

EFFECT OF SIMULATED HAIL DAMAGE ON YIELD AND QUALITY OF RUSSET BURBANK POTATOES¹

M. J. Wille and G. E. Kleinkopf²

Abstract

The yield and quality response of Russet Burbank potatoes to simulated hail damage was dependent upon the amount of damage and on the growth stage at which the damage occurred. Plots of Russet Burbank potato plants were subjected to 0%, 10%, 25%, 50%, 75%, or 100% defoliation at 3, 5, 7, 9, 11, or 14 weeks after emergence. A motorized flail was used to simulate the complex damage that occurs during a natural hail storm. Early season simulated hail damage, when the plants were mainly vegetative, caused yield losses proportional to the degree of damage. Simulated hail damage during the early phases of tuber growth caused minor yield losses (< 5%) at low defoliation levels but severe losses at the higher levels with proportional loss of tuber quality. Defoliation later in the season resulted in progressively less reduction of both yield and quality. At or near maturity, late season simulated hail damage caused insignificant losses unless the stems were damaged enough to prevent nutrition and carbohydrate translocation into the tubers. salvo cdo

Compendio

Los resultados en el rendimiento y la calidad de papas Russet Burbank en respuesta al daño por simulacro de granizo, dependieron de la intensidad del daño y del periodo de crecimiento en el cual se presentó el daño. Parcelas de plantas de papa Russet Burbank fueron sometidas a un proceso de defoliación de 0%, 10%, 25%, 50%, 75% y 100%, a las 3, 5, 7, 9, 11 o 14 semanas después de la emergencia. Para simular el daño complejo que se presenta durante una tormenta de granizo natural, se utilizó un azotador motorizado.

El daño por granizo, simulado al comienzo de la estación, cuando las plantas están principalmente en estado vegetativo, causó pérdidas en el rendimiento proporcionales al grado de daño. El daño por granizo simulado en las fases tempranas de la tuberización causó pérdidas menores (< 5%)

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²Research Associate and Professor, Department of Plant, Soil and Entomological Sciences, University of Idaho. Current address of first author: 304 Elder St., Nampa, ID 83686. Accepted for publication May 16, 1992.

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a niveles bajos de defoliación, pero las pérdidas fueron severas a niveles más altos y causaron pérdidas proporcionales en la calidad de los tubérculos. La defoliación hacia el final de la estación dio como resultado una reducción progresiva tanto en el rendimiento como en la calidad. En la madurez o cerca de ella, el daño por granizo simulado, hacia el final de la estación, causó pérdidas insignificantes salvo en los casos en que los tallos fueron dañados en tal grado que se impidió la traslocación de nutrientes e hidratos de carbono hacia los tubérculos.

Introduction

Artículo

Hail damage on potatoes in the Pacific Northwest can occur any time during the growing season. The tuber yield and quality response of Russet Burbank potatoes when hail damages the leaves and stems is dependent upon the amount of damage and on the growth stage when the damage occurs.

Hail tears leaves and may strip them from the plant. Stems and branches are often broken or severed. The impact of hailstones also causes bruising to the stem, often crushing the vascular tissue and impeding the exchange of solutes and water through the plant. After a few days, these bruises show as necrotic "pits" along the stem. Hail damage may vary from minor leaf loss to complete defoliation with bruised and broken stems. Previous studies conducted on potatoes (1, 7, 8, 10) have shown yield depressions with increasing defoliation estimates. However, the effect of hail damage during different stages of development has not been adequately defined under field conditions.

Normal plant development for the Russet Burbank cultivar is dependent upon the growing environment and the length of the growing season. Under best management practices, this cultivar will emerge between 20 and 30 days after planting, initiate tubers within three weeks after emergence, and continue tuber bulking until vine senescence (Fig. 1). Total dry matter production will be dependent upon the number of frost free days available for growth, the seasonal management of fertility and disease incidence.

During development individual characteristics of the plant can be identified (Table 1). These characteristics are important in identifying similar plant development stages among treatments or growing areas. After emergence (E-0), other visual characteristics can be used to help determine the stage of plant development so that damage estimates at similar growth stages can be assessed in subsequent seasons.

The purpose of this study was to evaluate simulated hail damage on Russet Burbank potatoes at selected growth stages under field conditions and to assess the damage in terms of yield and tuber quality.

