig. 2. Effect of RCP removal on the occurrence of cabbage yellows[18]
An experimental field was prepared as follows: *Fusarium oxysporum* f. sp. *conglutinans* was inoculated uniformly and RCP of cabbage grown in the field was plowed in the soil. In the following 3 years after the inoculation, susceptible cultivar of cabbage was successively planted. In a half of the field, all residues were removed, while in other half they were plowed into the soil and the occurrence of cabbage yellows was examined.

Table 2. Effect of RCP removal on the occurrence of Verticillium wilt of Chinese cabbage[2]

Treatment	Date of examination							
	Nov. 9			Dec. 9				
	No. of plants examined	No. of diseased plants (%)	Disease severity*	No. of plants examined	No. of diseased plants (%)	Disease severity*	No. of marketable plants (%)	Weight/plant (kg)
RCP removed	21.3	59.3	20.8	21.3	100.0	46.3	72.2	1.54
Calcium cyanamide, 150 kg/10 a	22.7	51.5	18.6	22.7	100.0	45.6	77.9	1.67
Glyphosate liquid diluted 100 times, 100 l/10 a	22.7	93.1	50.5	22.7	100.0	71.8	45.5	1.23
Paraquat liquid diluted 200 times, 100 l/10 a	19.3	95.7	57.9	19.3	100.0	75.4	46.5	0.99
Not treated	21.3	92.7	55.1	21.3	100.0	77.1	44.1	1.16

Chinese cabbage was transplanted in a heavily infested field on Apr. 23, harvested and treated on June 23. The crop was again sown in the field on Aug. 31, and the occurrence of Verticillium wilt was examined on Nov. 9 and Dec. 9.

$$* \text{ Disease severity} = \frac{3\times(\text{severe}) + 2\times(\text{moderate}) + 1\times(\text{light}) + 0\times(\text{healthy})}{\text{Total number of plants examined}} \times 100$$

Table 3. Effect of chemical control, enhanced by the RCP removal treatment, on the clubroot occurrence of cabbage[14]

Treatment		Dissased plants (%)	Disease severity
RCP	PCNB (kg)		
Left	0	66.7	22.6
do	25	28.6	9.5
Removed	0	68.4	31.1
do	25	15.4	3.8

In infested plots, immediately after each treatment, cabbage was transplanted on June 23. Development of clubroot was examined at the harvest time.

root of Chinese cabbage[1] and cabbage yellows (Fig. 2)[18]. Furthermore, this treatment enhanced the effect of chemical control against clubroot of cabbage (Table 3)[14] and Chinese cabbage[1]

Thus, the RCP removal is not only effective in suppressing the spread of soil-borne diseases in the field, but also it decreases directly the disease occurrence by repeated practice from year to year, and enhances the effect of other control measures. Anyway, the basic principle of this treatment is to apply it as a preventive measure. It is important to begin this treatment at the latest when the disease occurrence is observed only at a portion of the field, and the treatment should be repeated continuously from year to year. At this time, the amount of RCP is small, and hence selection and disposal can easily be done. Combination with other control measures is desirable.

Present situation of RCP disposal technique

Methods of RCP disposal are classified into two groups, i.e., the first group aims at the isolation of pathogens from the field simply by removing RCP from the field, although the isolation is only tentative as mentioned below. The second group aims at the inactivation of pathogens in crop residues. The former has a serious risk of expanding infested areas with pathogens, because fragments of RCP and/or pathogens released from crop residues as a result of decomposition of RCP are widely dispersed by wind or waterflow.

Methods of residue disposal, which are practically feasible, are required to fulfill the following conditions:

1) No risk of spreading pathogens, because they are inactivated.

2) Facilities, labor, and energy required for the disposal treatments can be saved.

3) Products derived from crop residues through the treatments can be well-utilized.

The treatments so far examined or actually practiced to a limited extent are roughly classified into several groups, and their characteristics will be briefly shown below:

1) Throwing away: As it needs less labor, and can be done easily, it is practiced to a considerable extent. However, this method has the greatest risk of spreading pathogenic agents. Particularly, the throwing into watercourses or rivers causes wide distribution of infestation through water systems.

2) Burying: When machines for agricultural engineering works are available, the burying treatment is not so hard even though the amount of crop residues is fairly large. The problem is the selection of burying sites and burying depth, both of which should not have a risk of spreading infestation. The safe depth of burying varies with kinds of pathogens, and topography, soil texture, the level of underground water, etc. of the burying sites selected. Burying depth of more than 50 cm is regarded to be safe for clubroot of cabbage, while there is an example of disease occurrence caused by the inoculum of radish yellows buried to the depth of about 1 m.

3) Heating and burning: Any pathogen is inactivated by burning. Wet-heating at 50–60°C also inactivates most pathogens within a relatively short time. Foliage or stems of some fruit vegetables are easily dried and burned, while heating or burning of succulent residues such as leaf- and root-vegetables is not practical, because much fuel and labor as well as facilities are needed.

4) Composting: It has been known for long. High temperature generated by aerobic fermentation of residues inactivates pathogens. However, in the surface layer of piled mass of residues, temperature rising is not enough, so that pathogens are apt to remain not inactivated. Therefore, care must be

Table 4. Occurrence of radish yellows in the potted soil mixed with RCP after anaerobically fermented[10]

Fermentation		Diseased plants in successive planting		
Ambient temperature (°C)	Period	First (%)	Second (%)	Third (%)
10	1 month	1.0	5.6	8.6
	2 months	0	0	0
20	1 month	0	0	0
	2 months	0	0	1.6
30	1 month	0	0	0
	2 months	0	0	0
No fermentation		90.0	98.2	71.8

Roots of Japanese radish, naturally infected by radish yellows were sliced to about 5 cm thickness, sealed into polyethylene-film bags, and incubated for anaerobic fermentation. Then the slices were mixed with partially sterilized soil in pots to which Japanese radish was planted successively 3 times in a period from March to July.

taken so as to expose the whole mass to high temperature by turning the mass. In addition to promote and sustain temperature rising of succulent residues, it is desired to reduce their water content before the piling, by employing preliminary drying, pressing, or addition of water-absorbing materials.

