UNIVERSITY of IDAHO
A College of Agriculture Publication

Injury to Russet Burbank Potatoes by Different Harvesting Machines

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IDAHO Agricultural
Experiment Station

BULLETIN 218
July 1954

Summary

During the 1947, 1948, and 1949 harvest seasons, various types of harvesters were compared at the University of Idaho Aberdeen Branch Agricultural Experiment Station to determine the source and extent of the mechanical injuries inflicted upon Russet Burbank potatoes by each of the harvesters used. The following are a few of the more pertinent results obtained from the research.

1. The proper management of any machine will result in fewer injuries.
2. The rubber-roller digger-picker caused less injury than any other type of harvester.
3. The bulker-combine did not injure any more potatoes than did hand-picking into baskets when the tubers had been dug by a two-chain digger.
4. Hand-picking into baskets caused more injury than picking into sacks.
5. Two-chain diggers caused more injury than single-chain diggers.
6. Kickers or eccentrics on the digger chain caused more injury than idler wheels.
7. Trailer-type digger-pickers caused more injury than single-unit digger-pickers. The trailer-type digger-picker injured more tubers than any other type of harvester.
8. Large tubers are more likely to be injured than small tubers. Very few "bakers" get into the sack without being injured to some extent.
9. In fields containing many clods there were more injured tubers than in fields with few or no clods.
10. Padding the truck bed reduces the chance for injury during the bucking and hauling operations.
11. Proper cultural practices and careful management of the harvesting and storing equipment are the most important factors in reducing injury to potatoes.

Injury to Russet Burbank Potatoes By Different Harvesting Machines

by WALTER C. SPARKS*

As a direct result of mechanical damage in potato harvesting and handling operations some Idaho growers suffer losses amounting to as much as 50 to 75 percent of their crop. These losses come directly from reduction in grade of the harvested tubers and by the increase in the amount of rot, shrinkage, and water-loss during storage. Damaged and spoiled potatoes result in reduced prices and loss of markets resulting from consumer dissatisfaction over the great number of blemishes appearing on the tubers offered for sale.

Hardenburg (2)[1] showed in his studies in the Cleveland markets that "it is evident that bruising is the most serious single defect on the Cleveland market." The United States Department of Agriculture Bureau of Agricultural Economics (1) points out that " a little more than one-fourth of the housewives said they disliked mechanical and handling injuries such as cuts, sunburn, and bruises." Many other workers have reported similar results.

There are several published reports of work done to determine the cause and source of mechanical injuries to potato tubers and how they may be eliminated. The earliest studies on the causes of mechanical injury seem to have been done by Hastings (4) in North Dakota and Hardenburg (2,3) in New York. The most complete studies as to the source and extent of mechanical injuries were reported by Schrumpf (5) in Maine and Werner (6) in Nebraska. Hastings states that, "Very often it (mechanical injuries) is practically the only factor with which shippers have to contend in sorting potatoes to meet a certain grade." Werner points out that in 1928, 1929, and 1930 mechanically injured potatoes constituted approximately 67 percent of all potatoes that were discarded in preparing certified seed potatoes for shipment as U. S. No. 1 grade stock.

Each of these workers has made suggestions for reducing the amount of mechanical injury to tubers. Hastings points out that by removing the rear apron, or by making a continuous chain with the rear apron, or by padding the hooks, he was able to reduce digger damage by an average of 28.9 percent. Schrumpf showed that by padding the shaker-elevator digger bruising was reduced by about one-fourth. Werner, Schrumpf, and Hardenburg pointed out that tractor-drawn diggers cause much less injury to the tubers than do horse-drawn diggers; but Hastings found that in six tests behind tractor-drawn diggers, including four with power take-off, he obtained an average of 56.5 percent injury as compared with 35.5 percent average by horse-drawn diggers. Werner suggests that plenty of power be used to pull the digger so that it can be run deeply enough to prevent cutting the tubers.

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[1] Numbers in Parenthesis refer to literature citations.

Hardenburg, Hastings, Schrumpf, and Werner each found that some injury occurred when potatoes were picked into baskets. Werner also found injury occurring when tubers were dumped from the picking baskets into sacks. Schrumpf not only found injury occurring when the tubers where dumped from the picking baskets into barrels, but also noted an increase of 19.12 percent in bruising when the potatoes were poured from the barrels into the bins.

Schrumpf noted that the amount of major injury increased by an average of 2.55 percent in storage, and he attributed a large portion of this to the development of minor injuries into major injuries during the storage period. Werner also points out that these minor injuries serve as a starting point for more serious situations, such as browning in the field or shed, or rotting in storage or transit.

In an attempt to determine the source of the harvesting injuries occurring to Idaho Russet Burbank potatoes, samples were taken during the 1947, 1948, and 1949 harvest seasons at each of the various steps in the harvesting operations.

Experimental Procedures and Results

In the fall of 1947, three different types of combines (A, B, & C in Figure 1), a trailer-type digger-picker (A in Figure 2), and a level-bed two-chain digger (B in Figure 2) were sampled at various points to determine the amount and extent of the injuries occurring during the harvesting process and to determine the specific operation or point on the machine which was causing these injuries. The points sampled were the digger, the half-sacks, the truck, and the storage bin. The potatoes for the digger sample were taken at random as they passed over the rear of the digger but before they had fallen onto the ground or elevator chain. The picking sample was randomly taken from the half-sacks in the field for the hand picked and trailer-type picker, and from the bulk truck for the combine-type harvesters. The tubers were sampled in the cellar on the trucks before being piled in order to determine the injury received during the hauling and handling from the field to the storage bin. The final sample for the harvesting operation was taken from the storage bin after the tubers were piled.

At least three replications for each type of machine were obtained by taking samples at each of the foregoing places on each machine from one section of the field and then taking the next set or series from another section of the field, i.e., as the machine progressed down the field the sample was taken from the digger and the half-sacks simultaneously, or as nearly so as possible; the remainder of the sacks from which samples were taken were then followed into the storage where the truck and piler samples were obtained. Then for replication number two, the entire procedure from digger to bin was duplicated. By comparing the number and kind of injuries at each point with those at the preceding point, the amount and kind of injuries received during any operation could be calculated.

