THE UNIVERSITY OF MANITOBA

MECHANICAL DAMAGE TO POTATOES AT THE SOIL-MACHINE INTERFACE AT HARVEST TIME

by

Syed Iqbal Ahmad

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

Department of Agricultural Engineering

WINNIPEG, MANITOBA

May 1971

IN THE NAME OF ALMIGHTY GOD,

THE MAGNIFICENT, THE MERCIFUL.

ABSTRACT

MECHANICAL DAMAGE TO POTATOES AT THE SOIL-MACHINE INTERFACE AT HARVEST TIME

by

Syed Iqbal Ahmad

Potato production in Manitoba has changed markedly within the past 10 years. Growers have completely mechanised in order to cut down the production cost. This has increased the importance of damage done to potatoes by the harvesting and handling machines. Past studies have shown that the primary source of mechanical injury is harvesting operations, and approximately 30 per cent of the potatoes are rejected for sale due to mechanical injury during harvesting.

The objectives of the study were:

1. To determine mechanical damage to potatoes at the soil-machine interface,

2. To determine mechanical damage to potatoes before they are lifted from the ground,

3. To evaluate mechanical damage to potatoes by the time they leave the potato harvester,

4. To investigate the distribution of potatoes in the hill with respect to the main plant stem.

Data were collected from six potato growers in Manitoba, who voluntarily agreed to assist in the study. The damage study was conducted in 18 fields with three potato varieties. Four potato varieties were studied for potato distribution in the hill.

Mechanical damage to potatoes was calculated for each field at three harvesting stages. Approximately five per cent of the potatoes were damaged before they were lifted from the ground and nine per cent at the soil-machine interface. The total damage done to potatoes by the time they left the potato harvester averaged about 29 per cent. The weight of the tuber significantly affected mechanical damage at the soil-machine interface and on the harvester. It was concluded from the potato distribution study that there was no significant inter-varietal difference in the distribution of potatoes in the hill. The tuber distribution was largely affected by cultural practices, intensity of rainfall and soil conditions. Practically all of the tubers in all of the varieties were found within a space of 18 inches across the row and seven inches deep into the soil, measured from the top of hill.

ACKNOWLEDGEMENTS

I wish to acknowledge the timely assistance and guidance provided by Dr. J. S. Townsend throughout my work. Thanks are due to the Canada Department of Agriculture and Department of Agricultural Engineering, University of Manitoba for provisions of funds, research facilities and help for this project. The valuable suggestions made by Dr. Wm. E. Muir and Professor J. Menzies are sincerely appreciated. The co-operation and assistance by the participating Manitoba growers is gratefully acknowledged.

Collecting data for this study was an enormous job. I sincerely appreciate the painstaking help and efforts made by Mr. G. Berry in data collection. I would also like to acknowledge the assistance of staff and graduate students of Agricultural Engineering Department, University of Manitoba during the experimental stages of this study.

Last of all I thank Mrs. M. Cameron who successfully accomplished such a tiring job of typing and arranging the manuscript. This thesis is dedicated to my parents Dr. and Mrs. Syed Anwar Ahmad whose humble prayers to God made the successful completion of this thesis possible.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

Figure		Page
4.1	Horizontal Potato Distribution - Norland . . .	67
4.2	Vertical Potato Distribution - Norland	67
4.3	Two-dimensional Potato Distribution - Norland.	68
4.4	Horizontal Potato Distribution - Kennebec. . .	69
4.5	Vertical Potato Distribution - Kennebec. . . .	69
4.6	Two-dimensional Potato Distribution - Kennebec	71
4.7	Horizontal Potato Distribution - Norchip . . .	72
4.8	Vertical Potato Distribution - Norchip	72
4.9	Two-dimensional Potato Distribution - Norchip.	73
4.10	Horizontal Potato Distribution - Netted Gem. .	74
4.11	Vertical Potato Distribution - Netted Gem. . .	74
4.12	Two-dimensional Potato Distribution - Netted Gem	76

CHAPTER 1

INTRODUCTION

1.1 Potato Damage Defined

Potato damage is any injury to potatoes caused by agents other than disease, insects, or physiological factors. Thornton classified potato damage into three distinct types on the basis of shapes, sizes and causes of injury (54). The classification is as follows.

1. Shatter damage is that which results in tuber breakage due to forces which do not usually leave large areas of broken cells exposed on the tuber surface.

2. Mechanical damage is that which results from mechanical gouging or tearing of the tubers and produces areas of ruptured cells exposed on the tuber surface.

3. Internal blackspot is damage which has no external symptoms but has a dark area under the tuber surface. These areas are the result of forces breaking the cells and the subsequent enzymatic reactions. This type of damage is not present during harvesting but is found in storage due to pile pressure on the underlying potatoes.

Since this study does not consider post-harvest damage, the term mechanical damage includes both mechanical and shatter damage.

1.2 Scope of the Study

Potatoes are the most important horticultural crop in terms of tonnage produced and area planted in Manitoba and Canada. The Dominion Bureau of Statistics (DBS), preliminary estimate of the 1970 potato crop in Manitoba was 3.7 million cwt,* a decrease of 2.6 per cent over last year's crop(6). The acreage planted to potatoes increased from 29,000 acres in 1969 to 33,000 acres in 1970(6). An unfavourable growing season and late planting contributed to poor yields which resulted in an overall reduction in potato production in the 1970 potato crop in Manitoba. For Canada,DBS estimated 53.3 million cwt as compared with last year's crop of 51.9 million cwt. Canadian potato acreage was 313,900 acres in 1970(6).

Mechanical damage to potatoes is serious, affecting both the producer and consumer in that it represents a loss. This loss is more serious than poor yields, since the crop is grown, harvested and handled at great expense and is then unsaleable. The damaged tuber may also be a source of infection to a sound tuber with which it is in contact. Elaborate storages are not proof against the danger of damaged and infected tubers.

Mechanical damage to potatoes can be done before lifting. A considerable amount of damage can be done to

---

*cwt = 100 lb.

potatoes at lifting, and this is particularly so if the harvester is not adjusted to suit the prevailing soil and crop conditions. Green reported that the potatoes are more easily damaged when there is a relative movement between the tuber and the carrying bed(14). He explained that tuber damage depends on the strength of potatoes, their susceptibility to damage, the nature of the movement, and the number of potatoes moved at the same time.

The problem of potato damage exists and can occur before lifting, at lifting and after lifting. This brings losses to the grower and dissatisfaction to the consumer. The main object of this study was to find out where the most of the damage is being done to potatoes at harvest time, that is, before lifting, at lifting or after lifting under Manitoba conditions.

The distribution of potatoes at harvest time has great influence on the design of new harvesters and performance of existing ones. The potato distribution pattern reveals how wide and deep the potatoes grow in the soil. This can help in determining the harvesting depth to avoid tuber damage by the harvester blade.

1.3 The Objectives

The specific objectives of this study were:

1. To determine the overall mechanical damage to potatoes at harvest time in Manitoba in 1970.

2. To determine the mechanical damage done to potatoes at the harvester blade and to express this as a percentage of the overall harvesting damage.

3. To determine the amount of damage done to potatoes before the crop is lifted and to express this as a percentage of the overall harvesting damage.

4. To investigate the distribution of potatoes in the ridge with respect to the main plant stem location.

1.4 General Approach

Growers from Portage la Prairie, Carberry, Carman and Winkler indicated genuine interest and offered assistance for this study. In accordance with the harvesting dates of the participating growers, a field schedule for this study was prepared. It should be noted that no particular instructions regarding harvester setting, travel speed or operating procedure were given. A piece of land regardless of area, but with uniform soil texture and planted to one variety of potatoes was called a "field". A total of 18 different fields were covered. For damage analysis three samples at four different locations in the field were collected. Sample one consisted of carefully hand-dug potatoes from the area behind the tractor wheels but in front of the disturbed soil at the blade. Sample two consisted of potatoes from the disturbed soil up to the start of the primary apron and sample three came from the potatoes which went into the truck. Each sample was washed, tested for damage and recorded. Catechol was the chemical used for damage detection. Potatoes were classified as undamaged, slightly, moderately and seriously damaged. Weights and number of potatoes falling into each category were recorded. Norland, Norchip and Netted Gem were the varieties that were included in the damage study. Five samples at five different locations in each field were taken to estimate the yield.

Norland, Norchip, Kennebec, and Netted Gem were included in the potato distribution study. Twenty-four distribution samples were taken, that is, six samples per variety.

1.5 The Delimitations

This study like other studies has its limitations. The harvesting season lasted only one month, from September 15 to October 15. During this period Manitoba had considerable rainfall and freezing temperatures which slowed down the harvest operations and affected the yield. In order to collect samples to evaluate damage before lifting and at soil-machine interface, the tractor operator had to stop for 5 to 10 minutes. As his time was very important, he was only stopped at the end of a row. Other sampling was done when the tractor operator was waiting for another truck.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Potato Production in Manitoba

In recent years potato production in Manitoba has undergone rapid changes and development. The development of potato handling machinery and shortage of labor for hand picking, along with contract production for processing firms have contributed towards the establishment of potato production as a special enterprise. This has also encouraged the growers to produce potatoes on coarse textured soil--a texture more suited to the mechanical handling of potatoes. Consequently potato acreage in Manitoba has increased to 33,000 acres in 1970, compared with 24,500 acres in 1964, an increase of 34.7 per cent(6).

