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CONTROL OF BLACKLEG DISEASE OF THE POTATO

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FIG. 93 Two potato plants showing advanced stages of the blackleg disease. Note the decided blackening at the base of the stem.

BULLETIN No. 194.

CONTROL OF THE BLACKLEG OR BLACK-STEM DISEASE OF THE POTATO.

W. J. Morse.

Bulletin 174 of this Station, issued December, 1909, discussed the character and appearance, means of distribution, distribution in America and economic importance of the blackleg disease of the potato. At the same time methods for prevention and eradication were outlined and discussed. It was then stated that these recommendations were made on more or less empirical grounds and were not based upon regularly conducted experiments. It is now proposed to give the results of certain field trials and experiments whereby these recommendations were tested on a large scale under actual farm conditions. Before taking up the details of these experiments and the results obtained therefrom it is perhaps best to summarize some of the more important parts of Bulletin 174 and to give a brief account of certain preliminary studies which led up to the experiments mentioned.

"Blackleg," "black-stem," "black stalk-rot" or "stem-rot" is a bacterial disease which attacks both the stem and tuber of the Irish potato. Various investigators, mostly in Europe, have isolated from the diseased plants and described under different names bacteria which were again capable of causing very similar effects upon the host upon inoculation.* Hence so far as our present knowledge goes blackleg, strictly speaking, is a general term applied to a type of bacterial disease which attacks and destroys the base of the potato stem, producing a characteristic blackening of the diseased tissues, rather than a term applied to a single disease caused by a specific organism. However, the organisms are so near alike and are so nearly identical in their

* *B. phytophthorous* Appel, *B. solanisaprus* Harrison, *B. atrosepticus,* van Hall, *B. melanogenes* Pethybridge and Murphy, etc.

effects upon the host that so far as the practical agriculturalist alone is concerned the distinctions made are, in the opinion of the writer, of little consequence. Preventive measures which are effective with one under Maine climatic conditions would be, in all probability, equally applicable to all. Blackleg is not the same as the Southern bacterial disease of the potato stem and tuber caused by *B. solanacearum* Smith.

Both stems and tubers are attacked. The diseased plants as observed in Maine* first appear more or less unthrifty and usually undersized. The branches and leaves, instead of spreading out normally, tend to grow upward, forming a more or less compact top, frequently with the young leaves curled and folded up along the mid-rib. Later they become lighter green or even yellow and the whole plant gradually dies. If the disease progresses rapidly the plants may fall over suddenly and wilt with very little previous signs of disease. The same general symptoms may be produced by certain other stem diseases, or even mechanical or insect injuries of the stem at or below the surface of the ground.

The appearance of the diseased stems at once differentiates blackleg from other described potato diseases. Stems so attacked are characterized by an inky-black discoloration (See Fig. 93) extending from the base of the stem, where it attaches to the seed piece, up sometimes one, two or even three inches above the surface of the ground. Under favorable weather conditions the disease may, in exceptional cases, follow up the stem for several inches, or even out on the larger branches. The seed pieces from which the diseased plants spring are invariably decayed, and young tubers which have been formed before the destruction of the stem may sometimes be attacked by a soft rot caused by the bacteria being conveyed to them along the underground branches of the stem upon which they are produced.

The disease is carried over from year to year by the organisms living in decaying, bruised, cracked or otherwise imperfect seed potatoes. They are readily killed by drying and are probably incapable of existing in a living state on the surfaces

* The following discussion should be understood as only applying to the character of the disease as observed by the writer in this State.

of dry, sound potato tubers. Under ordinary conditions blackleg has not been observed in Maine to spread from hill to hill in the field and, as will be shown later, there is quite conclusive evidence that the germs do not live over winter in the soil under the climatic conditions which exist in this State.

Observations extending over 5 years indicate that the disease is much less prevalent in those seasons which have relatively little rainfall between planting and blossoming time. While it is quite generally distributed over the potato growing sections of the State and sometimes, in very wet seasons, fields may be found which show 10, 15 or even 20 per cent. of diseased plants, as a general rule it occurs only as occasional, affected stalks scattered over the fields. Only in exceptional cases is the crop materially reduced from this cause.

The writer has had opportunity to study numerous outbreaks of rot in potato fields and in storage in Maine and other parts of New England during the last 15 years and has yet to see the first case of a severe epidemic of this kind that could be traced to the blackleg or stem rot disease. These epidemics are invariably preceded by outbreaks of the late blight fungus *Phytophthora infestans* DeBary on the foliage, and occur with equal frequency on fields which are free from blackleg as upon those which are attacked with this disease. Moreover such epidemics were as common long before the blackleg disease made its appearance, and now occur in those parts of New England where blackleg has never been seen, whenever the weather conditions are favorable for outbreaks of late blight on the foliage, and spraying with bordeaux mixture is not thoroughly done. The nature of the decay in such cases may be soft and foul-smelling and large numbers of bacteria may be found in the decayed tissues, but the writer has failed in repeated trials to isolate bacteria from such tubers which, upon inoculation to sound tubers, would produce alone and unaided any disease whatever. In all probability the soft rots observed in epidemics of this kind are caused by saprophytic bacteria of the soil which follow after and farther break down the tissues of the tuber after they have been killed by the late blight fungus.

It is perfectly possible however, as has already been stated, for the bacteria associated with the blackleg disease of the stem to produce a rapid and complete soft rot of the tuber under

favorable conditions of temperature and moisture if they come in contact with the interior tissues. Therefore, there is no doubt that some of the soft rot in storage may come from this source. It is also evident that diseased plants only spring from tubers produced by previously diseased plants, or from tubers infected in storage or while being cut for seed purposes by coming in contact with those already diseased.