Figure 1. Three different types of bulker-combine potato harvesters used during the 1947 harvest season, (A) side delivery bulker-combine No. 1, (B) side delivery bulker-combine No. 2, (C) overhead delivery bulker-combine.

Figure 2. (A) trailer-type digger-picker, (B) two-chain level-bed digger.

Injury Classes

The injuries received by the tubers were classified into five general classes; digger cuts, serious bruises, hard bruises, slight bruises and uninjured. Any tuber which had been cut, sliced or shaved in any way by the digger blade was classified as a digger cut (A in Figure 3). Broken tubers, smashed tubers, gouged tubers, and tubers that had been hit by the end of a digger chain link or had been caught in the chain and rendered unsalable were all classified as serious bruises (B in Figure 3). Serious bruises were grouped with the digger cuts to form the category "culls" listed in this paper.

Any tuber which had received a bruise hard enough to break off a knob or second growth, to cause cracks greater than ½ inch in

length, or to remove the skin and a small portion of the flesh of the tuber but did not cause a pare-away of greater than 5 percent of the tuber was put into the category of hard bruises (C in Figure 3). The tubers in this class were not injured seriously enough to be scored against by the inspector and only when the injury detracted greatly from the appearance was it not allowed in the U. S. No. 1 grade.

Those tubers which had very small cracks, skinned areas, or bruises which caused an indentation or slight discoloration were classified in the category of small bruises (D in Figure 3). Some of the tubers in this class had bruises which did not cause a break in the skin but showed an area of bruised and darkened or necrotic tissue upon being peeled (A and B in Figure 4).

Only those tubers which did not show any of the above defects were classified as uninjured.

Figure 3. Classification of injuries reported in this paper (A) digger cuts, (B) serious bruises, (C) hard bruises, and (D) slight bruises.

1947 Results

The effects of five different harvesting machines on the amount of cullage occurring at various points are shown in Table 1 and

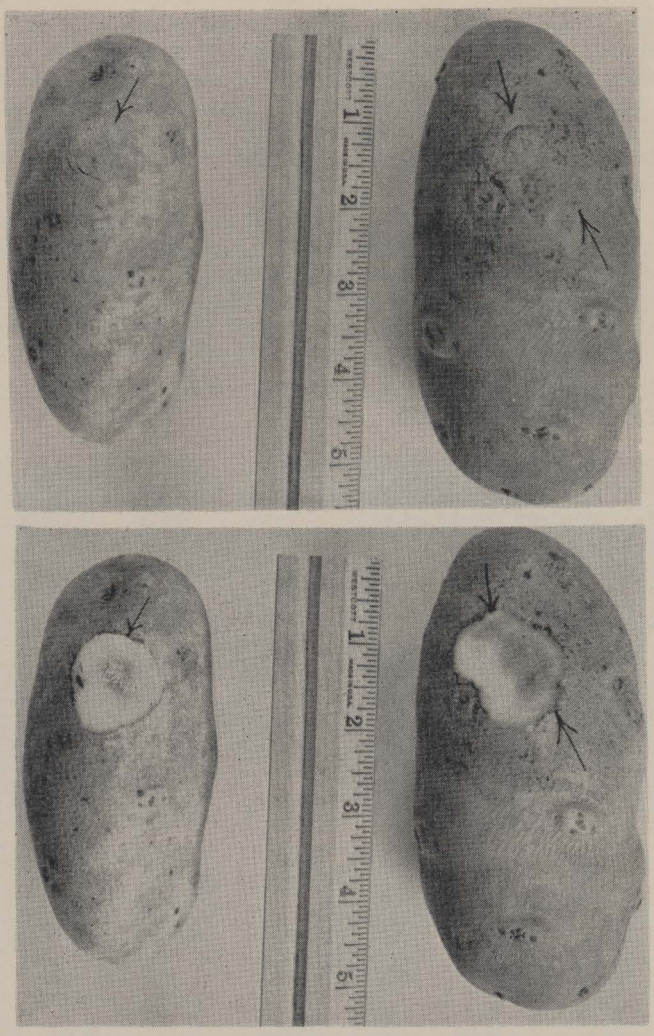

Figure 4. Slight bruises before and after removal of the periderm layer.

Figure 5. This shows that as an average of all types of harvesters, the greatest amount of cullage occurred during the digging operation, with 5.39 percent of all tubers being reduced to culls by the digger. Only 2.22 percent culls were produced during the picking, and 2.24 percent during the handling and hauling process from the field to the storage. The piling operation caused another 4.50 percent cullage, thus by the time the tubers were in the storage bin they had accumulated a total of 14.35 percent cullage.

The variation due to machines is easily noted. The two machines which, during the digging operation, produced less cullage than the average did not have eccentrics or shakers on the digger chains;

Table 1. Mean percent of the various types of injury present at four sampling points on five different potato harvesters during the 1947 harvest season.

Point of Sample		TYPE OF INJURY					
		Cuts	Serious Bruises	Slight Bruises	Skinned[1]	Uninjured	Cullage[2]
		Percent					
Digger		2.18	3.98	50.95	3.82	39.07	6.16
Picker		2.61	5.37	61.79	4.69	25.54	7.98
Truck		3.64	6.21	70.72	5.01	14.40	9.85
Bin		3.14	11.21	76.87	4.26	4.52	14.35
MSD[3]	.05	N.S.	4.47	16.51	N.S.	18.13	4.63
	.01	N.S.	5.09	18.81	N.S.	20.66	5.27

[1] Skinned refers to those tubers having only the periderm removed. In later tables skinned is included in slight bruises.
[2] Cullage is obtained by adding the cuts and serious bruises together.
[3] Difference required for significance at odds of 19:1 and 99:1.

whereas, the three diggers which resulted in more than the average amount of cullage for the digging operation did employ eccentrics on the digger chains. The two machines which showed the least cullage by the time the tubers were in the bin were bulker-combines.

Table 2. Effect of various types of harvesters on the type and percentage of injury present in the storage bin in 1947.

Digger Type	Cuts	Serious Bruises	Small Bruises	Skinned[1]	Uninjured
	Percent				
Side-delivery combine II	2.94	5.88	80.39	8.82	1.96
Overhead delivery combine	5.75	11.06	80.08	1.77	1.33
Side-delivery combine I	2.35	6.74	78.30	2.64	9.97
Flat bed digger	1.52	17.63	72.04	2.13	6.69
Trailer type digger-picker	3.16	14.74	73.55	5.92	2.63
Total	15.72	56.05	394.36	21.28	22.58
Mean	3.14	11.21	76.87	4.26	4.52

[1] Skinned refers to those tubers having only the periderm removed. In later tables skinned is included in slight bruises.