5) The use for feed: This is an excellent method of making use of crop residues. However, it still has a risk of dispersing pathogens, because a part of the residues fed to livestock are left uneaten and removed outside, or some kinds of pathogens are not inactivated even though they passed through the alimentary canal of livestock. Such a risk can be avoided by the use after anaerobic fermentation of the residues, i.e., feeding in the form of silage, which inactivates pathogens. Furthermore, effects of agricultural chemicals applied to vegetables must be taken into consideration. Thus, many problems still remain for the use of crop residues as livestock feed.

6) Anaerobic fermentation: Recently, studies were initiated on this method[5–13]. When Japanese radish residues containing RCP were piled up so as to make the heap which is sealed as a whole by plastic film, anaerobic fermentation proceeded. In the course of the fermentation all pathogens were completely inactivated. The period required for inactivating pathogens by this method is about one month at ordinary temperature (Table 4)[10]. It was confirmed that some amounts of soil (including infested soil) which happened to be intermixed with crop residues to be piled up gave no adverse influence on the inactivating effect[13]. The similar treatments were very effective in inactivating pathogens of Fusarium wilt of cucumber and tomato, and clubbroot of Chinese cabbage (Tables 5 and 6)[12]. Furtherermore, the crop residues after this treatment can be used as silage to feed livestock, or the possibility of returning them to the soil after exposed to aerobic fermentation was recognized. Although this treatment has not a few problems to be solved such as the mechanism of

Table 5. Inactivation of *Fusarium oxysporum* in stems of cucumber and tomato by anaerobic fermentation of the stems[12]

Treatment		Fusarium wilt of	
		Cucumber	Tomato
30 (°C)	10 (days)	0 (%)	0 (%)
	20	0	0
20	10	100	50.0
	20	46.7	13.3
10	10	100	86.7
	20	100	75.0
Not	10	100	100
sealed	20	100	100

Chopped stems naturally infected by Fusarium wilts were anaerobically fermented. Small pieces of the fermented stems were incubated on Komada's medium[17], and the number of pieces, on which *Fusarium oxysporum* was detected, was counted.

Table 6. Inactivation of clubroot pathogen in clubbed roots of Chinese cabbage by anaerobic fermentation of the clubbed roots[12]

Treatment	Plot	Dilution of residues and % of diseased plants (%)			
		1/4	$1/4^2$	$1/4^3$	$1/4^4$
30 °C 1 month	1	0	0	0	0
	2	0	0	0	0
30 °C 2 months	1	0	0	0	0
	2	0	0	0	0
Not treated	1	84.6	100	91.3	82.4
	2	100	100	93.8	87.5

Clubbed roots of Chinese cabbage caused by *Plasmodiophora brassicae* were anaerobically fermented. Then, finely crushed clubs were mixed with partially sterilized soil in pots to which Chinese cabbage was planted to examine the occurrence of the disease.

Table 7. General comparison of various methods of crop residue disposal[19]

Method of treatment	Risk of pathogen dissemination	Need for equipments	Labor or energy (fuel etc.)	Utilization after treatment
Throwing away	++	−	+	×
Burying in soil	− ~ (+)	−	++ ~ +	×
Feed for cattle	+ ~ (−)	− ~ +	+	○
Burning	−	++	+ ~ ++	×
Heating	−	++	+ ~ ++	○
Composting (aerobic)	− ~ (++)	+ ~ ++	+ ~ ++	○
Anaerobic fermentation	−	+	+ ~ ++	○

−: none, +: low to moderate, ++: high, ( ): probable, ○: usable, ×: unusabele.

inactivation of pathogens, kinds of pathogens to which the treatment is applicable, an efficient method of treatment, etc., it is expected that this treatment will become highly practicable, because of its advantage that it is a simple method without using particular facilities, many materials and much labor, and the product after the treatment has good utility.

Characteristics of these treatments listed above and their merit and demerit are compared each other in Table 7[19].

Future problems

Effectiveness of the RCP removal, inactivation of pathogens, which is an essential prerequisite of practical crop residue disposal, and the comparison of conventional methods of crop residue disposal so far tried are discribed in this paper.

It seems that the following problems must be solved in order to establish the crop residue disposal technique as an integral step of the farm work system.

1) Development of a new technique by which a large amount of crop residues can be taken out from the field, without scattering any of them, to outside of the field, aiming at avoiding the spread of pathogens, or a method by which crop residue treatment can perfectly be made in individual fields.

2) Pretreatments such as drying, pressing or addition of water-absorbing materials for succulent residues of vegetables, aiming at reducing their water content in order to facilitate further treatment. Similarly, appropriate pretreatments depending on the property of crop residues.

3) Effective methods of utilizing the products of the residue disposal treatment. In this connection, quality management and marketability of the products are related problems.

Customary practice of RCP removal is effective in preventing the occurrence and spreading of soil-borne diseases. Hence, it is important as a countermeasure for "crop damage due to continuous cropping", which is caused mainly by severe occurrence of diseases. On the other hand, it is desirable to make use of a large amount of crop residues as organic matter resources. It is expected that the research on the crop residue disposal technique will develop a technological system including that technique and contribute to the effective utilization of resources and prevention of crop damage due to continuous cropping.

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