So long as Maine growers confined their efforts to the production of table stock, blackleg was not one of the more important potato diseases and attracted little attention. When the value of northern-grown potatoes for southern planting began to be appreciated an entirely new situation developed. The southern trade demanded early varieties, the favorite among which is the Irish Cobbler which is much more susceptible to the blackleg disease than the Green Mountain and certain other, late varieties commonly grown for table stock. Moreover blackleg appears to be much more destructive in Virginia and other southern States, where most of the seed tubers are sold, than in Maine. Consequently from the standpoint of the seed potato trade this disease has become one of considerable importance. If Maine seed potatoes for southern planting are to retain the place that their various superior qualities have secured for them it is absolutely essential that this disease be eliminated from among them. In other words, from a financial standpoint this is the most important disease problem that the seed potato growers are facing at the present time. It is believed that the experiments here reported demonstrate that any farmer can entirely eradicate the disease from his seed and from his farm in from one to 2 years and that so long as he keeps this seed pure and uncontaminated he may feel assured of immunity from blackleg.

Preliminary Experimental Work.

After isolating the bacteria associated with the disease in Maine and demonstrating by inoculation that they were capable of causing the typical blackening and decay of the stem as well as the soft rot of the tuber the first matters to determine before attempting to devise methods of control were the resistance of the organisms to drying, to exposure to sunlight, and to disin-

fectants and germicides. It was found that they were readily killed by drying, but broth cultures retained their vitality until all of the moisture was evaporated—ten months or more, or longer than the organisms would be required to remain alive in infected tubers. Exposure to sunlight for 60 minutes in petri-dish cultures killed all the organisms even in the less intense light of November and December. They were also readily killed when transferred to very weak formaldehyde solutions. At no time have any of the different strains studied been observed to form spores.

Spraying sound tubers with fresh, virulent cultures in 1909 and allowing them to dry and remain in an open shed away from direct sunlight for a week before planting failed to convey the disease to the resulting plants. This gave additional evidence that the organisms cannot remain alive for any length of time on the dry unbroken skin of healthy tubers. Wetting healthy seed pieces, after cutting, with cultures and watery extracts of diseased stems followed by keeping the soil constantly moist led to the production of diseased plants. Evidence was also constantly accumulating to show that seed tubers were the chief, if not the only source of infection. Therefore, it seemed conclusive that it was only those tubers which were partly decayed, cracked or imperfect which provided the proper conditions for harboring the germs alive and in condition to communicate the disease to the growing plants. As will be pointed out later there is every reason to believe that the germs are spread from diseased to healthy seed pieces by means of the knives used in cutting and by the freshly cut surfaces of the seed pieces coming in contact in the storage barrels and in the planters. If the cut seed tubers are allowed to "heat" a little before planting, on account of being barreled up too long, this danger of transference of the disease to healthy seed pieces is greatly increased.

In the fall of 1909 three barrels * of seed potatoes were obtained in Presque Isle from a field where a large percent of the plants had been killed by blackleg the summer before. Unfortunately late blight was very prevalent on this field during

* A barrel of potatoes as the term is here used is approximately equal to 2 3-4 bushels or 165 pounds.

the latter part of the season, resulting in a large amount of rot developing in storage and over half of the tubers were sorted out as entirely decayed during the winter. The most of this rot resembled that produced by *Phytophthora infestans*. At planting time these tubers were first sorted into 2 lots, those which were entirely sound and those which were partly decayed or were in some way imperfect. One-third of each lot was exposed to formaldehyde gas, one-third treated by immersing in formaldehyde solution in the usual way before planting and the remainder planted without any treatment. At the same time on the same field, which had not grown potatoes for many years, plots of equal size were planted with healthy seed tubers from 2 different sources.

A small amount of blackleg developed on parts of the field where the untreated, diseased seed was used, but the results were very unsatisfactory and inconclusive. This work was done at Orono, but unfortunately, the writer had very little control over the experiment beyond furnishing the seed. The ground allotted to the experiment was heavy clay, improperly prepared for the crop, very dry and filled with large clods of earth at planting time. The field was neglected and not properly cultivated—the potatoes were at times overrun with weeds and badly injured by potato beetles.

Coöperative Experiments.

Therefore, it was thought best to ask the potato growers to coöperate in testing the preventative measures outlined, on a sufficiently large scale and upon enough different farms to make the combined results conclusive. This might be objected to by some as placing certain important details of the work in the hands of individuals not trained in exact experimental methods. Granting this objection to be valid it would simply be operative in case the results were inconclusive. On the other hand if the results were comparatively clear-cut and conclusive they would be of additional value as indicating the probable success or failure of the average farmer in carrying out the remedial measures recommended. Moreover those who volunteeered to assist in carrying on these coöperative experiments are specialists in potato growing and are among the most pro-

gressive and up-to-date farmers in the State. They are very familiar with the character and importance of the disease and were intensely interested in the success of the experiments.

These coöperative experiments were conducted by Mr. O. J. Parsons, Patten; Mr. O. L. Donaldson, Presque Isle; Mr. J. F. Hussey, Mr. Ira J. Porter, Mr. W. T. Good, E. L. Cleveland Company, Mr. H. Edblad, and Mr. W. S. Blake, Houlton. The writer takes this opportunity to express his appreciation and thanks to these gentlemen for the careful and painstaking manner in which they carried out their portion of the work, upon which the entire success of the experiment depended. Collectively these gentlemen disinfected seed tubers sufficient to plant 142 acres. Formaldehyde solution was used for 88 acres and formaldehyde gas for 54 acres. On the different experimental fields taken together as large if not a larger area was planted with untreated tubers. However, on some farms only enough treated seed tubers were used to plant a few acres while on others they were all treated except enough to provide a check plot of suitable size.

Methods Used in the Coöperative Experiments.

Before starting the experiments the writer conferred with each individual experimenter and explained fully the methods proposed and in all but one instance visited the potato houses or farms and advised and assisted in starting the disinfecting work. In addition a typewritten outline was furnished to each. The following is a brief summary of this:

The seed * used should come from fields where the disease appeared the year before. In each case a check plot of untreated seed from the same source as the treated and selected seed should be planted at the same time and on the same field under identical conditions except for treatment. The different plots must be plainly marked and labeled by proper stakes driven into the ends of the rows.