Table 2 shows that the increase in cullage from the truck to the bin is 1.02 percent on the combines as compared to 9.73 percent on the half-sacks. When emptying half-sacks the potatoes are dropped or thrown from a few inches to several feet thus causing considerable damage. Injury is caused by the drop at this point and also by the change of direction. The potatoes are usually moving from the half-sacks in the direction the truck is parked while the piler chain moves at right angles to this direction. When unloading bulk trucks the drop from the truck to the piler is usually reduced to a minimum, usually 6 to 12 inches. The bottom of the bulk-truck unloading chain is just high enough to clear the hopper of the piler and the speed of the tubers as they strike the piler chain is slow as compared to the speed of tubers coming from half-sacks. The direction of movement usually is the same rather than at right angles. Two combines unloaded tubers so that the chain in the bottom of the bulk truck moved the same direction as that of the piler

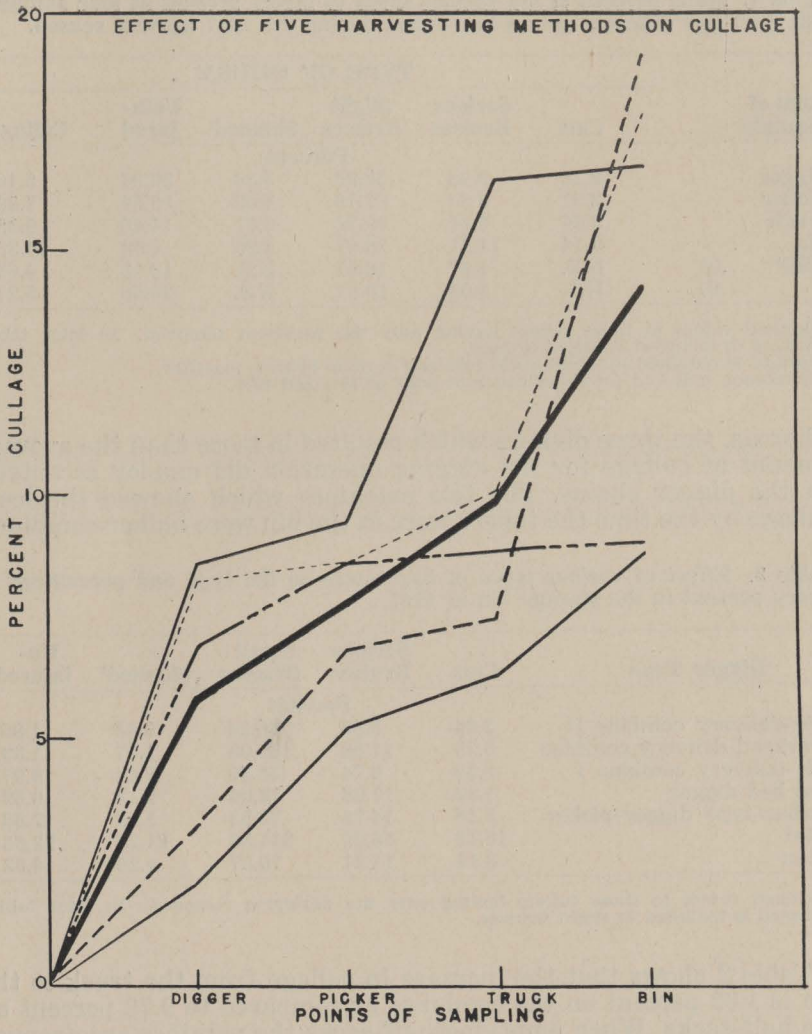

Figure 5. Effects of five harvesting methods on cullage.

chain. These two caused an increase of only .24 percent and .29 percent in cullage as compared to 2.52 percent effected when the bulk truck chain moved at right angles to the direction of movement of the piler chain.

The type of harvester which gave the least amount of injury at the digger was the flat-bed digger. Of course, at this particular point, no tubers had been touched by hand. The flat-bed digger had dug them and laid them out on top of the soil and there were only a little more than 3 percent culls at this point. The only other machine which approximated this low percentage was the side-delivery combine II. Picking up the tubers by hand increased the cullage by over

4½ percent, whereas, the side-delivery combine increased it by only 1½ percent. This shows that the human element of picking up the tubers caused far more injury than the best of the combines which is an entirely mechanical method of harvesting. The sample which was taken from the trucks after having been either bucked up onto the trucks or put into the truck by the elevator delivery of the combines showed that the side-delivery combine II had the least amount of cullage. This continued on into the bin. It should be noted that the hand picked tubers increased some 12 percent in cullage during the piling operations. It might be pointed out that this particular sample was the only one in which no piler was used. The potatoes were piled entirely by hand. Many culls were caused by the people walking back over the top of the tubers and throwing the potatoes up against the side of the bin. The combines had to use a piler and as was before stated the rear of the chain was only some 6 to 8 or at the most 12 inches above the padded hopper of the piler.

From these data, it is evident that one of the main points of injury during the harvesting operations is the digger itself. With this information Mr. E. N. Humphrey*, the cooperating Agricultural Engineer, designed a new type of potato digger. A comparison of this machine to the other types of machines was made during the harvesting seasons of 1948 and 1949.

1948 Results

In 1948 five different types of machines were tested at the Aberdeen Branch Station under comparable management and soil conditions, using the same crew, and traveling the same rate of speed. The sampling was done on the same day at the following points; the digger point, the picking table, the picking sacks or baskets, and the cellar. There were four replications of each point of sampling on each machine. This was effected by using two fields which were divided in the center in the direction of irrigation. The north half of Field 5d was considered as replication one, the south half as replication two, the north half of Field 3i was considered as replication three, and the south half as replication four. Each machine dug the necessary samples of tubers from each replication and then all machines were moved to the next replication. The five different types of machines used during the 1948 harvest season consisted of a two-row flat-bed digger which had a double chain (E in Figure 2) ; a trailer-type digger-picker (D in Figure 2) ; the station digger-picker which used rubber rollers to separate the potatoes from the dirt (A and B in Figure 6) ; a non-rubberized digger-picker (C in Figure 6) ; and a non-rubberized bulker-combine (C in Figure 1). Due to the loss of identity of several of the samples collected at the cellar and the fact that necessity demanded that the bulker-combine

* Mr. E. N. Humphrey, formerly Associate Agricultural Engineer, Idaho Agricultural Experiment Station, carried on research in a companion project jointly supported by the University of Idaho and the Idaho Advertising Commission. As a result of his studies the following two bulletins have been published:

(1) Humphrey, E. N. 1950.
Steps that can be taken to reduce mechanical damage to potatoes at harvest time. Univ. of Idaho Agr. Exp. Sta. Bul. 278.