2.1.1 Growing Areas

It is estimated that about 2.4 million acres of land in Manitoba have soil and climatic conditions that are suited to fully mechanised production of potatoes(50). Traditionally potatoes were grown on fine textured soils along the Red and Assiniboine Rivers (see Figure 2.1) near Winnipeg(48). Improvements in potato handling equipment brought the coarser soils of Portage la Praire, Steinbach and Winkler under potato cultivation. In recent years the

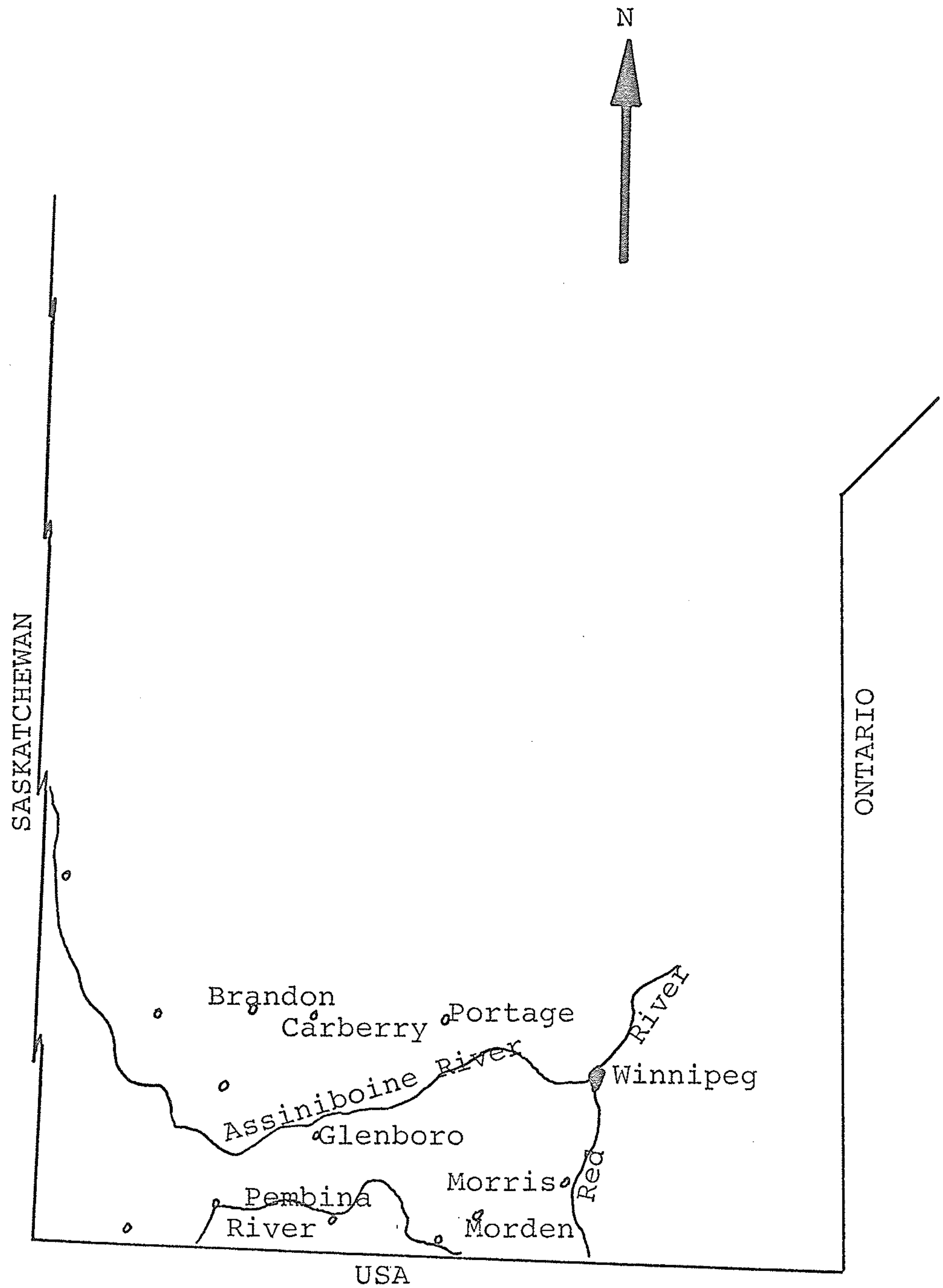


Figure 2.1. Manitoba Map Showing Potato Growing Areas(50).

building of processing plants in Winnipeg, Portage la Praire, Carberry and Teulon has caused an increase in the acreage of potatoes in these areas(48).

2.1.2 Potato Varieties

Many varieties of potato are grown in Manitoba, but only those which appear to be grown for commercial purposes are listed below(38).

1. Red Warba:very early; tubers red skinned, rough, blocky with deep eyes; good cooking quality.

2. Norland**: early, tubers red skinned, smooth, attractive, shallow eyed, fair cooking quality, sprouts easily in storage.

3. Viking: early, tubers bright red, smooth and attractive, good cooking quality; sets only a few tubers and these can quickly go oversize.

4. Irish Cobbler: medium maturity; tubers white blocky, medium to deep eyed; good cooking and chipping quality.

5. Norchip**: medium maturity, tubers white and round, good yielder and chipping quality. This is a new variety grown only for two years in Manitoba.

6. Norgold: early, tubers netted, smooth and shallow eyed, good yielder and good cooking quality.

**Varieties included in damage and distribution studies.

7. Red Pontiac: late; tubers red skinned, medium to deep eyed and good yielder.

8. La Rouge: late; tubers bright red, attractive and blocky, medium to deep eyed, good yielder and good cooking quality.

9. Netted Gem**: late, tubers netted, tubers long oval, smooth, shallow eyed, excellent mashing and baking quality.

10. Kennebec*: late; tubers large, white, smooth, thin skinned, shallow eyed, high yielder, good cooking and chipping quality.

2.1.3 Market Requirements

The strength in the potato market is due to a growing demand by potato processing firms in Manitoba and a lack of potato production in Eastern Canada and United States due to dry growing season(32).

2.1.3.1 Impact of Processing Industry

Manitoba had very little potato processing before 1956(48). By 1960, approximately 1,000 acres were planted to potatoes for processing. In 1961, Simplot Company planted 2,000 acres of potatoes in the Carberry district, to produce dehydrated and frozen potato products. In the following years, Simplot Company, two chipping firms, and one soup company in Manitoba purchased potatoes grown under contract

---

*Varieties included in distribution study only.

by the provincial growers(48). Consequently in 1969 the estimated acreage under contract was 20,500 acres, approximately 71 per cent of the total provincial acreage(31). As a result of the rapid growth of the processing industry potato production patterns within the province also changed. Growers started potato production on medium and coarse textured soils. They fully mechanised their potato production in order to cut down the production costs and handle larger volumes of potatoes grown under contract for the processors (see Tables 2.1 and 2.2)(48).

2.1.3.2 Table Stock Production

In 1969 Manitoba fresh market production remained static at 7,414 acres, the same as in 1968.[a] The yields harvested by the growers in 1969 showed an increase of 25 cwt per acre over that of previous year. The firm prices that had existed for the 1969 crop and the restricted marketing situation for cereal crops resulted in increased planting of potatoes for the fresh market in 1970(32). The estimated fresh market potato acreage in 1970 was 8,483 acres.[a] Manitoba table potatoes are sold in Saskatchewan, Ontario and some parts of the United States. It is estimated that 40 per cent of Manitoba table stock production moves beyond the boundries of the province(48).

---

[a] Personal Communication with Manitoba Vegetable Marketing Commission.

Table 2.1

Acreage and Percentages of Potatoes Contracted by Group and Soil Texture (48)

Group*	Total Potato Acres	Contracted Potato Acres	Contracted Acreages on: Medium and Coarse Texture	Contracted Acreages on: Fine Texture	Per cent Contracted on: Medium and Coarse Texture	Per cent Contracted on: Fine Texture
I	124	0	0	0	0	0
II	449	0	0	0	0	0
III	706	295	255	40	86.4	13.6
IV	3,249	2,859	2,709	150	94.8	5.2
V	6,188	4,652	4,652	0	100.0	0

*Farmers are grouped on the basis of potato acreage they grew in 1968.

Table 2.2

Harvesting Methods used by Contract Growers by Group(48)

Group	Number of Contract Growers	Harvesting Method	
		Harvesters	Pickers
I	0	0	0
II	0	0	0
III	4	2	2
IV	13	12	1
V	10	10	0
All Groups	27	24	3

2.1.4 Crop Yield

Potato crop yield depends upon the following factors (1):

1. Time of harvest,
2. Variety,
3. Soil fertility and moisture,
4. Planting and cultural practices,
5. Growing season.

In Canada the average yield per acre in 1970 was 170.0 cwt, approximately a 0.6 cwt per acre increase over that of the previous year(6). In Manitoba due to late planting and an unfavourable growing season the average potato yield for 1970 dropped to 112 cwt per acre, a 19 cwt per acre decrease as compared to the 1969 yield. An important factor which contributes to low yield is harvesting loss. Harvesting losses may come from potato leavings* and potatoes rejected on account of mechanical injury.

2.2 Potato Cultivation in Manitoba

Today growing potatoes is a highly specialised business requiring large capital investment. If the enterprise is to be profitable, the farmer should have both technical and business knowledge. Farmers must be prepared to keep up with rapid expansion in processing firms, improvements in potato handling equipment, and updated recommendations

---

*Leavings are ungathered potatoes during harvesting.

for varieties, fertilizer use and disease control.

2.2.1 Soil and Climate

The yield of tubers and their appearance depend largely on the texture and physical composition of soil. The ideal potato soil is a rich, deep, friable, well drained medium or sandy loam, free from stones, moderately acid, and containing adequate organic matter. The potato crop requires abundant moisture, but does not thrive in cold, water-logged soil(5). In Manitoba there are many kinds of soils--from orthic black to dark grey wooded and podzol soils(38). Under these general agronomic soil groups soils have coarse, medium, or moderately fine, and fine texture(38). Today in Manitoba potatoes are grown on all kinds of soil--for seed, table stock and processing. Practically all of the Manitoba soils where potatoes are grown are free of stones, a desirable condition(38).