A part were requested to carefully sort out before disinfection all badly bruised or cracked tubers and all that appeared

* The term "seed" is in common use in the potato growing sections for potatoes used for seed purposes. Although botanically incorrect, for convenience it will be so used in the following discussion.

in any way diseased or decayed. Others to disinfect and plant the seed tubers just as they came from the bin, and others were to try both methods. Those who were intending to plant only selected, treated seed were advised to reject all tubers when cutting which showed any discolored areas in the flesh, particularly those which showed browned or blackened rings at the stem end, no matter how slight. As a farther precaution it was recommended that extra knives and a jar of formaldehyde solution be provided when cutting seed and if, by chance, a diseased tuber was cut the knife blade could be dropped into the disinfecting solution for a time and another used in its place. Some were to disinfect by means of formaldehyde solution and some were to use formaldehyde gas. It was also suggested that selection of sound tubers without disinfection be compared with the forms of treatment mentioned.

The experimenters were cautioned not to allow treated seed tubers to come in contact with tools, baskets, or barrels which had been used for diseased or untreated seed. It was advised that all containers for treated seed either be exposed to formaldehyde gas in a disinfecting chamber or washed out thoroughly with formaldehyde solution. Planters recently used for contaminated seed were to have the parts which come in contact with the seed pieces thoroughly washed and scrubbed in formaldehyde solution.

Those who used the liquid treatment immersed their seed 2 hours in a solution of one pint of 40 per cent. formaldehyde in 30 gallons of water. Where the formaldehyde gas treatment was used the tubers were placed in open, slat-work crates and exposed to the gas generated by means of potassium permanganate, for from 12 to 24 hours in a tightly closed room constructed for the purpose. For each 1000 cubic feet of the disinfecting chamber 3 pints of 40 per cent formaldehyde and 23 ounces of potassium permanganate were used. When, as in some cases, a large proportion of the space in the disinfecting chamber was occupied by crates of potatoes only about three-fourths of the given amounts of the chemicals were used to avoid too great concentration of the gas and possible resulting injury to the germinating quality of the seed.

There was little variation in soil conditions. According to the map of the Soil Survey of the Caribou Area, Maine,* Mr. Donaldson's field consisted entirely of the Caribou loam which is the type of the best Aroostook potato soil. This was the only field which was included in the soil survey but so far as could be determined the soil on all the other experimental fields was either identical or conformed very closely to this type. In each case the fields were well cared for, were well drained, and consisted of either level or slightly rolling land.

Details of the Coöperative Experiments.

The Parsons Experiment.

Mr. Parsons' field consisted of about 11 acres of sod land. The portions where the treated seed was used comprised 7 rows near the East side and 15 rows near the middle, running entirely across the field, and together constituting about one and one-tenth acres. The seed was treated by soaking in formaldehyde solution and was carefully sorted when cut, Mr. Parsons looking after this himself. Untreated but selected seed was used on the remainder of the field. None was planted without selection.

The field was visited on July 5 but the plants were not sufficiently advanced to show the maximum amount of blackleg. Hence no records were made at this time except to note that the disease was beginning to appear on the untreated portions. On July 17 approximately one-half acre of each on adjoining portions of the treated and untreated plots was carefully examined for blackleg with the following results.**

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* Weston, H. L. and Rowe, R. W., Advance Sheets Field Operations of the Bureau of Soils, 1908, Washington, 1910.

** On each farm care was taken to select portions of the plots of equal size and in every way uniform except as for seed treatment upon which to make the records. Of necessity the area of the portions so selected varied on the different farms. For convenience in comparison the records made have been reduced to numbers of diseased plants per acre. A superficial examination of the field as a whole or certain portions of it was made in each case to ascertain if the portions selected for detailed examination represented average conditions. Moreover with few exceptions the owner or his personal representative was present and assisted at each examination of the experimental fields. In each case a preliminary draft of the write-up of the different experiments was submitted to the owner of the field for his approval before it was incorporated in this report.

Seed tubers untreated, selected. Diseased plants per acre 87
Seed tubers treated (formaldehyde solution), selected. Diseased plants per acre 0

The Donaldson Experiment.

Mr. Donaldson planted 270 barrels of seed of which 260 barrels were treated by soaking in formaldehyde solution. The remaining 10 barrels were planted without treatment.

Where the disinfection experiment was tried Irish Cobbler was the variety planted. The seed was grown on the same field in 1910. In writing to the Station under the date of August 15, 1910, Mr. Donaldson stated that on this field he counted on an average about 20 diseased plants per row 60 rods in length. The seed on the main portion of this field in 1911 was soaked in formaldehyde solution for 2 hours and then turned out on a clean platform to dry *before cutting*. The cutting was done by hired help but under the owner's supervision. Each seed cutter was given directions to discard all tubers which were in any way imperfect, and if by chance he cut a tuber which showed any signs of decay or browning in the flesh to discard it and place the knife he was using in a jar of formaldehyde solution which was provided. Extra knives were supplied so that there was always a sterile knife in the disinfecting solution in case the one in use became contaminated. Mr. Donaldson stated that it was practically impossible to hire seed cutters who would constantly observe these precautions and doubtless this may account for the very small amount of blackleg on the main field.

For the chief experiment one barrel of badly bruised and one barrel of selected seed was sorted out. One half of each lot was cut and planted without treatment. The other half of each lot was soaked for 2 hours in formaldehyde solution *after cutting*. The advantage of this latter variation from the usual practice of disinfecting before cutting is that much of the chance contaminations of healthy seed pieces while cutting can be overcome in this way. As will be seen later (p. 224) no detrimental results with regard to germination were secured from this treatment.

The four lots of treated and untreated seed were planted in four rows, each row being equivalent to about one-tenth of an

acre. The field was examined on July 6 and 18 with the following result.

Seed tubers bruised, untreated. Diseased plants per acre	70
Seed tubers bruised, treated (formaldehyde solution). Diseased plants per acre	20
Seed tubers selected, untreated. Diseased plants per acre	10
Seed tubers selected, treated (formaldehyde solution). Diseased plants per acre	0

An examination on July 6 of about one-half acre of the immediately adjoining portion of the main field where the seed was soaked *before cutting* showed only 2 affected plants per acre, while an examination of an equal area on a different portion of the same field on July 18 failed to reveal any diseased plants.