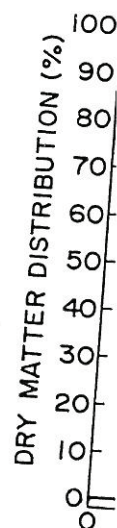


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TABLE 1.—*Stage of growth chart for Russet Burbank potatoes (Average of Three Years).*

Time Stage	Days from Emergence	Height (cm)	Canopy Description	Ave. Tuber Size (cm)	Hill Wt. (g.)
Emergence		1	first leaves appear	0	
E-1	7	5-12	leaves rapidly expanding; stems elongating	0	
E-2	14	12-20	8-10 leaf stage	0	
E-3	21	25-40	first buds appear; tuber initiation	.5-1	15
E-4	28	40-50	first flowers appear; branch initiation	1-3	75
E-5	35	50-60	row closure	3-4	225
E-6	42	60-70	most flowers open	4-5	430
E-7	49	70-80	full bloom	5-7	610
E-8	56	80-90	early blooms falling; vines lodging	7-9	790
E-9	63	90-100	second inflorescence	9-10	970
E-10	70	100-106	lateral vine growth	tubers to 225 g.	1150
E-11	77	106-112	blooms have fallen; lower leaves yellow	80% of tubers marketable	1275
E-12	84	112-120	leaves begin to yellow	tubers to 290 g. or greater	1370
E-13	91	"	all leaves yellow	most tubers mature	1400
E-14	98	"	leaves dying and falling	fully mature stolons drying	1420

ber of passes through each plot. Sections of a separate area of the field were treated in the same manner as experimental plots for each treatment level, and five plants representing each defoliation level plus the control were accurately measured for leaf area. The average of the five plants of each treatment was calculated, and the degree of defoliation was then calculated as a percent of the control group. See Table 2 for an example of defoliation level as measured with a leaf area meter.

The motorized flail was selected as the defoliation device because it more adequately simulated hail damage especially at the higher levels of defoliation. With the tractor mounted flail, the operator could easily vary the amount of plant damage by changing the speed of flail rotation and/or the forward speed of the tractor. Plants flailed at higher defoliation levels showed significant stem damage as well as leaf defoliation similar to true hail damage.

The center row from each plot was harvested between September 25 and 30, of each year. Tubers from each treatment were graded and separated by weight into the following tuber size classes:

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TABLE 2.—*An example of defoliation level as measured with a leaf area meter.*

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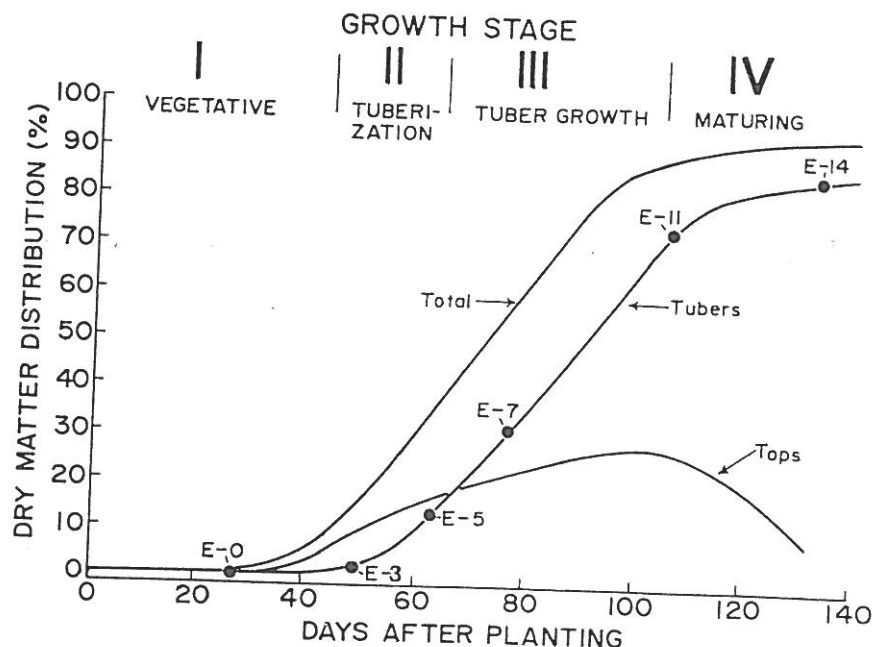


FIG. 1. Percent dry matter distribution for Russet Burbank potatoes at various stages of growth (after Kleinkopf, *et al.*, 1981). E-0 through E-14 are weeks after emergence and represent defoliation dates used in this study.