The potato has made its greatest development in areas where the average daylight temperature seldom exceeds 70° F and where the nights are cool. Tubers form best when the air temperature is about 60 to 65° F(5). These conditions exist in the parts of Manitoba where potatoes are grown. For example, in the Red River valley, South-west Manitoba, and the Assiniboine valley average temperatures from May to August are 62.5° F, 61.5° F, and 60° F respectively(38). The amount of rainfall and its distribution during the growing season markedly affect yield. In the best potato growing areas in humid regions, total rainfall between planting and harvesting should range between 12 and 18 inches. For best results it should be evenly distributed, with about 1 inch per week throughout the growing season(5). Although seasonal precipitation for potato growing areas in Manitoba varies considerably, the long term averages of total precipitation in the growing season from May to August for the Red River valley, South-west Manitoba and Assiniboine valley are 10.5, 10.8 and 11.0 inches respectively(38). These are quite close to the figures for best results. Moreover the precipitation in Manitoba is distributed from 2 to 3 inches per month from May to August(38). This is also a favourable factor for potato growing in Manitoba.

2.2.2 Maintaining Soil Fertility

Potato yields are usually higher when crops are rotated than when potatoes are grown on the same land year after year. Sod crops in the rotation are beneficial because they add organic residues to the soil. Also rotating the crops discourages the development of diseases such as scab, rhizoctonia, blackleg and wilts(38). Potatoes respond well to the addition of nitrogen, phosphorus and potassium when these elements are in low supply in the soil. Unless soil test recommendations indicate otherwise, 60 to 80 lb. of nitrogen and 30 to 50 lb. of phosphorus per acre should be added when potatoes are grown on loams and clay textured soils. Twenty-five to 35 lb. potassium per acre should be added with the above rates of nitrogen and phosphorus when potatoes are grown on sandy textured soils. Fertilizers are added as a side band application at the time of seeding(38).

2.2.3 Preparing the Soil

Soil is plowed in the fall to let the sod decompose and release plant food for the next crop year. Soil is generally worked to a depth of 6 to 7 inches(5). Lighter soils are usually plowed in the spring(5). Thorough cultivation in the fall and spring gets rid of many troublesome weeds, ensures a good seedbed, and benefits the moisture, aeration, temperature and available plant food material of the soil(5).

2.2.4 Planting and Cultivation

One important practice in potato production is the use of certified or foundation seed. Seed pieces are placed from 9 to 15 inches apart in rows spaced 36 to 40 inches apart. Varieties like Viking and Norgold may be planted at closer spacing. Wide spacing is used for Netted Gem and intermediate spacing for other varieties. Seed is usually planted 2 to 3 inches deep(38). Potato seeds decay easily if the soil is cold. Generally planting should be delayed until soil surface temperature is above 40° F(38).

The main reasons for cultivating the potato crop are to control weeds, to aerate the soil, and to loosen the surface soil so that it will absorb and retain moisture. Early fall plowing followed by frequent cultivation with a harrow can destroy the perennial weeds. Early spring cultivation before planting and when the crop is emerging, controls most early season weeds. Cultivation should be completed before hilling operations. After hilling, if it is necessary, weeds and disease may be controlled by recommended chemicals(5).

2.2.5 Irrigation Practices

In Manitoba most of the potatoes are grown under dry land farming. The moisture requirements of the crop are supplied by the rain which the province gets during the growing season from May to August. Uniform distribution of precipitation during growing season has aided successful potato growing in the province. Farmers who grow potatoes on lighter soils may irrigate their crop. An average of 0.15 inches of water per day after planting until harvest is recommended(5). Preferrably a sprinkler system should be used(5).

2.2.6 Top Killing

The destruction of potato tops prior to harvest reduces the work, bruising, and prevents losses from oversized potatoes(38). In Manitoba harvesting commences a week after top killing. In 1970 tops were killed with a rotobeater or with a chemical spray such as sodium arsenate for early maturing crops. The late maturing crop had the tops frost killed during the second week of September.

2.3 Potato Harvesting and Damage

Potato harvesting involves lifting the crop with mechanical equipment and separating the tubers from the soil and vines(1). Tubers can be damaged at every stage during harvest--before lifting, at lifting and after lifting(14). There are three main kinds of damage that can occur to potato tubers during harvest. First, the blade of whatever machine is used for digging can cut the tubers. Second, light knocks and scrapes can remove part of the skin of the tuber and cause surface damage. Third, sharper knocks produce deep, internal cracks in the flesh of the tuber. It is the third kind of damage that has the worst lasting effects(22).

2.3.1 Potato Harvesting in Manitoba

Potatoes are harvested by the following methods(48).

1. Digger, hand picking and sacks: with this method the potatoes are lifted with a potato digger and later picked by hand into baskets. The baskets are emptied into potato sacks. The sacks are loaded into trailers or trucks and hauled to the storage.

2. Digger, hand picking and bulk boxes: this method is similar to number one except that the potatoes from the picking baskets are dumped into bulk boxes mounted

on trucks for hauling to storage.

3. Indirect harvesting: the potatoes are lifted by a windrower or a digger. A second machine usually a potato harvester follows. It picks up the potatoes from the ground and conveys them to bulk box for delivery to storage. This method is generally preferred by the farmers when the tops are frost killed, and only practiced when potato acreage is small.

4. Direct harvesting: potatoes are lifted, one or two rows at a time, and conveyed directly into the potato bulk box by the harvester. This method is very popular amongst the Manitoba growers and used for early and late crops.

5. Direct- indirect harvesting: two or more rows of potatoes are lifted by a windrower and placed between the two undug rows. The harvester follows, lifts the two undug rows along with the windrowed potatoes, and conveys the potatoes into the bulk truck for hauling to the storage. This method is popular with the big growers when the tops have been frost killed or when the harvesting season is short.

It is reported that 42 per cent of the Manitoba growers use method four(48). Thirty-five per cent harvest by method one. Method two is used by 18 per cent and only five per cent use method five (see Table 2.3).

Table 2.3

Percentage of Growers using the Five Methods of Harvest(48)

Group	(Acreage of Potatoes)	Harvesting Method				
		One	Two	Three	Four	Five
I	(4 - 19.9)	21.7	3.3	0	0	0
II	(20-59.9)	13.3	3.3	0	3.3	0
III	(60-149.9)	0	10.0	0	5.0	0
IV	(150-299.9)	0	1.7	0	20.0	1.7
V	(300-Over)	0	0	0	13.3	3.3
All Groups		35.0	11.0	18.3	41.7	5.0

2.3.2 Harvesting Time

The potato harvesting season in Manitoba usually starts in August and continues until the middle of October. The potatoes harvested early in the season are called "New Potatoes" and are usually marketed immediately. The time of harvest for the new crop is determined by the market conditions rather than the crop maturity. The harvesting of late potatoes or the main crop potatoes begins a week after the tops have been killed either by frost or by artificial means. If the first killing frost does not come in early September, then the potato tops are killed mechanically or chemically. The main crop harvesting season extends from middle September to middle October.

2.3.3 Losses due to Harvesting Damage

Injury by mechanical means has been shown to be a source of losses. Not only do damaged potatoes have to be graded out before sale, but damaged areas serve as openings for rot organisms which can destroy potatoes in storage. The main sources of mechanical damage to potato tubers are harvesting and the subsequent handling operations(45).

Damage will detract from the value of the product due to poor appearance(54). The seriousness of potato damage depends upon the length of storage, storage conditions, the presence of disease organisms, and the use to which the product is to be put. Damage in early potatoes is not as important as in the main crop, since the new potatoes do not have to be kept beyond a few days. In fact, skin damage may increase the appeal to the consumer as an indication of a genuine new potato(15). Skinning of potatoes may be important where dry rot susceptible varieties are to be stored for some months.

Mechanical damage has great influence on the rate of loss of weight in potatoes during storage. Damaged potatoes lose weight more rapidly than undamaged potatoes (see Table 2.4)(18). The greatest danger lies in the fact that even in a sample of apparently undamaged potatoes an occasional slightly diseased or damaged potato may pass unnoticed and form a nucleus for the spread of infection(17). This is especially true in bulk storages.

In addition to the direct loss to the grower additional loss is absorbed by the potato industry. Fresh market shipping operations must increase the number of people on sorting lines in order to sort fresh market potatoes. Processors must add people to trim lines to hand trim unusable portions of individual tubers. This increases the cost of processing.

2.3.4 Factors Affecting Potato Damage

Factors which contribute to the damage of potatoes during harvest are as follows(14,23,33,11,1):

1. Crop maturity,
2. Soil conditions and temperature,
3. Harvester setting and operation,

Table 2.4

Percentage loss in Weight from Start of Storage(18)

Treatment	Days in Storage			
	21	52	118	199
Severely damaged - dry	5.4	11.6	-	-
Severely damaged - washed	5.8	8.3	12.5	16.1
Skinned - dry	3.6	4.9	6.2	8.0
Skinned - washed	5.8	7.1	8.9	10.7
Undamaged - dry	3.6	3.8	4.9	6.5
Undamaged - washed	2.8	3.2	3.7	6.4

4. Number and height of drops during harvesting and handling,

5. Varietal resistance to mechanical damage,

6. Tuber size.

Potatoes are likely to be bruised when they are harvested in an immature state and generally skinning is more prevalent in early crop potatoes. Soil texture, moisture and temperature also affect mechanical damage to potatoes. If there is not enough moisture in the soil at the time of harvest, fine textured soils produce clods and coarse textured soils separate from tubers too quickly on the harvester, thus increasing the amount of damage to potatoes. Cold tubers are more easily damaged. Usually the soil temperature should be above 40° F to avoid excessive damage. The depth of the harvester blade, the speed of forward travel, and the speed of the moving parts of the harvester influence greatly the amount of damage done during harvest. It has been concluded that there is no definite relationship between the amount of damage done and the forward speed of machine(1). The harvester blade depth setting depends upon the soil type and condition. It has been reported that mechanical injury to potatoes increases exponentially as the speed of the conveyors on the harvester increases(33). The height and number of drops through which potatoes are allowed to fall also contribute to damage. It has been found that varieties differ in their resistance to mechanical damage(11). The interesting point is that the varieties may exhibit relatively small differences in their resistance to static forces but dynamic handling conditions produce large differences(11). It is reported that the weights of damaged tubers are 20 to 30 per cent higher than undamaged tubers(1,33).