It should be remembered that the season before on this same field and where the seed for this year's planting was produced there were according to Mr. Donaldson's estimate nearly 300 diseased plants per acre—a decrease of over 99 per cent. A part of this decrease may, as compared with 1910, be due to unfavorable weather conditions. As has already been pointed out blackleg never does so much damage if the early part of the growing season is dry.

No blackleg was observed on the volunteer plants which came up between the rows and hills from tubers which remained in the soil over winter from the crop of the season before. This taken together with the fact that practically no diseased plants were found over the entire 50 acres where the treated seed was used is additional evidence that the disease did not live over in the soil where it appeared last year but was communicated to the crop of the present year by means of the regular seed tubers.

The Hussey Experiment.

1911 was Mr. Hussey's second year of formaldehyde disinfection for blackleg. In 1909 he observed some of the disease on his field with the Irish Cobbler variety. In 1910 from the crop of the season before he carefully selected sound and perfect tubers sufficient to plant about one-fourth of a 4-acre field. These were then soaked 2 hours in formaldehyde solution one

pint to 30 gallons of water. The remainder of the field was planted with seed tubers from the same lot just as they came from the bin without selection or disinfection. They were, he said, such as would generally be classed, so far as appearance goes, as good quality of seed stock.

Mr. Hussey made frequent and careful examinations of this field during the summer and reported that from 5 to 8 percent of the plants where the untreated seed was used were killed by blackleg. Only 2 plants so affected were observed during the entire season on the acre where the selected and treated seed was used.

In 1911 Mr. Hussey experimented with both Irish Cobblers and Green Mountains. The Irish Cobbler field was sod land and consisted of about 5 1-2 acres planted with seed from the treated portion of last year's field. The treated and untreated portions were located in alternate strips across the field, thus making a very fair test with regards variation in soil conditions. This field was given a superficial examination on July 6 and a thorough examination on July 19. No blackleg could be found on the entire field on either visit. Mr. Hussey stated that he had examined the field several times during the season and failed to find any diseased plants, thus showing that selection and disinfection in 1910 entirely eliminated the disease from his crop. Unfortunately there was none of the crop from the untreated portion of the 1910 field planted this year as a check, but past experience makes it absolutely certain that if planted it would have produced quite a percentage of diseased plants this year.

Mr. Hussey's experiment with the Green Mountain variety was upon land where potatoes were grown last year and more or less blackleg was observed. It furnished the most striking example in the series of the effectiveness of disinfection when properly done. The field consisted of about 6 acres. About 2 acres in the middle was planted with untreated tubers. The remainder on either side being disinfected.

On July 6 no accurate record was made but it was noted that the disease was quite frequent on the untreated portion and no affected plants could be found where treated seed tubers were used. On July 19 approximately one-third acre each of adjoining portions of the treated and untreated strips were

examined with considerable care with the following result expressed in numbers of diseased plants per acre.

Seed tubers untreated. Diseased plants per acre 163
Seed tubers treated (formaldehyde solution).
Diseased plants per acre 0

Examination of other different portions of the field taken at random at both visits indicated that the above represented very accurately the condition of the field as a whole. *No diseased plants could be found on any part of the field where treated seed was used.* In a letter received from Mr. Hussey Aug. 29, he stated that he had just observed several full grown plants on the portion of the field where the untreated seed was used, which were just beginning to show the disease but he could find none on the treated portions which were attacked.

The Porter Experiment.

Mr. Porter's experiment especially aimed at securing data as to the relative value of careful selection of sound and perfect tubers as compared with disinfection alone of seed potatoes just as they come from the bin. The potatoes used, however, apparently did not carry much disease in the beginning, hence the results are not so marked nor so conclusive as might have been the case had the seed tubers been less healthy. Irish Cobbler was the variety planted and the liquid method of disinfection was used. The plots were examined July 7 and 19.

In one large field adjoining plots, consisting in all of about one and one-third acres were planted with, first untreated tubers as they came from the bin, second selected, sound tubers untreated, and third selected, sound tubers treated by soaking in formaldehyde solution for two hours. The results obtained from the examination of these plots were as follows:

Seed tubers untreated, not selected. Diseased plants per acre 24
Seed tubers untreated, selected. Diseased plants per acre 0
Seed tubers treated (formaldehyde solution), selected.
Diseased plants per acre 0

In another field consisting of about 4 acres were three other experimental plots. The first was planted with untreated seed tubers just as they came from the bin. The second was the same as the first except the seed tubers were soaked in formal-

dehyde solution. On the third plot were used small, inferior potatoes sorted from the same source of supply as one and two and given the same treatment as regards disinfection as in the case of plot two.

On July 7 only plots one and two were examined. At this time the disease had not made much progress. No diseased plants were found on a half acre of plot 2 but 2 were found on an equal area of plot one. On July 19 a careful record was made of the number of diseased plants on one-fourth acre of each plot. Calculated in numbers of diseased plants per acre this shows:

Seed tubers untreated, not selected. Diseased plants per acre 24
Seed tubers treated (formaldehyde solution), not selected.
Diseased plants per acre 4
Seed tubers treated (formaldehyde solution), small and inferior.
Diseased plants per acre 20

No effort was made to have the plots of the same size in the two different experiments which were located from one-third to one-half of a mile apart. However, when the number of diseased plants found on the two different plots where untreated tubers were used just as they came from the bin were reduced to numbers per acre the results were found to be identical. Mr. Porter stated that the seed in each case came from the same bin.

The Good Experiment.

Mr. Good's field consisted of about 50 acres partly of Green Mountains and partly of Irish Cobblers on sod land on the Donahue farm in Ludlow. The experiment was conducted with the Cobblers. About 50 barrels of this variety were disinfected by soaking in formaldehyde solution and the remainder planted without treatment. The treatment was performed under Mr. Good's supervision as was the seed cutting but on account of the amount of seed used (250 barrels or more) it was impossible to obtain seed cutters who would reject entirely all unsound seed. However, as will be noted below, even under these conditions, over 90 percent of the disease was eliminated by the treatment.