(2) Martin, J. M., and E. N. Humphrey. 1951.
The Idaho potato harvester. Univ. of Idaho Agr. Exp. Sta. Bul. 283.

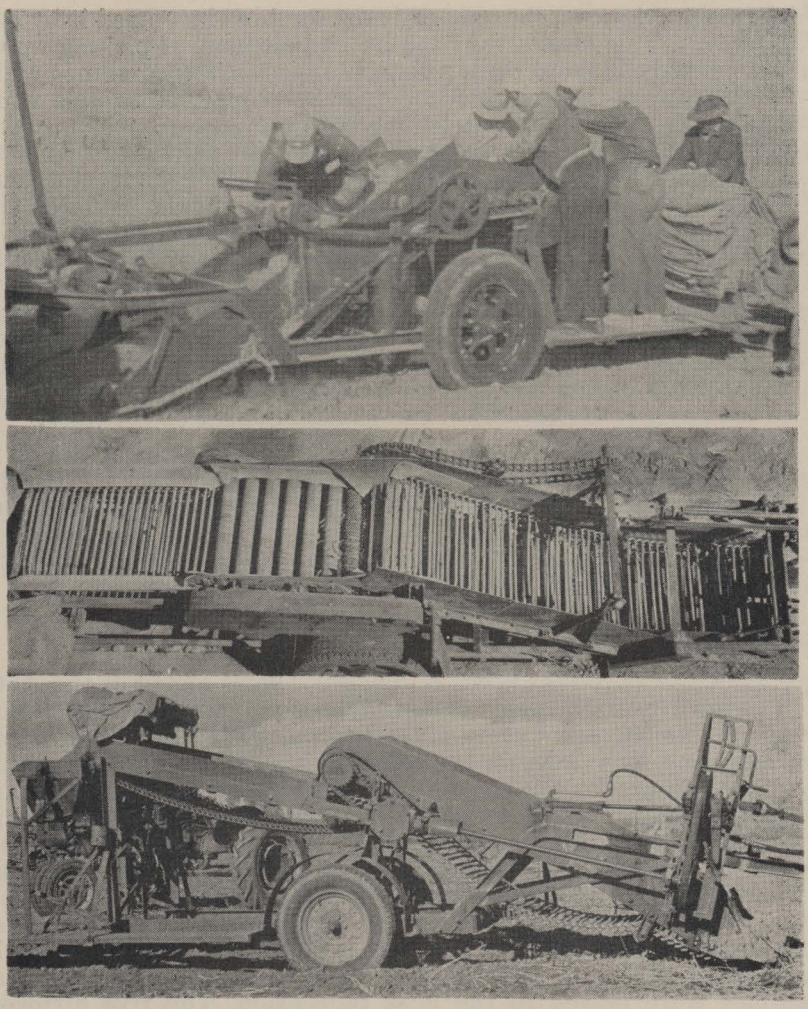

Figure 6. Two types of harvesting machines used in 1948 that were not used in 1947, (A) side view of rubber-roller digger-picker, (B) top view of rubber-roller digger-picker, (C) non-rubberized digger-picker.

put all the tubers from all replications into the same bulk truck and therefore only a massed sample could be obtained following this machine, the analysis of data at this point of sampling became unreliable. Because of this situation the figures in the table representing the cellar samples should be examined with care and not too much faith placed in them. One fact that should be noted is that the machine having the lowest percentage of injured tubers at the end of the digging operation was the bulker-combine, but by the time the potatoes had passed over the picking table of this machine, the percentage of injured tubers was the highest of any of the machines. This was because of the rapid speed of the cross

chain on the picking table of this particular type of machine. The sprocket causing the high speed of the picking table was changed and much less injury was obtained on later samples, but on this machine as compared to the other machines in the test, the data show many injuries occurring on the cross chain. The mean percentages of the various types of injury caused by five different types of harvesters at four sampling points during the 1948 harvest season are given in Table 3. The percentage of culls increases as the

Table 3. The mean percent of the various types of injury caused by five different types of harvesters at four sampling points during the 1948 harvest season.

Point of Sample	Culls*	Hard Bruises	Cracks	Small Bruises	Uninjured
			Percent		
Digger	1.79	14.01	.32	29.03	54.87
Picking Table	2.41	20.67	.22	45.90	30.78
Half Sacks	2.22	24.39	.90	56.34	15.99
Cellar**	5.11	27.29	1.49	43.76	22.35

* The term "culls" designates all digger cuts, serious bruises, and cracks large enough to be out of tolerance for U.S. No. 2 grade.
** The identity was lost on several of the bin samples, and the figures in the table represent the means of from one to four samples and little confidence should be placed in these means.

potatoes progress from the digger to the storage bin. The percentage of hard bruises present in the storage bin or half-sacks has almost doubled over that found in the samples obtained at the digger in half-sacks; the number of tubers without an injury of any kind is about one-third the amount found at the digger. A direct comparison among machines can be made after the tubers have been picked up and are in the half-sacks, or, in the case of the bulker-combine, in the bulk trucks. This comparison is given in Table 4.

Table 4. Effect of five different types of harvesters on the percentage of the various types of injury present in the half-sacks and bulk trucks in 1948.