2.4 Damage Detection

Quite often mechanical damage to potatoes is not visible(39). Chemical reagents can be used to make the damaged portions of the tuber more distinguishable. When a tuber is damaged, either on the surface or in the deeper layers, the enzyme tyrosinase is exposed. This catalyses the oxidation of naturally occuring tyrosine to give a reddish brown decomposition product. This eventually produces the black color of melanin(39). The rate of this chain reaction is slow and depends on the variety of potato. Tyrosinase also catalyses the oxidation of certain other mono-hydric phenols such as phenol, paracresol and catechol to produce highly colored quinones(39). Catechol turns black-red to purplish after 3 to 5 minutes when combined with enzyme tyrosinase(54). All the mono-hydric phenols are inexpensive and can be stored in air tight, light proof containers for a year or longer. Any of these available can be used for damage detection in potatoes.

2.5 Damage Evaluation

The National Institute of Agricultural Engineering, U. K. (NIAE) has developed a method for evaluating the severity of potato damage(34). The potato damage is assessed by the number of strokes required to remove the damage with a potato peeler set to remove 1/16 of an inch for each stroke. Table 2.5 depicts in detail the potato damage evaluation developed by NIAE.

Table 2.5

Evaluation of Potato Damage(34)

Damage Classification	Number of Strokes Required to Remove the Damage by a Potato Peeler Set to Remove One-sixteenth inch per Stroke
Slightly damaged	1
Moderately damaged	2
Seriously damaged	more than two

Note:

1. Sliced or cut potatoes are placed in seriously damaged category.

2. Sometimes slightly damaged tubers are also called skinned. But in NIAE terms skinning means only if the skin of the tuber is broken and tissues beneath are unbroken.

2.6 Damage Index

The damage index for a potato sample is a number which combines the relative importance of various classes of damage. The damage index is used as a measure of the economic importance of the total damage in a sample(1). Damage index may also be used as a performance rating method for potato harvesting and handling equipment. The damage index for any potato sample is obtained by multiplying the damage percentages in the sample with respective factors and adding the results. Table 2.6 calculates the damage index of an arbitrary sample.

Table 2.6

Damage Index

Damage Classification	Factor	Percentage in sample	Result
Undamaged	0	93	0
Slightly damaged	1	4	4
Moderately damaged	3	2	6
Severely damaged	7	1	7
			17

Damage Index = 17

2.7 Damage Studies

Mechanical injury investigations have been made in the past, and probably more will be made in the future. These studies have helped to make the potato industry aware of mechanical injury and of the losses involved. Hastings of North Dakota, in 1931 appears to have been the first to investigate mechanical injury to potatoes during harvest(28).

Results of extensive damage studies conducted in Canada, U. S. A. and U. K. are reported here.

2.7.1 Results of Damage Studies in Canada

Studies as to the amount and causes of mechanical damage done to potatoes have been conducted in the provinces of Alberta, New Brunswick, Manitoba and Ontario. In Alberta during the 1968 potato harvest over 35 per cent of the total potatoes produced were damaged(1). It was found that the average weight of a damaged tuber was 20 per cent higher than an undamaged tuber. It was concluded that there was no definite relationship between speed of operation and damage index(1). In Alberta the damage done by the digging section of the harvester was found to be greater than the damage done at any other section of the machine. Potato damage results at different stages of harvesting are depicted in Table 2.7(36).

In New Brunswick an average crop loss of 36.7 per cent with 7.1 per cent attributed to mechanical injury occurred (33). Potato damage, in New Brunswick was assessed as skinning (injury less than 7.95 mm deep), flesh wound (injury greater than 7.95 mm deep) and crack damage was expressed as a per cent of the original sample weight(33). It was found that potato injury can be expressed in terms of

Table 2.7

Potato Damage at Different Stages of Harvesting in Canada(36)

Harvester Speed (MPH)	Stage on Harvester Conveyor	Extent of Damage (per cent by weight)			
		Slight	Moderate	Severe	Undamaged
1.83	on primary apron	7	6.2	7.8	79
	on picking table	-	33.9	32.1	34
	on loading truck	3.5	17.0	34.5	45
2.35	on primary apron	26.8	27.0	15.2	31.0
	on picking table	15.4	18.6	-	66.0
	on loading truck	28.6	20.7	25.3	25.4

trim loss by measuring the weight of trim required to remove flesh and crack damage and expressing it as a per cent of the original sample weight. It was found that potato injury can be expressed in terms of trim loss by a regression equation of the form(33);

$$Y = C_o + C_1X_1 + C_2X_2$$

where:

Y = damage index trim loss,

C_o = constant,

C_1 and C_2 are regression co-efficients,

X_1 and X_2 are the types of injury defined as cracks and flesh wounds.

It was also found that trim loss is greatly affected by the speed of conveyors, forward speed and population of stones in the soil. The trim loss was found to increase exponentially as the speed of the conveyors on the harvester increase, while skinning increase linearly, see Figures 2.2 and 2.3(33). The records of the processing companies in Ontario revealed that 12 per cent of the potato crop is bruised in harvesting (29). In Manitoba potato damage during a 1966 potato harvesting damage survey was estimated to be from 17 to 72.2 per cent(49).

2.7.2 Results of Damage Studies in U. S. A.

Hastings found that on an average the digger injured 38 per cent of the potatoes(20). Sparks in 1957, studied

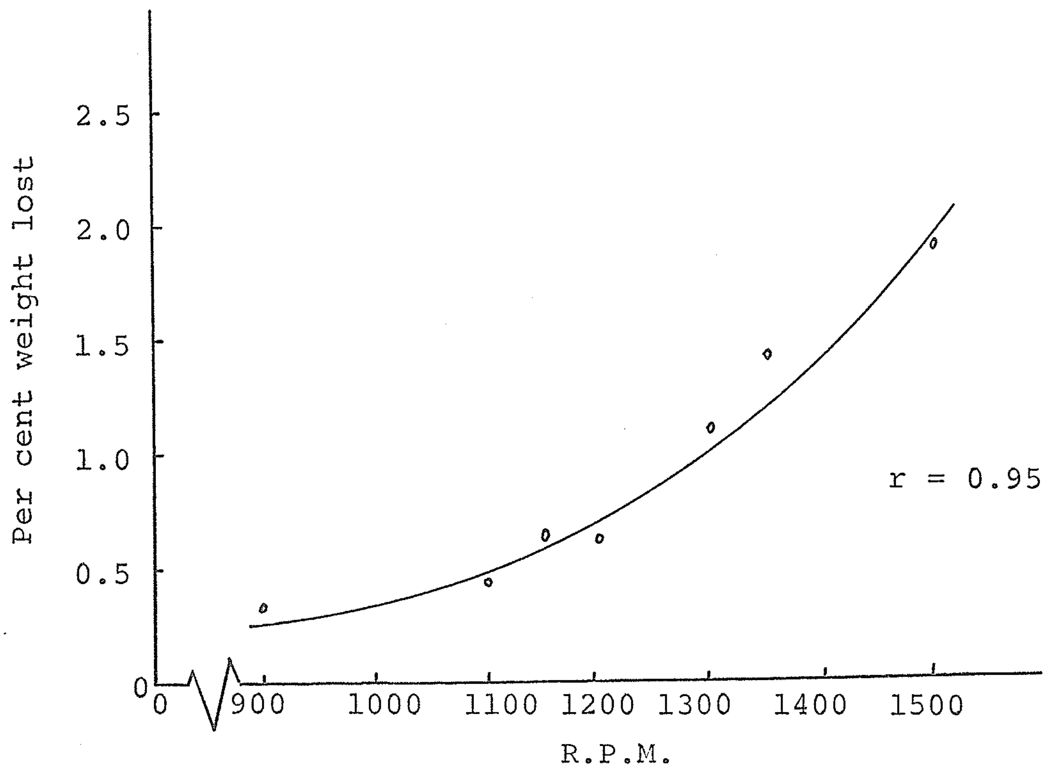


Figure 2.2. Effect of Engine Speed (Conveyor Speed) on Mean Trim Loss. (33)

r is sample correlation coefficient

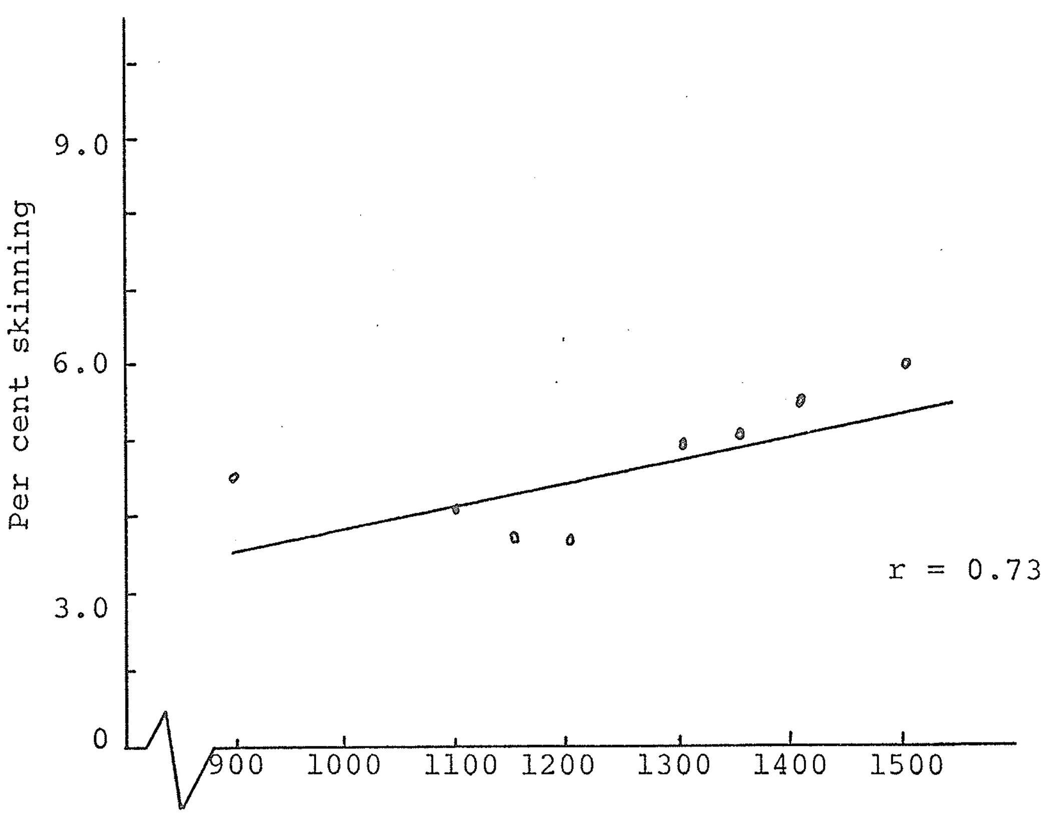


Figure 2.3. Effect of Engine Speed (Conveyor Speed) on Mean Skinning Damage.(33)