The field was visited on July 6 but on account of not being able to determine the exact boundary between the treated and

untreated portions of the field, accurate comparisons between adjoining portions could not be made. However, an examination of a portion of the extreme western part of the field where the treated seed was known to have been used revealed no diseased plants while on the other side of that part of the field planted to Cobblers where untreated seed was planted several diseased plants were seen on an equal area.

On July 19, the limit of the areas upon which treated and untreated seed was used having been accurately determined, approximately one acre of each was critically examined with the following result:

Seed tubers untreated. Diseased plants per acre	53
Seed tubers treated (formaldehyde solution). Diseased plants per acre	5

The Cleveland Company Experiment.

On the Cleveland Company farm disinfection was performed by means of formaldehyde gas and two varieties of potatoes were used. These were the Irish Cobblers and the White Rose, sometimes called the Ensign Bagley.

The field of Irish Cobblers consisted of about 20 acres, the larger portion of the seed for which was treated. This field was visited the first time and quite carefully inspected on July 19. At least some portion of nearly every acre was critically examined, but in no case could hills affected by blackleg be found, either where the treated or untreated seed was used. This indicated that the seed was originally free from the disease and in this case treatment was unnecessary so far as blackleg was concerned.

The White Rose seed was known to be considerably affected with blackleg and it was with this seed that the real test was made. This portion of the field consisted of about 10 acres of which all but about one acre was planted with disinfected seed. After being satisfied that the plots selected were representative of the different parts of the field as a whole with regards amount of blackleg about one-tenth acre each, of plants from treated and untreated seed, was carefully examined. The results obtained were as follows:

Seed tubers untreated. Diseased plants per acre 390
Seed tubers treated (formaldehyde gas).
Diseased plants per acre 150

While there was a considerable number of diseased hills on the treated portion of the field the fact should not be overlooked that over 60 percent of the disease as compared with the plants grown from the untreated seed was eliminated by the treatment. As is stated elsewhere in this paper while the large amount of blackleg on the treated seed, compared with the results obtained in the Parsons, Donaldson and Hussey experiments, may indicate that the gas treatment is less effective than the liquid treatment. It should be noted that in these last mentioned experiments the owners were able to either cut the seed themselves or have it done under their immediate supervision.

The Blake Experiment.

Mr. Blake treated sufficient selected seed to plant about 20 acres of Irish Cobblers. About half of this was soaked in formaldehyde solution and the remainder given the gas treatment in the Edblad disinfecting room. Unfortunately no untreated check plot was planted at the same time with the same lot of seed. Such a plot was planted some 10 days or 2 weeks later and there was also some doubt as to whether the seed was from the same source as that originally planted. Obviously this could not be used as a check on the treated portion. The field was carefully examined first on July 7 and again on July 20 as it represented the only case where the liquid and gas methods of treatment were applied to seed on the same field. No comparisons between these could be made, however, for only two plants showing the disease could be found on the whole 20 acres. This disease was said to have been observed on the crop of the year before from which the seed was obtained, therefore it would seem that its absence the present season must be the result of seed selection, disinfection or both.

The Edblad Experiment.

Mr. Edblad disinfected all of his seed by the formaldehyde gas method except about 1 barrel of the Irish Cobblers which was not treated, and planted the following varieties: Green

Mountain 9 1-2 acres, Irish Cobblers 4 acres, Early Rose, 2 acres, Beauty of Hebron 1 1-2 acres, Twentieth Century 1 acre.

Since the Irish Cobbler was the only variety treated where a check plot was saved this is the only case in this experiment where accurate comparison could be made between treated and untreated seed from the same source. However, since the disease did develop on the other portions of the field with other varieties which had been treated it is of interest to note these facts as bearing upon the effectiveness of the gas method of disinfection. While the results with some of the varieties in this experiment were not equal to the expectations of the writer, Mr. Edblad expressed himself as entirely satisfied with the results from a commercial standpoint and stated that he felt that he had profited sufficiently to more than pay for the expense and trouble involved in treating his seed.

The field was visited on July 7 but on account of not being able to definitely locate the boundaries of the different plots no accurate record was made at that time. On July 20 the field was examined in the company of Mr. Edblad by carefully going over representative plots of each different variety of one-fourth to one-half acre in size. Calculated in number of diseased plants per acre there was:

Seed tubers untreated, Irish Cobbler.	
Diseased plants per acre	96
Seed tubers treated (formaldehyde gas), Irish Cobbler.	
Diseased plants per acre *	0
Seed tubers treated (formaldehyde gas), Green Mountain.	
Diseased plants per acre	0
Seed tubers treated (formaldehyde gas), Early Rose.	
Diseased plants per acre	18
Seed tubers treated (formaldehyde gas), Twentieth Century.	
Diseased plants per acre	40

No record was made as to the amount of blackleg on the one and one-half acres of Beauty of Hebron. Mr. Edblad

* The record was taken for the treated and untreated Irish Cobblers on adjoining plots July 20. At the time of the early visit (July 7) a few diseased hills were seen on another part of the field where treated Irish Cobblers had been used, so the effectiveness of the treatment in this case was doubtless not quite so great as the figures would indicate.

stated that the seed tubers of this variety were in very poor condition when he received them, and he only planted them in order to get a start with this variety. He exposed them to formaldehyde gas for the same length of time as his other

Tabular Summary.