Type of Machine	TYPE OF INJURY				
	Culls	Hard Bruises	Cracks	Small Bruises	Uninjured
			Percent		
Two-chain two-row Baskets*	721	52.31	2.31	35.56	2.57
Two-chain two-row Sacks*	1.65	37.01	0.82	55.80	4.69
Trailer-type digger-picker	3.50	25.00	2.25	59.50	9.75
Non-rubberized digger-picker	0.64	12.25	0.43	66.02	20.64
Rubber-roller digger-picker	0.62	8.07	0.93	52.48	37.57
Non-rubberized bulker-combine	4.64	37.77	0.00	49.22	8.04
M.S.D. .05	N.S.	11.81	N.S.	N.S.	10.83
.01	N.S.	16.56	N.S.	N.S.	15.18

* The potatoes were dug with the two-chain, two-row machine. **Baskets** designates that they were picked up into picking baskets and dumped into half-sacks. **Sacks** designates that they were picked directly into picking sacks.

This shows that the machine inflicting by a significant amount, the greatest percentage of hard bruises was the two-chain level-bed digger with the tubers picked up with picking baskets. When the potatoes dug by this same digger were picked into picking sacks, the percentage of hard bruises was reduced by a significant amount. The machine causing the smallest percentage of hard bruises was the rubber-roller digger-picker. It caused significantly fewer hard bruises than did any other machine except the non-rubberized digger-picker. The bulker-combine caused significantly fewer hard bruises than did the two-chain digger when the tubers were picked into picking baskets, but made the same percentage when the tubers were picked into picking sacks.

Figure 7. Additional types of mechanical harvesters used in 1949, (A) single-chain level-bed digger, (B) rubber-roller bulker-combine.

The percentage of uninjured tubers present in the half-sacks and the bulk truck (Table 4) shows that the rubber-roller digger-picker had significantly more tubers free from injury than did any other machine. The tubers dug by the two-chain flat-bed digger had fewer tubers free from injury than did any other machine, but the amount was not significantly less than that obtained from the trailer-type digger-picker or the bulker-combine. These data demonstrate that the machine which injures the tubers least is the rubber-roller digger-picker. It also shows that tubers dug with the bulker-combine are injured no worse than those dug with a level-bed two-chain machine and picked up by hand.

From these results it can be seen that the rubber-roller type dirt-separating mechanism did reduce injury and that this machine in this year proved to be much better than other types of machines which were tested along with it. For this reason a similar test was conducted in 1949 using more machines on three types of soil.

1949 Results

During the 1949 harvest season various types of machines were used on three separate fields which differed in soil type as well as number of clods. The types of harvesters used were: (1) the bulker-combine which was non-rubberized. This machine was a two-row machine which dug the tubers, passed them across a picking table, and then elevated them into a bulk truck which ran at the side of the machine. The combine had a separate motor for running the digger and the elevator chain. It was the same machine used in the 1948 tests and will be designated as the non-rubberized bulker-combine, (2) bulker-combine which employed rubber dirt-separating rollers as designed at the Aberdeen Branch Station (B in Figure 7). This was a two-row combine which used an auxiliary engine to dig and elevate the potatoes into the bulk truck. This machine will be called the rubber-roller bulker-combine, (3) digger-picker machine with rubber rollers, rubber on the digging chain, rubber on the picking table chain, and rubber on the hopper. This is the machine designed and built at the Aberdeen Branch Station. It is a single row harvester and does not employ an auxiliary engine but is powered by the power take-off from the tractor. It will be known as the rubber-roller digger-picker and is the same machine used in the 1948 trials, (4) a digger-picker, non-rubberized machine very similar to the number 3 type machine except that it did not have rubber rollers, chains, or hopper. It is also a single row machine powered by the power take-off from the tractor. It will be listed as the non-rubberized digger-picker, (5) a digger-picker which employed a trailer type picking arrangement which was pulled after the regular standard type digger. It was non-rubberized and was powered by the tractor. It is designated as the trailer-type digger-picker and is similar to the machine of this type used in the 1948 trials, (6) a two-chain level-bed digger. After digging, the potatoes were picked up by using picking sacks and baskets. This machine is a two-row machine and employs the two-chain principle to separate the dirt from the tubers. This is the same machine that was used in 1948, (7) a single-chain level-bed digger (A in Figure

7). This is a one-row machine and the tubers were picked up by the two methods: picking sacks and baskets.

All machines used in this test were gathered at the Aberdeen Branch Station and the digging took place the same day with the same crew operating each of the machines. Three separate fields were selected for this test; one a field in which the soil was heavy and contained many hard clods. The second was on a field which had few clods and the third field was somewhat sandy with practically no clods. These three fields were selected as being representative of the majority of the soils in the upper Snake River area and were chosen in an attempt to determine the injury occurring to tubers under the various types of soil conditions with the various types of machines.

Due to the difficulty in obtaining samples at the storage bins when the potatoes were harvested, a sample of two 60-pound half-sacks or approximately 350 tubers was obtained from each machine on each field after the tubers were in half-sacks or, in the case of the bulker-combines, in the bulk trucks. This gave a total of about 1000 tubers from each machine. When examining the samples for injury the weight, and the amount and type of injury on each tuber, were recorded. In this way the effect of the size of the tuber upon the type and amount of injury could be determined. Table 5

Table 5. The effect of seven different types of harvesters on the percentage of the various types of injuries found in the half-sacks and bulk trucks in 1949.

Type of Machine	Tubers Examined	TYPE OF INJURY				
		Culls	Hard Bruises	Cracks	Slight Bruises	Uninjured
				Percent		
Single-chain baskets*	643	1.08	7:30	2.64	60.80	28.14
one-row sacks*	491	1.41	5.29	3.25	57.84	32.17
Two-chain baskets*	897	3.89	15.83	3.56	57.07	19.73
two-row sacks*	867	3.68	12.68	7.49	50.17	25.95
Trailer-type digger-picker	966	3.51	21.42	2.69	63.45	8.79
Non-rubberized digger-picker	944	2.00	19.59	3.38	57.83	16.10
Rubber-roller digger-picker	1024	2.43	5.66	1.84	47.26	42.77
Non-rubberized bulker-combine	1030	2.52	14.75	1.84	65.63	15.24
Rubber-roller bulker-combine	1114	1.33	17.32	0.80	69.21	11.31
M.S.D. .05		N.S.	5.62	N.S.	8.12	9.34
.01		N.S.	7.75	N.S.	11.87	12.86

* **Baskets** means that after the tubers were dug and laid out on top of the ground they were picked up with baskets and dumped into half-sacks. **Sacks** means they were picked directly into sacks using a picking belt.

shows that when all sizes of tubers are considered the mean percentage of culls caused by the various machines was 2.43 and that even though the machines varied from 1.08 to 3.89 percent they did not differ significantly. The two-chain two-row level-bed digger caused more culls than any other machine while the rubber-roller

bulker-combine caused fewer culls than any other machine except the single-chain level-bed digger when picked up in baskets.