mechanical injury at all stages of handling from field to consumer(44). He found that 11.5 per cent of the tubers were injured badly enough during harvesting and storing to be classed as culls. In California it was found that there was no difference in the amounts of damage done to potatoes by hand and mechanical harvesting by the time potatoes were in the storage(52). There was less injury in the field with the hand method but the rough handling of the potato sacks in loading on to the trucks and in emptying at the storage caused a considerable increase in damage(52). It was discovered that harvesting potatoes into water reduced the potato damage by more than 50 per cent(55). The estimated mechanical injury into a conventional potato truck was 10.2 per cent and into a water truck it was 4.9 per cent(55). Harvesting operations damaged 38 per cent of the potatoes during 1969 in Washington(28). Harvesting operation is considered to be the greatest source of mechanical injury to potatoes(45).

2.7.3 Results of Damage Studies in U. K.

The amount of damage done to potatoes was estimated at different time intervals after harvesting(34). It was found that 24 hours after harvesting potato damage ranged from 2.4 to 41.4 per cent. The main causes of potato damage during harvest were found to be the harvester blade and glancing blows against digger chains and links(15). It is suggested that to minimize damage, the soil separation area on the harvester should be increased while decreasing the agitation. It is emphasized that the main aim in design of potato harvester should be a smooth flow for the potatoes and the avoidance of sharp drops and sudden changes in speed and direction(15). It is estimated that approximately 45 per cent of potatoes are damaged during harvest in U. K. Potato damage results of 1965 studies in U. K. are depicted in Table 2.8(1).

2.7.4 Potato Damage at Lifting Time

The relationship between potato vine killing and impact damage to potatoes was examined at harvest time in U. K.(58). The results of six chemical and two mechanical treatments on two different soils are as follows.

1. There is an increase in the water content of tubers following the vine killing operation.

2. Once this increase in water content has occurred, the tuber dry matter percentage remains unchanged for a period of at least three months after the vine killing treatment where the tuber is left undisturbed in the soil.

3. There was less damage to tubers harvested from plots where the tops were killed by mechanical means, when compared to chemical killing. The least damage was suffered by potatoes harvested from plots receiving no vine killing treatment.

Table 2.8

Potato Damage at Different Stages of Handling in U. K.(1)

Damage Assessment Point	2240 lb Boxes Per cent Weight in Damage Categories				Damage Index	1900 lb Boxes Per cent Weight in Damage Categories				Damage Index
	Undamaged	Slight Damage	Moderate Damage	Severe Damage		Undamaged	Slight Damage	Moderate Damage	Severe Damage	
As Lifted	55.1	16.0	13.6	15.3	164	52.3	18.8	16.2	12.0	152
Into Box	45.2	19.6	19.7	15.6	188	47.3	17.1	16.7	19.0	200
Arrival at Store	46.2	28.4	13.4	13.4	159	34.4	30.0	13.7	22.0	225

2.8 Potato Distribution in the Ridge

2.8.1 Introduction

The distribution of potatoes in the ridge at harvest time is an important feature affecting the design of new potato harvesters and the performance of existing ones. Bailey investigated the distribution of potatoes at different depths and widths in the ridge(4). He experimented with six different varieties and also investigated whether inter-varietal differences existed.

2.8.2 Reported Procedure

Bailey described a "co-ordinator" which he used for measuring co-ordinates of potatoes in the ridge (see Figure 2.4). The co-ordinator consisted of a steel rail fifteen feet long, marked at 3 inch intervals. A horizontal bridge rested at one end of the rail and carried a spirit level and a graduated scale. The second support of the bridge was so arranged that the bridge could be levelled. The bridge also carried a cursor which in turn carried a vertical sliding member with a pointer at its lower end, and a graduated scale. The horizontal and vertical scales were so arranged that the zero of the horizontal scale corresponded to the tip of the pointer being on the center line of the rail, and the zero of the vertical scale to the tip of the pointer being on the level of the bottom of the rail.

To measure the co-ordinates of the potatoes, soil

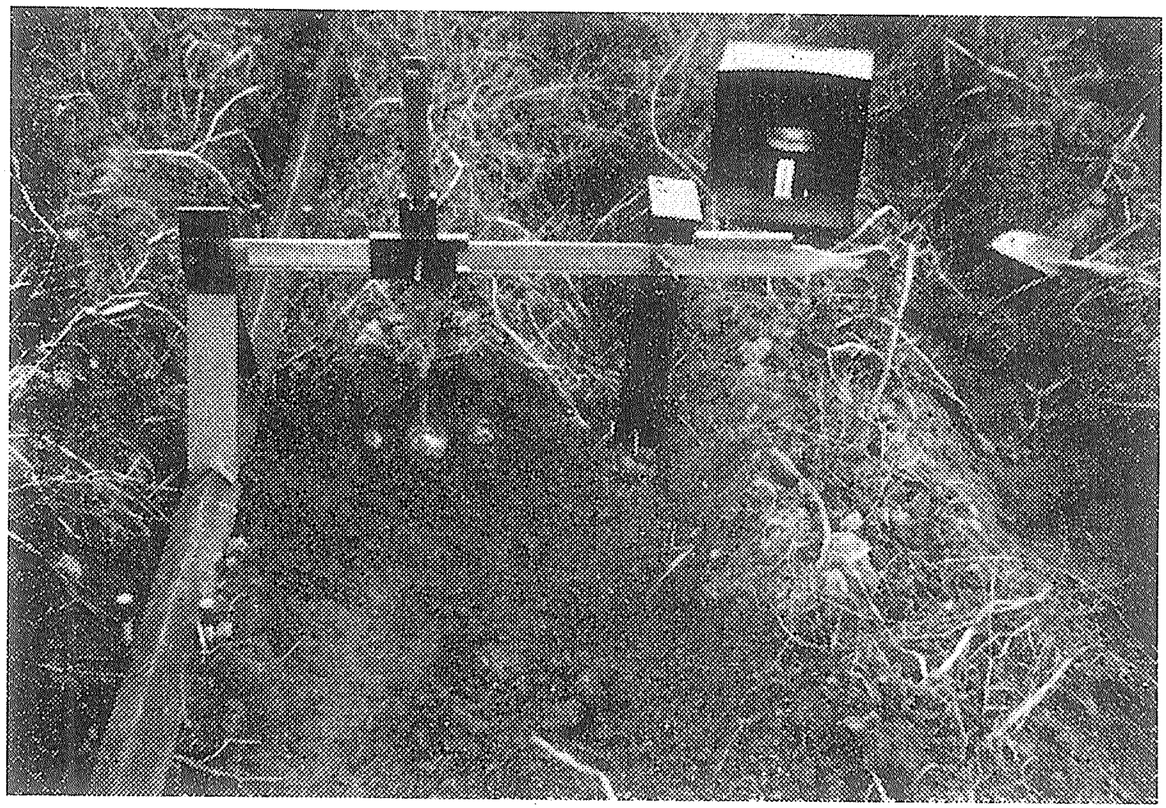


Figure 2.4. Co-ordinator for Potato Distribution Measurements(4)

was removed until the top and the sides of a tuber potato were accessible. The co-ordinates across the ridge and for depth were taken for the top of the tuber. The tuber was then removed and the co-ordinates were taken for its bottom point from the impression in the soil. This procedure was repeated for each tuber until no more tubers were found.

2.8.3 Reported Results

The co-ordinates of all the tubers and ridge profile for the varieties were plotted. The outlines of the potatoes were drawn by hand to emphasize the concentration of potatoes in the ridge. It was shown that for each variety the distribution of potatoes was not symmetrical about the center line of the ridge (see Figure 2.5). The non-symmetrical growth of potatoes about the center line of the ridge was attributed to the cummulative errors in steering the tractors during hilling and cultivation. Graphical representation of potato distribution was also reported (see Figures 2.6 and 2.7).