Experiment.	Variety.	Condition of Seed.	Treatment.	No. diseased plants per A.
Parsons	Green Mountain	Selected	None	87
	" "	"	Formaldehyde solution	0
Donaldson	Irish Cobbler	Bruised	None	70
	" "	"	Formaldehyde solution	20
	" "	Selected	None	10
	" "	"	Formaldehyde solution	0
Hussey	Irish Cobbler	Selected	None	0*
	" "	"	Formaldehyde solution	0*
	Green Mountain	Not selected	None	163
	" "	" "	Formaldehyde solution	0
Porter	Irish Cobbler	Not selected	None	24
	" "	" "	Formaldehyde solution	4
	" "	Selected	None	0
	" "	"	Formaldehyde solution	0
	" "	Small, inferior	Formaldehyde solution	20
Good	Irish Cobbler	Not selected	None	53
	" "	" "	Formaldehyde solution	5
Cleveland Co.	Irish Cobbler	Not selected	None	0*
	" "	" "	Formaldehyde gas	0*
	White Rose	" "	None	390
	" "	" "	Formaldehyde gas	15
Blake	Irish Cobbler	Selected	Formaldehyde solution	0**
	" "	"	Formaldehyde gas	0**
Edblad	Irish Cobbler	Not selected	None	96
	" "	" "	Formaldehyde gas	0***
	Green Mountain	" "	" "	0**
	Early Rose	" "	" "	18**
	20th Century	" "	" "	40**

* Seed used was apparently not diseased in the beginning. In the Hussey experiment it had been eliminated through treatment the year before.

** No satisfactory check plot of the variety available for comparison.

*** See note on page 217.

varieties to obtain what beneficial effects that he could from the treatment. He did not, however, select out and plant only the perfect tubers and did not save a check plot planted with untreated seed.

When examined on July 7 and 20 there was a large amount of blackleg on this field, fully 20 per cent of the hills either failed to grow or the plants had been destroyed by the disease.

Discussion of Results.

Effectiveness of the treatment: Taken as a whole the results of the coöperative experiments are sufficiently clear-cut and conclusive to indicate that the preventative measures outlined are exceedingly efficient. In fact the uniformity of the results is surprising when it is remembered that so many individuals, including the men employed to cut the seed, were responsible for them. It will be noted that in every case where both selected and treated seed was used the disease was absolutely eliminated and in every case where either selection or disinfection was practiced alone and proper check plots planted for comparison the amount of blackleg was materially reduced, except where the small, inferior seed was used in the Porter experiment. However, it should be remembered that the check plot here is the seed just as it came from the bin, and that the small seed in question represents practically the poorest grade that could be sorted from it. Had Mr. Porter planted an untreated check plot of this small, inferior seed also it doubtless would have carried considerably more disease than the treated plot. The case would have been similar to the one where Mr. Donaldson compared plots planted with treated and untreated seed which was bruised and otherwise imperfect.

While not a part of the experiments here recorded certain observations made on the John Watson farm in Houlton during the past five years have a bearing on this subject. In 1907 in connection with certain experiments then being carried on a special disinfecting room was constructed on this farm in which to treat seed potatoes for scab.* Every year since that time all the seed used on this farm has been disinfected with formaldehyde gas, primarily as a protection against scab. Both Green Mountains and Irish Cobblers have been planted, the latter entirely during the last 2 years. A part of the time the seed tubers used were picked up from various sources without knowledge of the conditions under which they were grown.

* Bul. Me. Exp. Sta. 149: 304-314 (1907).

During this period blackleg has been observed but once and then only three or four plants were seen on a 20-acre field—a record, so far as observed, not equalled by any other field in the immediate neighborhood where untreated seed tubers were used.

Selection versus Disinfection: An analysis of the data furnished by these experiments does not lead one to any very definite conclusion as to the relative value of selection of sound, perfect seed potatoes for planting as compared with disinfection with formaldehyde alone. As has been pointed out above both apparently are necessary. In the Porter experiment, where the seed carried only a small amount of disease in the beginning, disinfection alone failed to eliminate all of it while selection did. On the other hand in the Hussey experiment with Green Mountains where the seed carried considerable disease it was absolutely eliminated by treating with formaldehyde solution alone. However, the writer believes that careful selection of seed tubers and rejecting for planting all that are in any way cracked, bruised, discolored or decayed is absolutely essential and no amount of disinfection with present known methods can be relied upon to entirely take the place of it. On the other hand the formaldehyde treatment appears to be equally essential and must be practiced to supplement selection of seed.

Gas versus formaldehyde solution: In no case except the Blake experiment were adjoining plots planted to compare the relative effectiveness of formaldehyde gas and solution. Here practically no disease developed on either piece and the check did not admit of accurate comparison. The writer was present when Mr. Blake's crew were treating and cutting seed and knows that it was quite carefully selected. Doubtless much of the freedom from disease in this instance was the result of seed selection. In the Cleveland Company and Elblad experiments, the only ones in which gas alone was used, the results are not so uniformly effective as in the case of the experiments where the seed tubers were soaked in formaldehyde solution. In each case where the best results were obtained with formaldehyde solution the owner of the potatoes was able to either cut the seed himself or be present and personally superintend the work at all times. This was not the case where the gas alone was used and the average man employed to cut seed cannot be depended

upon to throw away all tubers which show diseased areas in the interior to which the disinfecting agent could not possibly penetrate.

That formaldehyde gas generated by means of potassium permanganate is exceedingly efficient in killing the germs of many contagious diseases of man, which are much more resistant than the bacteria associated with the blackleg disease of potatoes, is well known. Moreover it has been shown that for a surface disinfectant of potatoes for scab formaldehyde gas generated in this way and by simple evaporation of the concentrated liquid by heat gives as good results as the ordinary method of soaking the seed tubers in dilute formaldehyde solution.* The method recommends itself for practical work on account of its *apparent* simplicity and the ease and rapidity by which disinfection can be accomplished by its use. However, its use in the hands of practical farmers develops certain fundamental difficulties which are not present when the liquid method of treatment is used. There is very little opportunity or excuse for one to fail to follow directions in the case of the latter. It was found in these experiments and in others where the formaldehyde-permanganate method of gaseous disinfection has been used for potato scab that it was almost impossible to get the men in charge of the work to comply with *all* of the requirements necessary. Frequently the rooms used for the purpose are too cold and no provision is made for a moist atmosphere. There is also a tendency to pile the tubers too deep in the crates and to place the crates too close together and too close to the wall to allow for complete circulation and penetration of the gas to all parts of the surface of each and every potato. Where the tubers are immersed in the dilute formaldehyde solution for 2 hours there is a certainty that the entire surface of each potato comes in contact with some of the disinfecting agents.