The percentage of hard bruises varied from a low of 5.29 on the single-row one-chain level-bed digger picked up in baskets to 21.42 found on tubers harvested by the trailer-type digger-picker. This difference is highly significant. The single-chain digger and the rubber-roller digger-picker caused signifcantly smaller percentages of hard bruises than any of the other machines, and were the only machines except the two-chain sacks machine causing significantly fewer hard bruises than the trailer-type digger-picker.

Small bruises caused by the various machines were numerous, but the rubber-roller digger-picker showed a significantly smaller percentage than any other machine except the two-row two-chain digger when the tubers were picked into picking sacks. The rubber-roller digger-picker delivered more uninjured tubers than any other machine. This means that there were significantly more potatoes put into half-sacks without injury with the rubber-roller digger-picker than with any other machine tested.

As a summary for the 1949 trial, we can say that the best machine in this test was the rubber-roller digger-picker which was designed and built at the University of Idaho Aberdeen Branch Experiment Station. The trailer-type digger-picker which caused injury to the greatest number of tubers was the most commonly used type of mechanical harvester up to 1950.

Combined Data for 1948 and 1949

Due to the method of obtaining the samples in 1947 under vari-

Table 6. Two years results on injury caused by various types of harvesters. Samples obtained from the half sacks on trucks and from the bulk trucks.

Type of Machine		Culls	Hard Bruises	Cracks	Small Bruises	Un-injured
				Percent		
Two-chain Baskets	1948	7.21	52.31	2.31	35.56	2.57
Two-row	1949	3.89	15.83	3.56	57.07	19.73
2-yr. ave		5.55	34.07	2.94	46.31	11.15
Two-chain Sacks	1948	1.65	37.01	0.82	55.80	4.69
Two-row	1949	3.68	12.68	7.49	50.17	25.95
2-yr. ave		2.84	24.84	4.16	52.98	15.32
Trailer-type	1948	3.50	25.00	2.25	59.50	9.75
Digger-picker	1949	3.51	21.42	2.69	63.45	8.79
2-yr. ave		3.51	23.21	2.47	61.47	9.27
Non-rubberized	1948	0.64	12.25	0.43	66.02	20.64
Digger-picker	1949	2.00	19.59	3.38	57.83	16.10
2-yr. ave		1.32	15.92	1.91	61.92	18.37
Rubber-roller	1948	0.62	8.07	0.93	52.48	37.57
Digger-picker	1949	2.43	5.66	1.84	47.26	42.77
2-yr. ave		1.53	6.86	1.39	49.87	40.17
Non-rubberized	1948	4.64	37.77	0.00	49.22	8.04
Bulker-combine	1949	2.52	14.75	1.84	65.63	15.24
2-yr. ave		3.58	26.26	0.92	57.42	11.64

ous soil conditions, various management practices and other non-comparable conditions, these results are not included in the mean results for the various machines for two years. The mean percentages of the various types of injury obtained from the half-sack samples in 1948 and 1949 at the Aberdeen Branch Station are given in Table 6. This shows that the machines producing the smallest percentage of culls by the time the tubers were in half-sacks or bulk trucks were the two types of digger-pickers and the worst was the two-chain digger after which the tubers were picked into baskets. The rubber-roller digger-picker caused considerably fewer hard bruises than any other machine while the two-row two-chain digger with tubers picked into baskets caused the most.

In the 2-year average the machine which inflicted the fewest harvest injuries to the potatoes was the rubber-roller digger-picker. More than twice as many tubers were still uninjured by the time they had reached the half-sack when harvested by this machine as there were with any other machine. From the rubber-roller digger-picker 40 percent of the tubers were still unblemished by the time they were in the half-sack, as compared to 18 percent from the non-rubberized digger-picker; 11 percent from the bulker-combine and the two-chain digger when picked into baskets. The trailer-type digger-picker was the most commonly used mechanical harvester in 1948-49 and with it only 9 percent of the tubers were put into half-sacks without a blemish of some type.

Table 7. The effect of the number of clods in the soil at harvest time upon the percent of the various types of injury found in the half-sacks and bulk trucks during the 1949 harvest season.

No. of Clods		Culls	Hard Bruises	Cracks	Small Bruises	Uninjured
				Percent		
Many		3.82	13.60	4.69	60.70	17.18
Few		1.83	15.31	2.66	57.66	22.61
None		1.83	11.53	2.15	57.83	26.12
M.S.D.	.05	1.70	N.S.	N.S.	N.S.	5.39
	.01	2.34	N.S.	N.S.	N.S.	7.43

Effect of Cloddiness of Soil on Amount of Injury

Table 7 gives the percentage of each type of injury found in the half-sacks and the bulk trucks under each type of soil. In soil having many clods there were significantly more culls than in the other two soils. When hard clods are present in the soil it is difficult to get potatoes through the harvesting operation without injuring them. The various machines reacted differently on the various soils. The rubber-roller digger-picker resulted in significantly fewer injured tubers on the field with few to several clods than any other machine except the single-chain digger when picked into sacks. It also shows that the rubber-roller digger-picker was significantly better than any other machine when the fields had many clods. When the field had few to no clods the single-chain digger was the best but was not significantly better than the two-chain

digger or the rubber-roller digger-picker. One important fact brought out is that when the fields have few or many clods the digger-picker machine with rubber rollers is the best machine for harvesting tubers without injury.

The Effect of Picking into Sacks as Compared to Picking into Baskets

In order to compare the injury received by picking into picking sacks with picking into baskets, two adjacent rows were dug with each of the two types of level-bed diggers. One row with each method of digging was picked into sacks and the other was picked into rubber-covered wire baskets. The results (Table 8) of these

Table 8. Summary Table of means on the effect of the method of hand picking tubers, the type of digger used, the size of tubers, and the clodiness of the soil upon the percent of uninjured tubers present in the half-sacks.