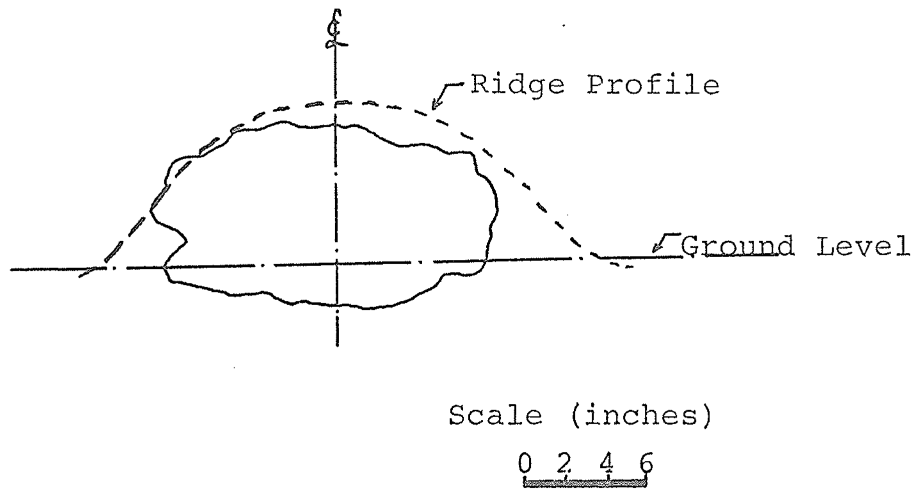


Figure 2.5. An Outline Drawn Around all Potatoes(4).

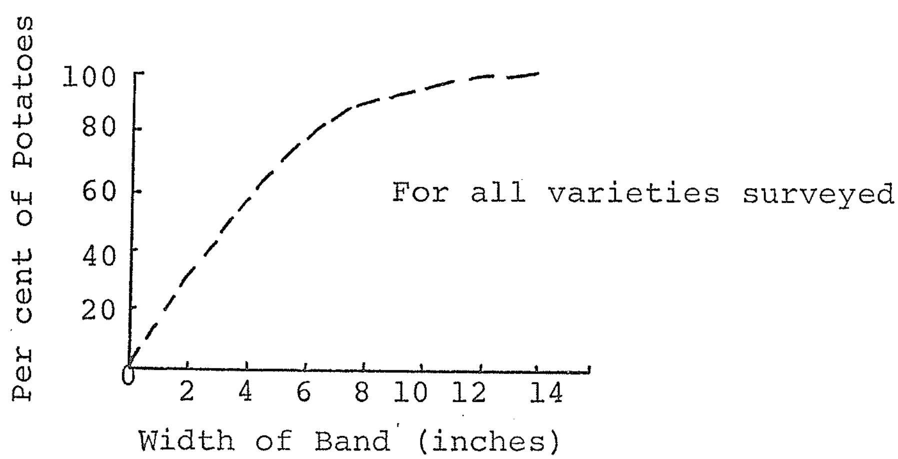


Figure 2.6. Percentage of Total Weight of Potato Contained in Symmetrical Bands of 2, 4, etc., inches Horizontally. (4)

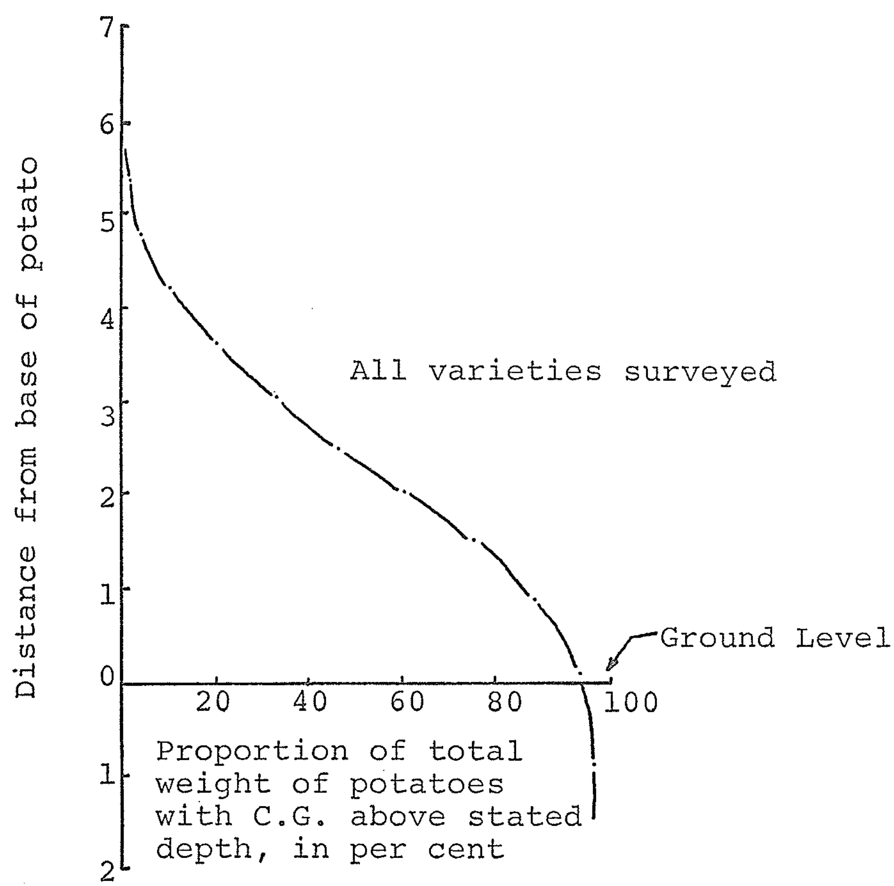


Figure 2.7. Percentage of Total Weight of Potatoes Contained above Referred Depths. (4)

CHAPTER 3

INVESTIGATIONAL STUDY

3.1 Procedure

The procedure adopted to obtain data for this study was as follows:

1. Selection of test sites,
2. Collection of samples,
3. Testing for damage,
4. Damage classification, weighing and recording,
5. Potato distribution measurements,
6. Determination of crop yield.

3.1.1 Selection of Test Sites

At the potato harvester field day, held at Carman, Manitoba, on September 4, 1970, an appeal was made to the growers present to co-operate in this project. Growers from Portage la Praire, Carberry, Carman and Winkler voluntarily agreed to participate in study. In accordance with the harvesting dates of the participating growers, a field schedule for the study was prepared. A test area of uniform soil texture and planted to one variety, was called a "field". It was decided that the study would include as many fields, soil conditions and types and varieties of potatoes as possible. Eighteen different fields, with soil texture of fine, medium and coarse were included. Netted Gem, Norchip, Norland, and Kennebec were the varieties that were included in the study. The farms from which data was obtained are shown in Figure 3.1.

3.1.2 Sampling Procedure

Simple random sampling techniques were followed. The following procedure was adopted for sampling.

1. To determine the damage done before lifting, the sample consisted of all the hand dug potatoes from the area from the rear of the tractor wheels to the beginning of the disturbed soil in front of the harvester blade (Figure 3.2). The sample was designated number one.

2. To determine the damage done to the potatoes at the soil-machine interface, the sample consisted of all the hand dug potatoes from the disturbed soil area ahead of the primary apron (Figure 3.2). This sample was designated number two.

3. To estimate the total damage done to potatoes a sample of approximately 10 pounds was drawn from the potatoes which came off the harvester boom (Figure 3.3). This sample was designated number three.

4. To estimate the crop yield, five random samples from five different rows were collected.

5. Potato plants were selected at random for potato distribution. Six plants per variety were surveyed and four varieties were included in the distribution study.

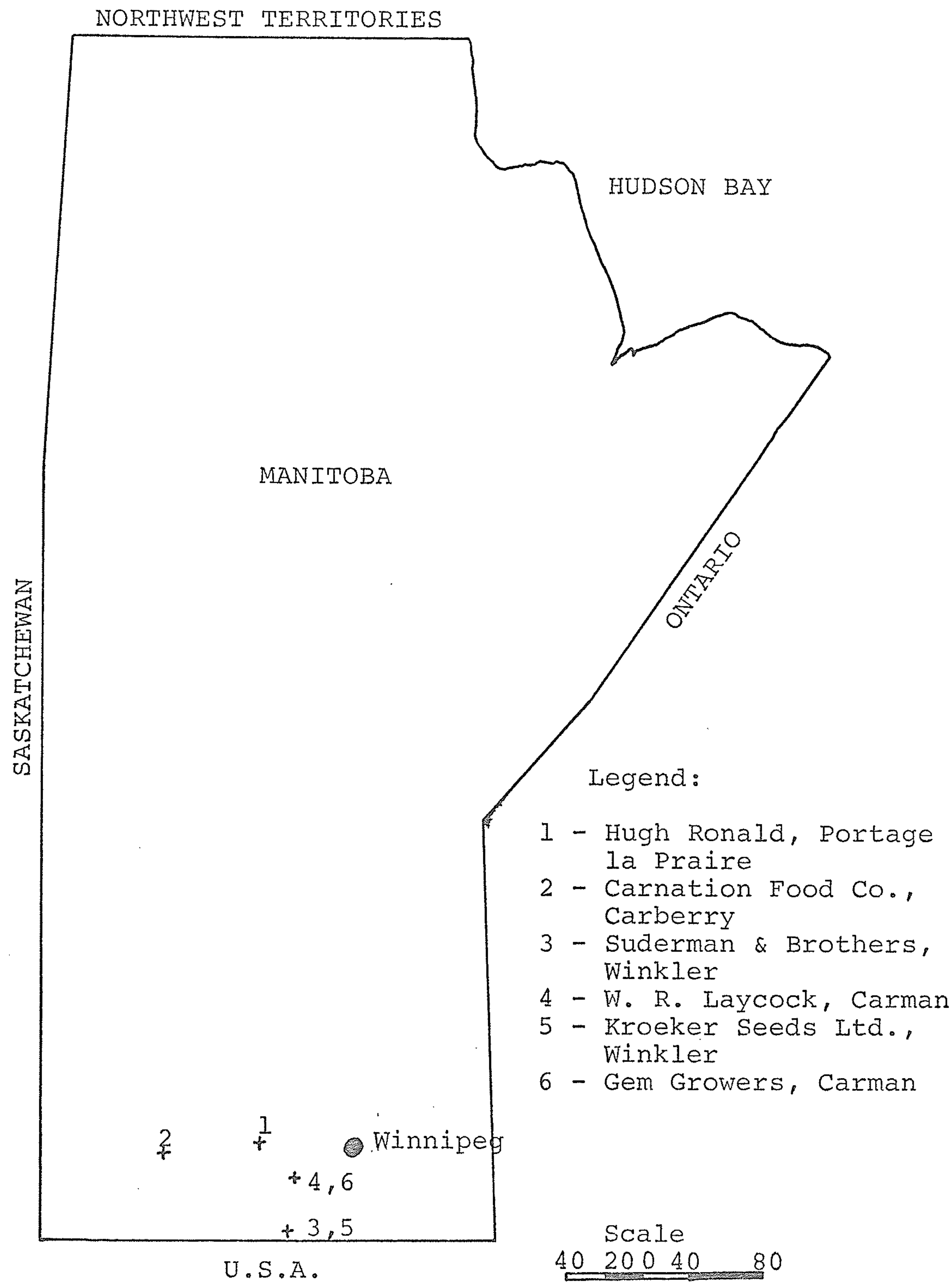


Figure 3.1. Map Showing Locations from where Data were Obtained.