Blackleg Not Carried Over in the Soil in Maine.

Field observations extending over 5 consecutive years have failed to reveal a single case where there was any evidence to

* Jones, L. R. and Morse, W. J., Repts. Vt. Exp. Sta. 16: 165-168 (1903), 17: 397-402 (1904), 18: 287-291 (1905). Morse, W. J., Potato Diseases in 1907, Bul. Me. Exp. Sta. 149: 304-316 (1907).

show that the disease had been carried over in the soil and the growing crop infected by that means. On the other hand the appearance of the disease on fields not planted with potatoes for years or never before planted with any agricultural crop, and on farms for the first time following the use of seed from a different source all indicate the seed tubers as the source of infection. Moreover, as has already been mentioned, the disease does not occur in patches but in scattered hills all over a given field, and always begins at the base of the stalk where it joins with the seed piece, which latter is invariably destroyed by a soft rot.

Two of the experimental fields used this season gave very positive evidence in support of this view. Mr. Donaldson's Irish Cobbler field and Mr. Hussey's Green Mountain field were both planted the second time in succession. In both cases the disease appeared on the field in considerable amounts in 1910 and a part of the crop there produced was used for seed purposes in 1911. Where the seed was treated it was practically eliminated on Mr. Donaldson's entire field of 50 acres. On Mr. Hussey's field no diseased plants could be found where the treated seed was used and 163 per acre appeared where the seed was planted without disinfection. On such fields there are always quite a percentage of "volunteer" plants which spring from tubers which were either not brought to the surface or were covered up by the digger and remained in the soil all winter. These are frequently easily recognized on account of their springing up irregularly on the sides of the rows or between the hills. On the two fields mentioned not a plant of this kind was observed to be attacked with the disease.

Infection of Healthy Seed-pieces at or Following Cutting.

The bacteria causing this disease multiply fairly rapidly in the presence of a sufficient food and moisture supply at temperatures of from 65° to 75° F. and with great rapidity at from 76° to 85° F. At the temperatures usually maintained in the potato houses for winter storage—often but a few degrees above freezing—they multiply very slowly but are capable of remaining alive under these conditions for considerable periods of time, provided they are not allowed to dry out. Doubtless

the reason why infected tubers are not entirely destroyed by the disease before planting time or at least before the young plants which spring from such tubers can reach the surface of the soil is that, while sufficient moisture is present to keep the organisms alive, the temperature conditions are not right for their rapid multiplication till the soil in which the tubers are planted becomes thoroughly warmed up.

There is every reason to believe that in cutting seed the disease may be spread from diseased to healthy seed pieces by contact of their freshly cut, moist surfaces and less frequently from the hands of the operator or through the medium of knives used. It is a common practice to cut seed tubers and place them in barrels some weeks, or even months, before they are needed for planting. Although plaster or lime is usually sprinkled over such seed, which forms a more or less dry, protective coating over the cut surfaces, the conditions for the rapid multiplication and spread of bacteria are often very favorable. Seed cut in this way is very likely to "heat," especially if a few days of warm weather are experienced before planting, unless they are daily turned out of the barrels and exposed for a time to the air.

On one of the farms visited there was accidentally provided an excellent opportunity to observe how the blackleg disease may spread from diseased to healthy seed tubers after cutting and while being planted. The variety in this case being Carmen No. 1, planted without disinfection. During the planting the man in charge of the work was taken suddenly ill. After 2 or 3 days a substitute was obtained. but in the meantime several barrels of cut seed were allowed to remain in the field, covered with canvas. This provided right conditions of warmth and moisture in the barrels for rapid multiplication of any bacteria which might be present, and signs of "heating" and decay were evident when the barrels were opened again. Before the foreman of the farm was aware of it the new man in charge of the planting had planted 4 to 6 barrels of this seed. He at once ordered it stopped and substituted freshly cut tubers from the same bin from which the first lot was obtained.

The field was examined by the writer on July 19. Where the freshly cut tubers were used there was hardly a plant missing from the whole field and only about 15 or 20 plants per

acre showed blackleg. On the adjoining portion where the tubers were used which remained out in the barrels after being cut about 20 per cent of the hills had either failed to germinate or were attacked by blackleg. Somewhat less than one-third of an acre was examined and the diseased plants counted, giving 325 per acre where the "heated" seed was used.

It was evident that the seed tubers in this instance were quite free from disease. To the casual observer there appeared to be an absolutely perfect stand over the entire field except where the seed had been injured by standing in the barrels. The small amount of blackleg that the potatoes originally carried was largely increased as the result of the germs of the disease multiplying in and on the infected pieces and then being communicated to the healthy seed pieces in handling and planting.

No doubt quite a proportion of the failures to germinate were due to the same cause. However, other bacteria and fungi are, as a rule, associated with germination failures and seed potato decay after planting. It is well known that poor stands will result where cut seed tubers are allowed to stand in barrels or in piles for any length of time without proper attention, even where blackleg is entirely absent.

Treating Seed Potatoes with Formaldehyde Solution After Cutting

It is the universal practice to recommend that potatoes be soaked in formaldehyde solution *before* cutting when treating for scab. The writer has followed this procedure in advising treatment for blackleg. It is obvious that soaking *after* the seed is cut possesses decided advantages, provided the seed pieces are not injured thereby. If the latter process is followed more thorough disinfection would result and much, if not all, of the danger of chance contamination of healthy seed pieces would be avoided. Realizing the advantages of this method Mr. Donaldson tried it experimentally with very successful results. Not only were the germinating qualities of the tubers not injured but a more even stand was secured and, as will be seen in the next section, they were stronger and more vigorous during the early part of the season.

It is not safe to make general recommendations on the strength of this single trial alone but those who are treating

their seed with formaldehyde solution are advised to try it in a small way experimentally. If successful it could be done just before planting, the seed being soaked and dried in the sun as fast as needed for planting. It would not be practical to attempt to disinfect cut seed by the gas process.

Vigor of Plants as Affected by Formaldehyde Disinfection.