Materials and Methods

Field studies were conducted during 1986, 1987 and 1988 at the University of Idaho Research and Extension Center, Kimberly, Idaho. The field experiments consisted of three-row plots, 15.25 meters long in a randomized complete block design. Seed pieces of Russet Burbank potatoes were planted in 90 cm rows with 30 cm between plants. At each of six growth stages [E-3, E-5, E-7, E-9 (1986 only), E-11 (1987-1988 only), and E-14] plants received one of six treatments: 0%, 10%, 25%, 50%, 75%, or 100% defoliation. See Table 1 for a description of growth stages. Each treatment was replicated five times. At stages E-11 (in 1987) and E-14 (all years) only the 50% and 100% defoliation levels were applied. The plots were planted between April 19-21 of each year, and emergence (E-0) was established between May 18 and May 27 of each year.

A motorized flail covering three rows was used for defoliating the plants. Three row plots with the center row harvested reduced the border effect that may have occurred with one or two row plots. At each treatment date, defoliation level was controlled by the speed of the flail and the num-

TABLE 2.—An example of defoliation percentage as measured by leaf area meter. Stage E-5, 1988.

% Desired Defoliation	leaf area (cm ²)		% Actual Defoliation
	Observed	Expected	
0	5696	—	—
10	5089	5126	10.6
25	4247	4271	25.4
50	3241	2848	43.1
75	1612	1424	71.7
100	200	0	96.5

- USDA Large #1, 283 g. and above
- USDA Small #1, 113-283 g.
- USDA Large #2, 283 g. and above
- USDA Small #2, 113-283 g.
- Undersize and culls (includes tubers smaller than 113 g)

Tuber specific gravity was measured on all plots.

Results

Stages of plant development are identified below as weeks after emergence.

Growth Stage E-3—At growth stage E-3 (three weeks after emergence) plants were 20-40 cm tall, entirely vegetative with elongating stolons with no tubers. Root penetration was primarily lateral away from the seed piece with less than 10% of the roots below the seed piece.

Simulated hail damage at the E-3 stage (Table 3) resulted in a decrease in total yield and was related to the amount of defoliation. Yield reductions, were not uniformly distributed among the tuber grades but a reduction in U.S.#1 grade tubers (by weight) up to 49% of the large #1s, 27% of small #1s, and 38% of total #1s occurred. Neither the #2 grades, culls nor specific gravity was affected.

Growth Stage E-5—At growth stage E-5 (five weeks after emergence) the plants were 50-60 cm in length, with developing tubers 3 to 4 cm in diameter. Root development was primarily below the seed piece at this growth stage. Most of the tubers harvested will be initiated during this period. Normal tuber development from plants at this early period of growth can be severely reduced by hail damage or loss of foliage.

Simulated hail damage to plants at the E-5 stage (Table 4) resulted in a significant loss in total yield at 50%, 75%, and 100% defoliation. The

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TABLE 3.—Effect of simulated hail damage three weeks after emergence (E3) on yield of Russet Burbank potatoes. 1986-1988.

Defoliation (%)	U.S.#1	U.S.#2	Culls*	Total Yield	Marketable Yield
	t ha ⁻¹				
0	38.2	9.1	5.3	52.6	47.3
10	36.2	8.3	5.5	49.9	44.4
25	34.2	9.0	5.5	48.7	43.2
50	31.7	8.7	5.5	46.0	40.4
75	28.5	8.8	5.7	43.1	37.4
100	24.2	8.2	6.4	38.8	32.4
LSD (.05)	3.3	2.8	0.9	3.1	3.1

*Culls include tubers less than 113 grams.

TABLE 4.—Effect of simulated hail damage five weeks after emergence (E5) on yield of Russet Burbank potatoes. 1986-1988.