Method of Picking	
Picking Sacks	26.29
Baskets	20.54
M.S.D. 5% point	5.32
Type of Machine	
Digger single-chain	26.24
Digger two-chain	20.58
M.S.O. 5% point	5.32
Size of Tubers	
4 to 6 ounces	31.93
6 to 8 ounces	14.89
M.S.D. 5% point	5.32
1% "	7.89
Type of Soil	
Field 3i (no clods)	26.12
Field 8a (few clods)	22.61
Field 6e (many clods)	17.18
M.S.D 5% point	5.39
1% "	7.43
Interactions	
None of the interactions were significant at the 5% point; therefore they are not listed.	

two picking methods show that when the tubers were picked into sacks there were significantly fewer injured tubers than when the tubers were picked into rubber-covered wire baskets.

After digging and picking into sacks an average of 26.19 percent of the tubers was still uninjured, but a mean of only 20.54 percent remained uninjured after picking into rubber-covered wire baskets. The standard error of a difference between these means for significance at the 5 percent point is 5.32 percent.

Single-Chain vs. Two-Chain Diggers

The single-chain digger injured by a significant amount fewer tubers than did the two-chain digger. The mean percentage of

tubers with no injuries was 26.24 for the single-chain digger as compared to 20.58 for the two-chain digger. The minimum difference between these means needed for significance at the 5 percent point is 5.32 percent.

Tuber Size in Relation to Percentage of Uninjured Tubers when Hand Picked

There was a significantly greater percentage of the tubers from 4 to 6 ounces in size which remained uninjured when picked by hand than tubers from 6 to 8 ounces in size. The mean percentage of uninjured tubers in the 4 to 6 ounce size group was 31.93 as compared to 14.89 percent for the 4 to 6 ounce size group. Any difference between these means greater than 5.32 was significant at the 5 percent level and anything greater than 7.89 was significant at the 1 percent level.

Hauling

In an attempt to determine exactly where the injury was occurring during the hauling and handling process from the field to the cellar, sacks from the bottom and top layers of the same load were taken at random and the amount of injury present was determined. The potatoes examined on this portion of the injury study had all received identical growing, harvesting, and picking treatments, and any differences in the amount of injury present on the tubers from the sacks on the bottom layer and that present on the tubers from the sacks on the upper layers, was assumed to be due to the position of the sack in the load. The results are given in Table 9 and

Table 9. Influence of the layer in which the sacks are placed on the truck during the hauling operation upon the percent and type of injuries found.

	INJURY BY TYPE				
Layer	Cuts	Serious Bruises	Slight Bruises	Skinned	Uninjured
			Percent		
Top	3.20	8.94	61.65	10.05	17.18
Bottom	3.46	8.91	63.85	10.02	13.79
M.S.D. at 5% level	N.S.	N.S.	N.S.	N.S.	N.S.

indicate that there are no significant differences among the layers in which the sacks are placed. The bottom layers had more cuts and more slight bruises, but the differences were not significant.

The top one-half and the bottom one-half of each sack were kept separate in order to determine whether there were any differences in injury occurring in the tubers due to the position in the sack. Table 10 shows only a slight difference in the percentage of culls and uninjured tubers in the top and bottom halves of the sacks and this difference is not significant.

Table 10. Effect of position in the half sack upon injury occurirng during the hauling operation.

Position	INJURY BY TYPE				
	Cuts	Serious Bruises	Slight Bruises	Skinned	Uninjured
	Percent				
Top ½ of Sack	2.78	7.56	64.90	10.78	13.98
Bottom ½ of Sack	3.79	10.26	59.66	9.37	16.92
M.S.D. at 5% level	N.S.	N.S.	N.S.	N.S.	N.S.

Tuber Treatment for the Detection of Injuries

It was difficult to distinguish slight bruises and only by a very careful and tedious examination could some of these slight bruises be detected. Consequently a method was sought which would increase the number of potatoes that could be examined in a given period of time. Since iodine is a common indicator for starch, it was reasoned that by dipping the tubers in an iodine solution, any small breaks in the periderm would allow the iodine to come in contact with the starch of the potato and thus make these slight bruises more easily detected. Table 11 shows that tubers showing

Table 11. Effect of treating tubers with iodine upon the type of injuries detected.

Lot	Cuts		Serious Bruises		Slight Bruises		Skinned		Uninjured	
	I_2	Eye	I_2	Eye	I_2	Eye	I_2	Eye	I_2	Eye
I	6	6	3	3	58	40	19	32	23	28
II	1	1	7	7	57	45	10	16	25	31
III	3	3	9	9	69	61	15	21	17	19
IV	12	12	9	9	72	64	13	19	14	16
V	2	2	9	9	59	56	13	16	16	16
VI	7	7	7	7	59	56	18	20	12	13
VII	3	3	5	5	66	60	16	21	10	11
VIII	9	9	8	8	91	80	17	26	20	22
Total	43	43	57	57	531	462	121	171	137	156
Mean	5.38	5.38	7.13	7.13	66.38	57.75	15.13	21.38	17.13	19.50
M.S.D. .05	N.S.		N.S.		4.20		2.90		1.71	
.01	N.S.		N.S.		4.45		4.31		2.53	

small bruises and skinned areas were more readily detected by this method than by visual observation.

Discussion

One of the most important phases of a potato harvesting operation is the careful management of the harvesting machinery. The careful handling of a poor machine will probably result in more good potatoes than the poor management of the best machine. There is no substitute for proper supervision and handling of potato harvesting equipment.

In these trials the digger was found to cause the greatest amount of cullage, but the piling operation also caused many culls. The

method of piling which caused the most bruising was hand piling without the use of any kind of mechanical device. Here again, supervision was the important factor; while the boss was close and carefully watching the piling operation there was little damage, but as soon as he left, speed became all important to the buckers because they usually are paid so much per sack for bucking, hauling, and unloading. Instead of letting the top of the sack down carefully onto the pile and carefully pouring the tubers out, the buckers would sometimes stand on the truck and throw the tubers some 5 to 10 feet out of the sacks onto the pile. Again careful supervision becomes the important factor.