The writer has used formaldehyde experimentally as a disinfectant for seed potatoes nearly every year for the past ten years and before the present season has never observed any marked difference in the germinating qualities or rapidity of growth of plants from treated and untreated seed. If short sprouts have started at the time of treatment these are partly or wholly killed back, hence on theoretical considerations one would assume that the untreated tubers would have a slight advantage.

In the Parsons, Porter and Donaldson experiments the plants from the treated seed tubers germinated first and were plainly stronger and more vigorous during the early part of the season. This was especially marked on the Donaldson farm. Here both the poor and the good seed which was treated gave more vigorous plants than the portion of the same lot of tubers which was not treated. This was so marked that it could be detected some distance from the field even up to the middle of July. There was nothing to indicate that the formaldehyde produced a stimulating effect similar to etherization, but rather that the result was due to freeing the seed pieces from bacteria and fungi which might attack them and set up an early decay. In opposition to this hypothesis it is hard to see how these would be likely to carry, aside from the germs of the blackleg disease, any bacteria or spores of fungi which would not exist in abundance in the soil in which they were planted. However, when the weaker plants from the untreated seed were dug up in July the seed pieces were usually decayed while those from the more vigorous plants where the treated tubers were used were quite free from decay at this time.

Method of Eliminating Blackleg from Seed Potatoes.

From the foregoing discussion it is evident that if seed potatoes are carefully selected so that only those which are absolutely sound and perfect are used for seed purposes and these treated with formaldehyde that the disease can be eliminated in from one to two year's time.

For home use it is strongly recommended that only formaldehyde solution be employed. This consists of one pint of 40 per cent. formaldehyde in 30 gallons of water in which the potatoes should be soaked 2 hours and then spread out on a clean place to dry, preferably in the sun. Exposure to sunlight will also assist in destroying the bacteria causing the disease and tend to hasten germination.

It is only advised that the formaldehyde gas method be used by the large seed dealers who must pick up a considerable amount of their stock under conditions which preclude a knowledge of the amount of disease which appeared on the fields where the stock was grown. In such cases a special disinfecting room should be provided and fitted up with provisions made for the proper regulation of the temperature and moisture conditions during treatment. This work should be placed in the hands of a competent man who thoroughly understands each step and detail of the process. All seed tubers which are not known to be free from the germs of blackleg and potato scab should be disinfected in this way before being shipped.*

There seems to be a general misapprehension among potato growers as to the cost and amount of labor involved in the liquid method of treatment. Mr. Donaldson, following suggestions furnished him by the writer, worked out a satisfactory method adapted to his conditions whereby he was enabled to treat 260 barrels of seed potatoes for a total cost of about $10.00 for labor and formaldehyde, a little less than 4c. per barrel or about 20c. for each acre planted. The following is Mr. Donaldson's account of how this was done:

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* For a detailed description of the method of disinfecting seed potatoes with formaldehyde gas generated by means of potassium permanganate the reader is referred to page 324 of Bulletin 174, or to page 9 of Miscellaneous Publication No. 375 of this Station.

"First I bought 20 molasses barrels at 50c. each—got molasses and sugar enough out of them at 30c. a gallon to pay for them. I soaked them out clean and mixed the solution using one pint of formaldehyde to 30 gallons of water.

"For a platform to set the barrels on while soaking the potatoes I used my bobsleds with a long body and raised them off the ground by putting pieces of board or plank under the runners as the case might be to make them set level and keep them off the ground. I then bored a one inch hole in the side of each barrel, near the bottom, and put in a cedar plug. Ten of the barrels were then placed on the elevated sled body with the plugs to the outside and filled with potatoes. Ten molasses casks held about 16 standard barrels of potatoes. The solution was then put into these 10 barrels enough to cover the potatoes and let stand for 2 hours. It was then drawn off from the holes in the bottom into pails and turned into the other 10 barrels which had already been filled with potatoes and were set up on the sled platform the same as the first 10. Of course, there was a little waste each time and enough new solution was added each time to cover all of the potatoes. As soon as the solution was drawn off from the first 10 barrels the potatoes were turned down on another platform to dry. This platform was 15 x 20 feet and for a floor had inch boards nailed to plank stringers which had good bearings underneath. Around the platform were nailed pieces of 2 x 4 on edge to keep the potatoes from rolling off.

"I used 3 gallons of formaldehyde which cost me $6.00 to soak 260 barrels of potatoes.* My potatoes were clean, having been put over a rack once in the winter and once before cutting. I always do this because they can be made almost perfect in this way if they are good potatoes at the start. If the potatoes are clean the solution can be used over and over again without becoming dirty. * * * * * The cost of the labor the way I handled it would not be over one-half hour for two men, or 20c. for each batch of about 16 barrels. I had the lumber and have it now, so the cost of that was nothing. I was about

* The cost of the formaldehyde varied in the different experiments from 25c. to 75c. per pint or pound. The latter price is much too high. Formaldehyde can be sold at retail for 25c. a pint at a fair profit.

one-half day getting ready, making an additional expense of about one dollar."

By proceeding in a manner similar to that just described seed potatoes can be disinfected with formaldehyde solution quite rapidly and with comparatively little expense. Any sound cask such as a molasses, kerosene, or alcohol barrel can be used and with good care these should last for many years. The number of barrels needed will be from 2 up, varying with the number of barrels of potatoes to be treated and the rapidity with which the seed is needed for planting. The use of two lots of barrels is essential to rapid work. By this means the solution is made to work all of the time—one-half of the barrels can be emptied and filled again with a fresh lot of potatoes while the solution is acting on the other lot. Placing the barrels on a low platform enables the operator to quickly and easily draw off the solution without waste into pails from which it is turned into the other barrels which contain another lot of potatoes to be treated. Generally this platform consists of a single wide plank, elevated a little higher than the top of a common pail, and the barrels are placed in a row upon it.

Adjoining the narrow platform on which the barrels stand should be another which is large and broad, and upon which the disinfected tubers are poured out to dry. This larger platform is not absolutely necessary. A piece of canvas spread on the ground will serve the same purpose or the potatoes may be dried on clean, dry grass land.