Defoliation (%)	U.S.#1	U.S.#2	Culls*	Total Yield	Marketable Yield
	t ha ⁻¹				
0	34.6	11.2	5.8	51.3	45.8
10	34.7	12.3	5.6	52.5	47.0
25	30.8	14.3	5.5	50.5	45.0
50	27.2	14.2	5.2	46.6	41.3
75	20.9	15.5	5.7	42.1	36.3
100	14.2	14.8	6.6	35.6	29.0
LSD (.05)	2.9	2.4	0.8	3.1	2.8

yield of U.S.#1 grade tubers was severely reduced by up to 75% of large #1s and 48% of small #1s when compared to the untreated control. This reduction in U.S.#1 tubers was accompanied by an increase in U.S. #2 grade tubers. This increase in U.S. #2s was primarily due to an increase in small #2s. At the higher defoliation levels, there was an increase in the yield of the cull class.

Growth Stage E-7—At stage E-7 (seven weeks after emergence) the plants were well into the tuber bulking stage of growth. All tubers were expanding and the total weight of tubers was increasing linearly during this stage. Vines were 70-80 cm long. At this early expansion stage, as at E-5, the plants were very sensitive to any interruption of growth.

Plants defoliated at stage E-7 (Table 5) exhibited significant decreases in total yield and in all grades of U.S.#1 potatoes proportional to the degree

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TABLE 5.—Effect of simulated hail damage seven weeks after emergence (E7) on yield of Russet Burbank potatoes, 1986-1988.

Defoliation (%)	U.S.#1	U.S.#2	Culls*	Total Yield	Marketable Yield
	t ha ⁻¹				
0	39.6	8.5	5.7	53.9	48.1
10	34.5	9.1	6.0	49.6	43.6
25	33.2	9.3	6.5	48.9	42.4
50	28.2	9.3	6.5	44.0	37.5
75	22.1	11.3	7.8	41.2	33.4
100	14.5	9.4	9.6	33.5	24.0
LSD (.05)	4.2	1.7	1.2	4.1	4.7

of damage. These grades were again reduced both in terms of yield and as a percentage of total yield. The percentage of small #2s and therefore of total #2s increased. The weight of culls increased as the severity of defoliation increased. Specific gravity of potatoes was not affected by defoliation except at 100% level where it was reduced by 0.008 ($P.05 = .003$).

Growth Stage E-9—At growth stage E-9 (nine weeks after emergence) plants were in the middle of the linear bulking phase of growth. Tuber weight of 170 to 285 g. was common. Vine growth was prostrate due to lodging and vine length was 90-100 cm.

By the E-9 stage, smaller differences in total potato yield were found due to the simulated hail. Again, the yield of large U.S.#1s was adversely affected by defoliation at the higher levels (Table 6). Defoliation at this stage also exerted a significant effect on tuber quality where the specific gravity measurement dropped as much as 0.007 for the highest treatment level.

Growth Stage E-11—At growth stage E-11 (eleven weeks after emergence) plants were near the end of the linear bulking phase of growth. Average tuber weight of 200 g. was common. Total vine length may be 100-125 cm depending on the type of fertility program used by the grower. Usually two sets of inflorescences were visible. Vine dry weight had peaked and started to decline (Fig. 1).

Defoliation at this stage mainly affected yields of U.S.#1s and #2s (Table 7). Differences in total yield up to 20% between treatments were clearly discernable. The amount of total #1s and of total #2s was reduced due primarily to the decrease in large tuber size classes. Specific gravity was also affected, dropping by 0.004-0.005.

Growth Stage E-14—By fourteen weeks after emergence, vines were senescing. Diseases may have been causing early plant death. Carbohydrates and nutrients were being transported from the vines to the tubers and in some cases the leaves were yellowing. Tubers were approaching their maximum size and weight.

TABLE 6. — *Effect of simulated hail damage nine weeks after emergence (E9) on yield of Russet Burbank potatoes in 1986.*

Defoliation (%)	U.S.#1	U.S.#2	Culls*	Total Yield	Marketable Yield
	t ha ⁻¹				
0	31.6	4.2	7.5	42.7	35.3
10	31.6	4.8	6.9	43.2	36.3
25	32.6	6.5	7.4	46.4	39.0
50	25.1	3.9	7.0	36.0	28.9
75	25.5	3.9	7.2	36.6	29.4
100	23.9	2.8	7.1	33.8	26.7
LSD (.05)	7.1	1.5	2.2	9.0	7.4

TABLE 7. — *Effect of simulated hail damage eleven weeks after emergence (E11) on yield of Russet Burbank potatoes. 1987-1988.*

Defoliation (%)	U.S.#1	U.S.#2	Culls*	Total Yield	Marketable Yield
	t ha ⁻¹				
0	37.3	11.2	5.9	54.4	48.5
50	31.7	9.3	6.3	47.4	41.1
100	29.9	7.3	6.1	43.4	37.3
LSD (.05)	2.7	2.6	1.1	2.6	2.7

Hail damage at this time had little effect on either yield or quality. The only significant treatment effect was a reduction in total yield of 7% for the most severe treatment. There were no significant differences in tuber quality among treatments (Table 8).