These data point out that the mechanical methods of harvesting potatoes are as good, and in some cases better, than picking them up by hand. These data are not correlated with cost figures, but a study being carried on at the present time will include both injury and cost in order to determine which method of harvesting is the most economical from the standpoint of injury to the tubers as well as the cost of harvesting each hundred pounds of potatoes. The only year that the bulker-combine caused much more injury than did hand picking was in 1949 on the field containing no clods. In this field the soil was sandy and it was very difficult to maintain a cushion of soil on the digger chain. Some of this injury may have been prevented had the eccentrics or kickers been removed from the machine, but the normal procedure of the farmers was to use eccentrics on this type of soil, and since this test was to approximate the practices followed by farmers, the kickers were allowed to remain on the machine. A later test showed that the injury was reduced when the kickers were replaced by idler wheels. One of the places causing the most injury on the bulker-combine was the cross-chain or picking table chain. This chain moved very rapidly and the tubers were bruised when hit by the steel cross-chain which caused a 90 degree change in direction. When the drive sprocket for the cross-chain was changed and the speed of the cross-chain was reduced the injury caused at this point was reduced greatly.

It has long been thought that picking into baskets has caused more injury than picking directly into picking sacks, probably because of the extra handling the potatoes receive when dumped from the basket into the sacks. The data obtained from this study substantiate this belief. It was noted that there was a big variation among pickers in the amount of injury shown by the tubers which had been picked into baskets. Some pickers tossed the tubers as far as 2 feet into the baskets whereas others never threw the potatoes over 6 inches to a foot. This extra energy given the potatoes by throwing was enough to cause considerable injury. This again points out the inability of the farmer to fully control the human element in the harvesting operation.

A common method of analysing injuries occurring to potatoes during the harvesting and handling is to select a fairly large tuber and examine it for the presence of bruises. The fact that a large

tuber should be selected rather than a small one is substantiated by the data presented. Large tubers receive more injuries than small ones.

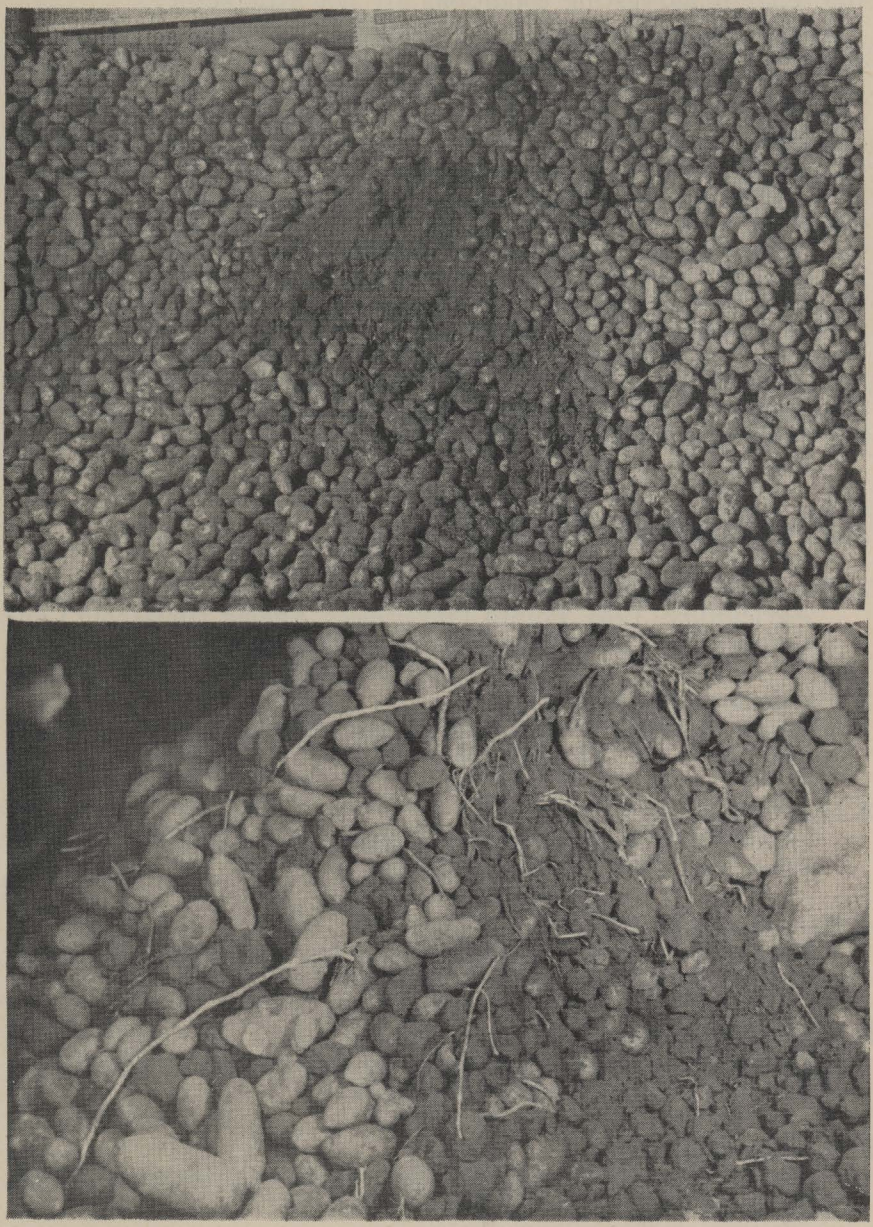

Figure 8. Dirt hauled into the storage cellar by bulker-combine harvester, (A) ful-bin view of dirt and trash in with potatoes, (B) close-up view of the dirt and trash in potatoes.

One of the most serious objections many farmers have to mechanical harvesting is the large amount of soil hauled into the cellar. Figure 8 shows that great quantities of clods can be hauled into the cellar if harvesting conditions are not satisfactory.

These data also point out that the more cloddy the soil, the more injury incurred by the tubers. This indicates that farming practices which cause the fewest number of clods are to be followed, especially by those farmers who plan to harvest their potatoes by mechanical methods. In order to reduce the number of clods at harvest time and to keep the amount of soil hauled into the cellars at a minimum, keep machinery off the fields as much as possible, especially when the soil is wet. Each pass across a field by a tractor, cultivator, or other piece of machinery causes compaction of the soil; the wetter the soil the more the compaction. The soil should not be worked in the spring when it is wet nor should the field be cultivated immediately after irrigating when the soil is wet. Cultivation should only be done to control weeds or to aid in irrigation. A mechanical harvester should not be expected to overcome the problems presented by poor cultural practices and improper supervision of labor and equipment.

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