Figure 3.2. Stakes Showing Sampling Location for Samples 1 and 2.

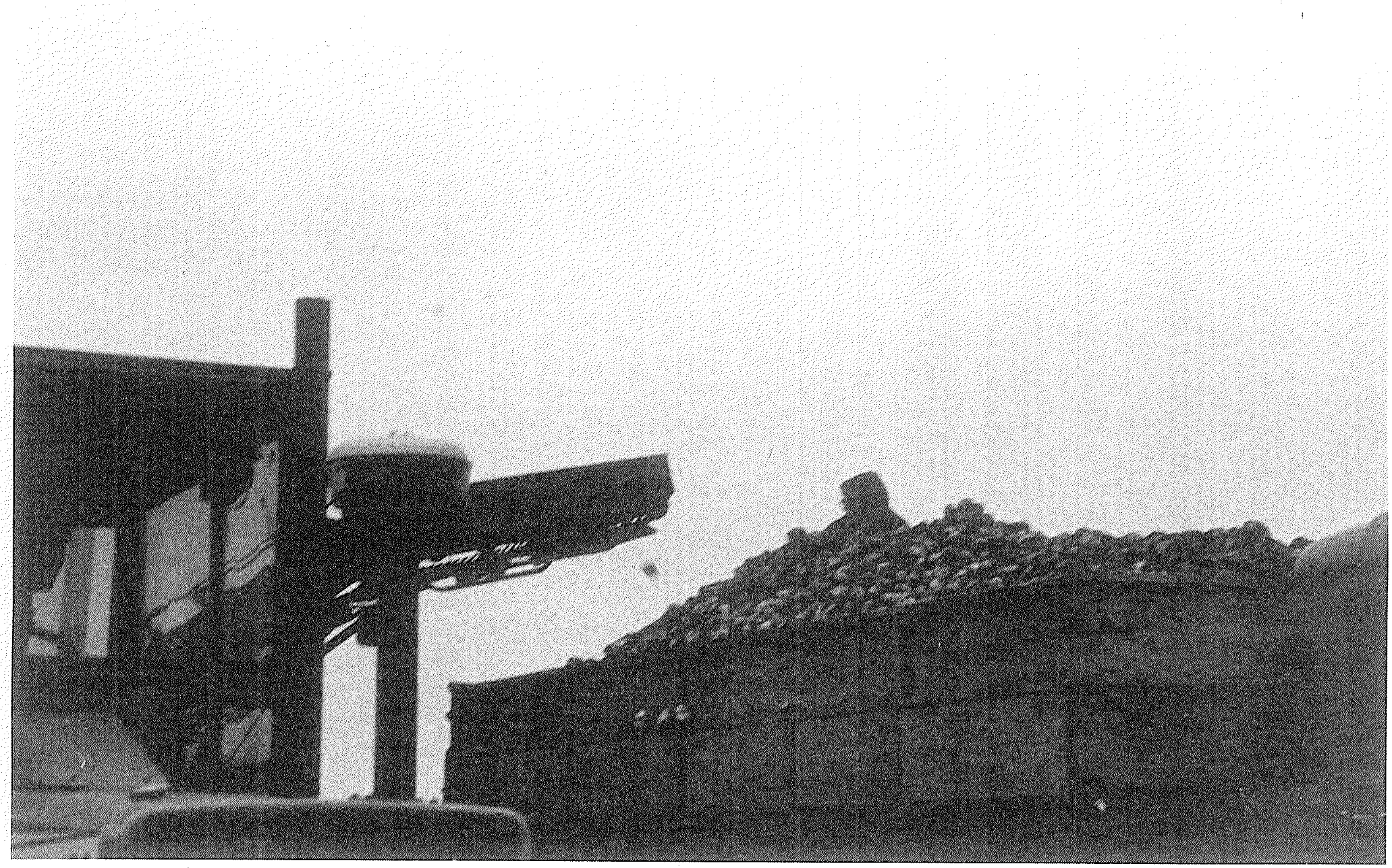


Figure 3.3. Collecting Sample No. 3.

6. No instructions to the operator with regard to harvester setting and operations were given throughout the data collecting.

3.1.3 Testing for Damage

Catechol was the chemical reagent used to aid in the detection of mechanical damage to the potatoes. The catechol was mixed with water at the rate of 2 ounces per gallon. A teaspoon of liquid detergent was also added to the catechol solution to act as a wetting agent. Testing for damage was done in the field from where samples were collected.

Potato samples for damage testing were washed, weighed, and immersed in the catechol solution for about 2 minutes. Then the potatoes were taken out of the solution and allowed to dry for about 10 minutes. The bruises showed up as dark red or purplish stains on the potato surface (Figure 3.4).

3.1.4 Damage Classification

Each potato was examined for red stains and the severity of damage was assessed by peeling with an ordinary potato peeler. Approximately 1/16 of an inch was removed with each stroke of the peeler. The potatoes in each sample were divided into four categories according to the severity of injury they received (Figure 3.4). The classification was as follows:

1. Undamaged,

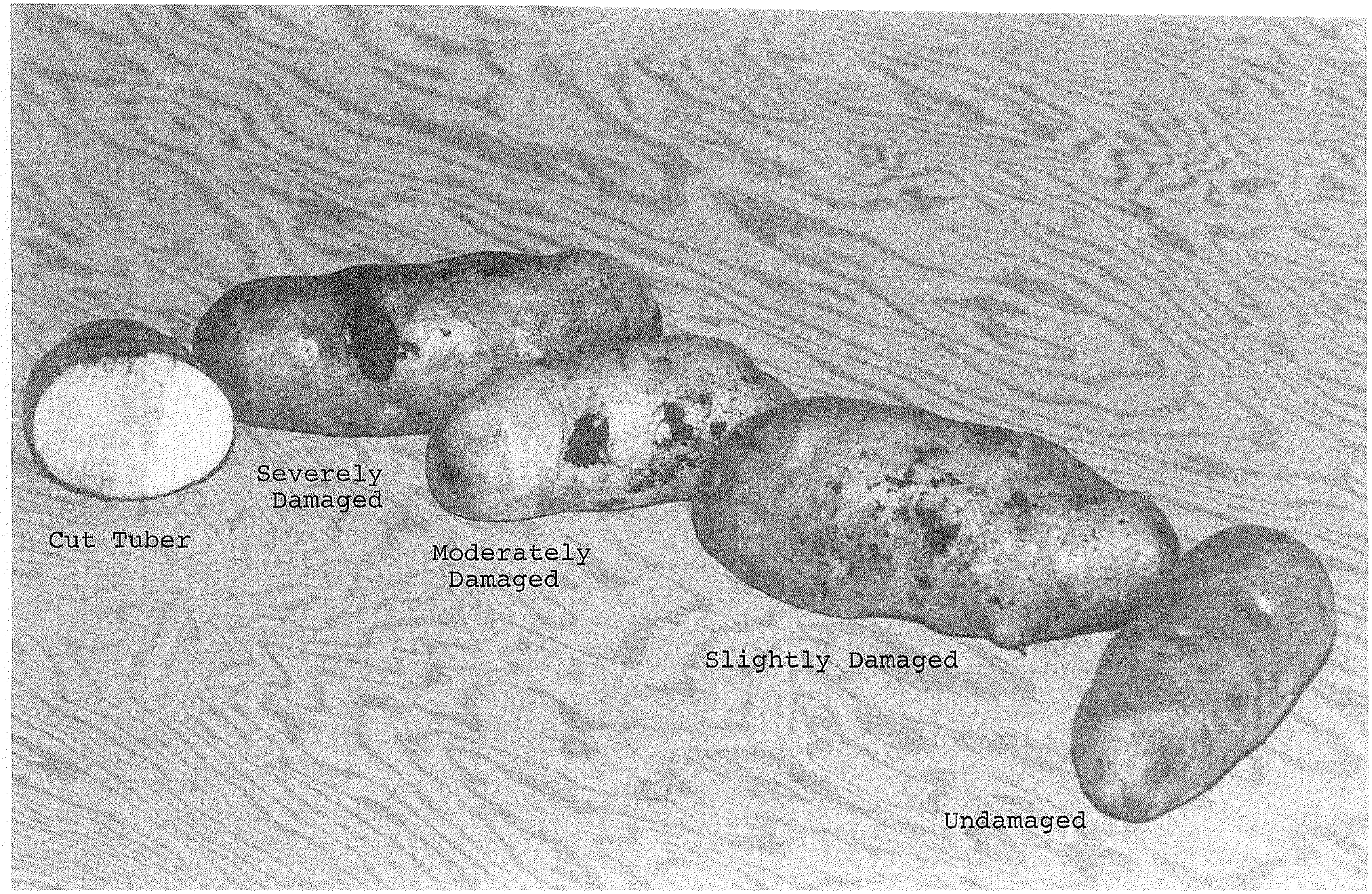


Figure 3.4. Damage Classification.

2. Slightly damaged - the stain was removed by one stroke of the peeler (Figure 3.5),

3. Moderately damaged - the stain was removed by two strokes of the peeler (Figure 3.6),

4. Severely damaged - the stain remained after two strokes of the peeler. Cut, broken and crushed potatoes were classed as severely damaged (Figures 3.6 and 3.4).