Discussion

Changes in environmental conditions can drastically affect the growth and development of the Russet Burbank cultivar. A warm spring may encourage early emergence and vegetative growth as well as decrease the days to tuber set. A cool, wet spring may delay emergence and vine growth and increase the days to tuber set. Early season environmental conditions can also affect the number of tubers set. Nutrition has a marked effect on vine size and may cause delay in tuber bulking at high levels of N fertility (5, 6). Nutritionally deficient potato plants will be reduced in size and show signs of senescence earlier in the season. Incidence of disease can also affect the development of the potato crop. Because of these environmentally

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TABLE 8. — *Effect of simulated hail damage (E14) on yield*

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Russet Burbank. Induced early tuber set at this station. Smoothness of percentage of U.S. tubers.

Later in the season less quality loss maturity the carbohydrates and non-carbohydrate a the degree of s

By using regression versus percent yield of potato plants. In this case, these regression bank potatoes E-5 > E-3 > E-1 (8), Colorado (8), Colorado (8), Colorado (8) to simulate

TABLE 8. — *Effect of simulated hail damage fourteen weeks after emergence (E14) on yield of Russet Burbank potatoes. 1986-1988.*

Defoliation (%)	U.S.#1	U.S.#2	Culls*	Total Yield	Marketable Yield
	t ha ⁻¹				
0	34.7	10.5	6.0	51.2	45.3
50	36.0	9.3	6.2	51.5	45.3
100	33.8	7.7	6.0	47.5	41.5
LSD (.05)	3.2	2.5	0.8	2.9	2.6

induced differences in plant development during different growing seasons, it is important to accurately characterize the stage of plant growth before comparing potato hail damage losses between areas or years.

Prior to tuber initiation, E-0 to E-3, defoliation affects yield by altering the effective length of the growing season and therefore the total amount of photosynthate available for tuber enlargement. This was expressed by a reduction in the total yield of potatoes. The reduction in the number of the U.S.#1 grade tubers was a result of irregular tuber growth patterns after defoliation of the above ground plant. Even though tubers were small (less than 1 cm) on the plant at the time of defoliation, this early season stress caused quality losses in the final harvest.

Russet Burbank potatoes were the most sensitive to defoliation during early tuberization and the early phase of tuber enlargement. Defoliation at this stage adversely affects not only total yield but the size and smoothness of the tubers as well. There was a downward shift in the percentage of U.S.#1 tubers with a proportionally upward shift in U.S.#2 grade tubers.

Later in the season, during tuber enlargement, defoliation results in less quality losses in proportion to the yield reductions. As the crop reaches maturity the main effect of hail damage is to interrupt the flow of carbohydrates and nutrients from the haulm to the tubers. The total amount of carbohydrate available for translocation into the tubers would depend on the degree of stem damage received by the potato plant.

By using regression analysis, data comparisons of the slopes (total yield versus percent defoliation) can be useful in determining relative sensitivity of potato plants to defoliation during different growth stages. In this case, these regression coefficients show yield and quality of Russet Burbank potatoes to be sensitive to defoliation in this relative order: E-7 > E-5 > E-3 > E-9 > E-11 > E-14. Similar results have been shown in Idaho (8), Colorado (10), Maine (7) and Minnesota (1) for stage of growth sensitivity to simulated hail damage on potato plants.

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The effects of simulated insect damage on yield loss in potatoes have also been investigated (1, 2, 3, 4, 9). These studies have shown that insect defoliation can cause similar yield and quality losses as that reported for hail damaged potatoes. However, at high levels of hail induced defoliation, additional yield or quality losses due to severe stem damage may occur which may not be characteristic of insect defoliated potato plants.

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