The weight and number of potatoes falling in each category were recorded.

3.1.5 Other Relevant Information Obtained

The following information was also obtained:

1. Soil type and condition,
2. Weed growth,
3. Method of top killing,
4. Harvester make, model and type,
5. Harvester blade type and operating depth,
6. Harvesting speed.

3.2 Potato Distribution Measurements

The method used to determine potato distribution was designed to determine the potato distribution at different depths and distances from the main stem. The distribution measurements were taken for four varieties--Norland, Norchip, Netter Gem and Kennebec.

3.2.1 Equipment

The list of equipment used for the potato distribution

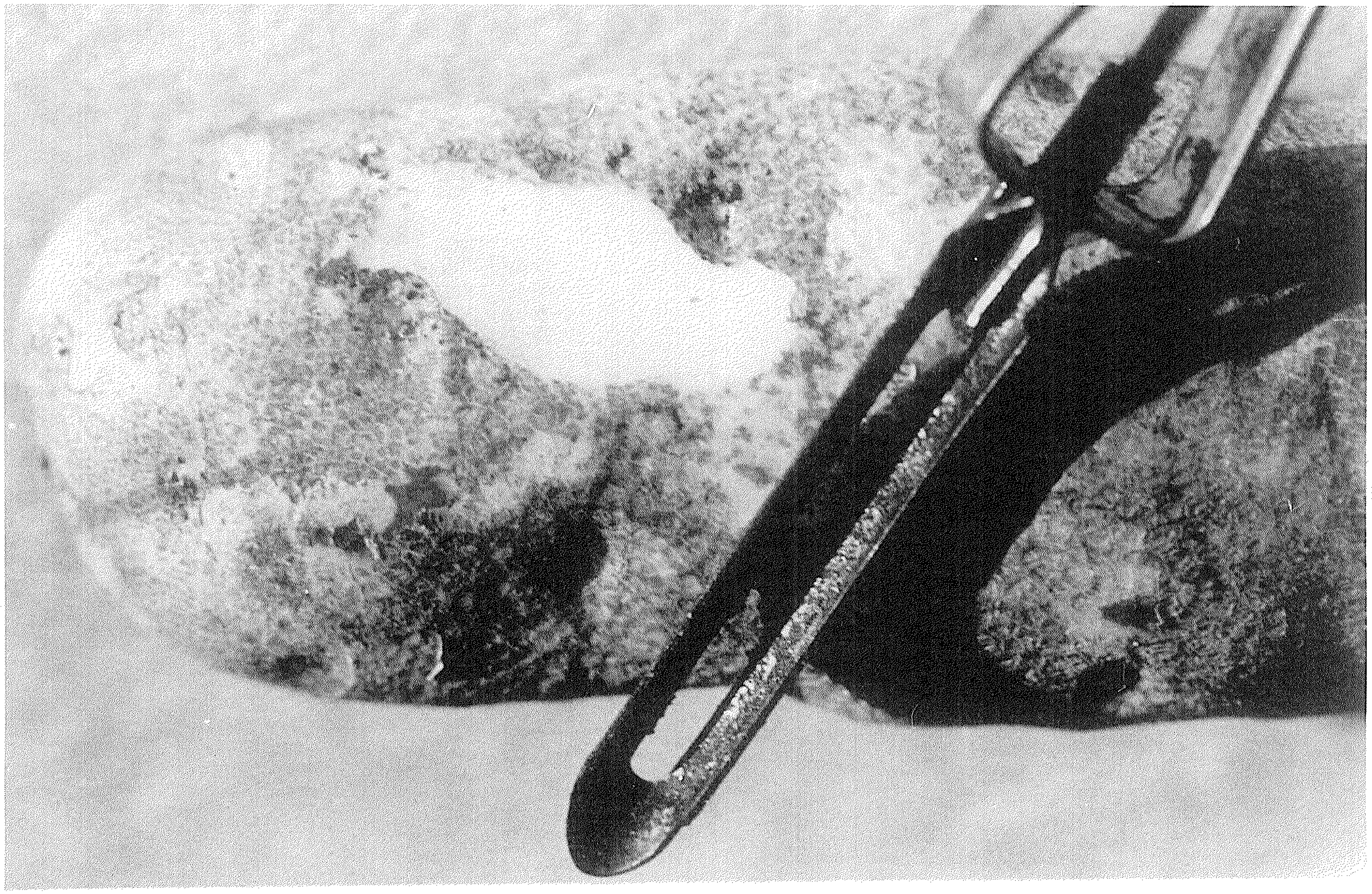


Figure 3.5 Slightly Damaged Tuber.
(Stain Disappears with one cut of Peeler)

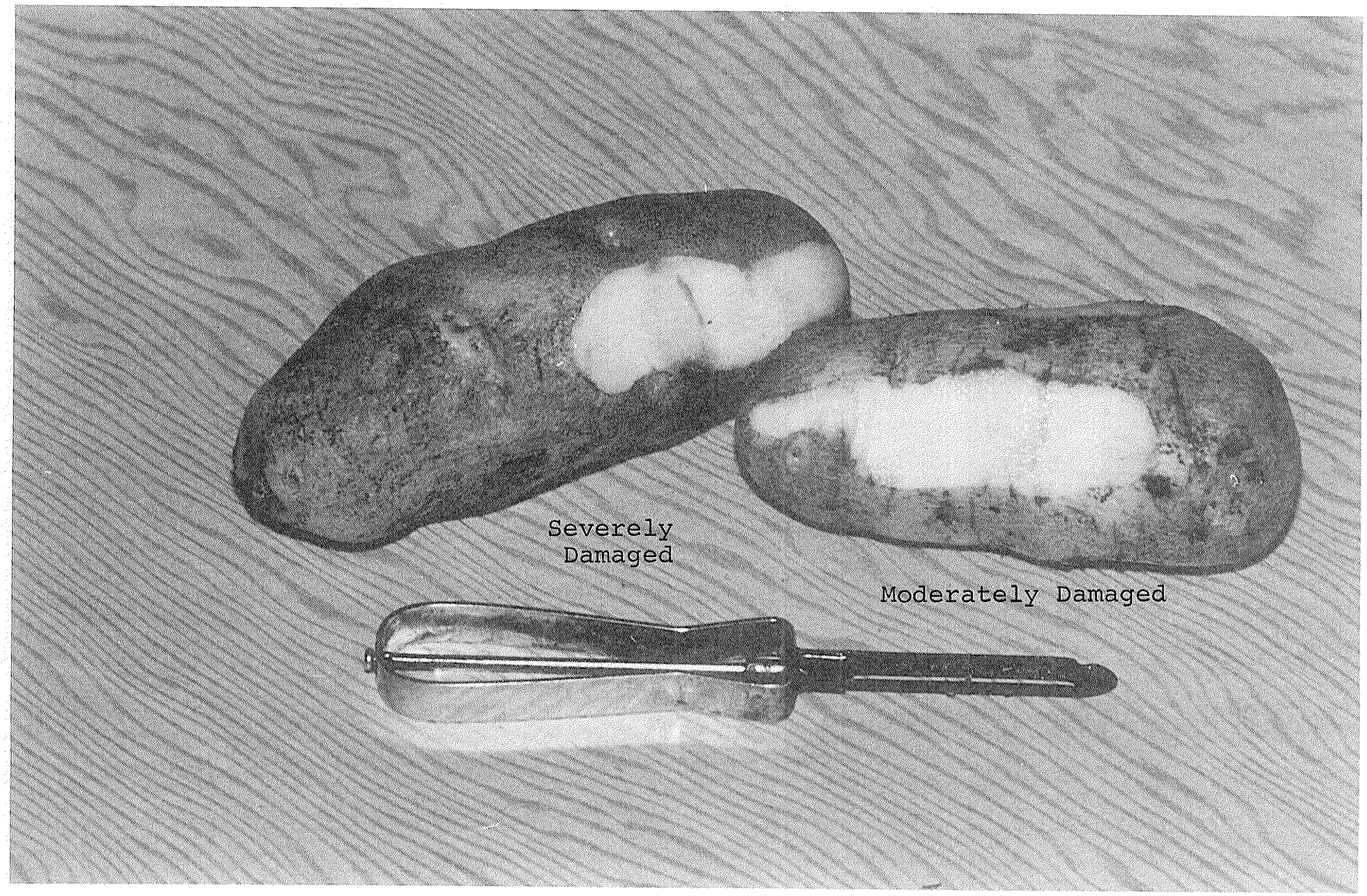


Figure 3.6. Moderately and Severely Damaged Tubers after Two Strokes of Peeler.

study follows.

1. Water pump and Internal combustion Engine Assembly: the water pump delivered water at 10 gallons per minute when the pump operated at 500 revolutions per minute. The pump was powered by a three horsepower engine through a three to one speed reduction. The engine was operated at 1600 revolutions per minute. A pressure gauge and by pass valve assembly were installed to control the water pressure.

2. Hose--Assembly: three-quarter inch diameter hoses were used for inlet and outlet of the water pump and half inch diameter hose was used on the by-pass valve for the return line. A fine screen filter was used on the suction hose to protect the water pump from damage. A high pressure spray gun was attached to the delivery hose for directing the high pressure water.

3. Steel plates: steel plates were used to isolate the selected plant from the neighbouring ones. Six steel side plates, 20 inches long by 19 inches wide and 3/16 inches thick were fitted with 3/8 inch diameter by 26 inch long rods on the 20 inch edges (Figure 3.7). Two plates were pounded into the ground on either side of the selected potato plant, to a depth of approximately 10 inches.

A steel cover plate 40 inches long by 20 inches wide and 3/16 inches thick was placed on top of the two side plates. The cover plate had 3/16 inches diameter holes drilled on a 1 inch spacing grid pattern (Figure 3.8). The

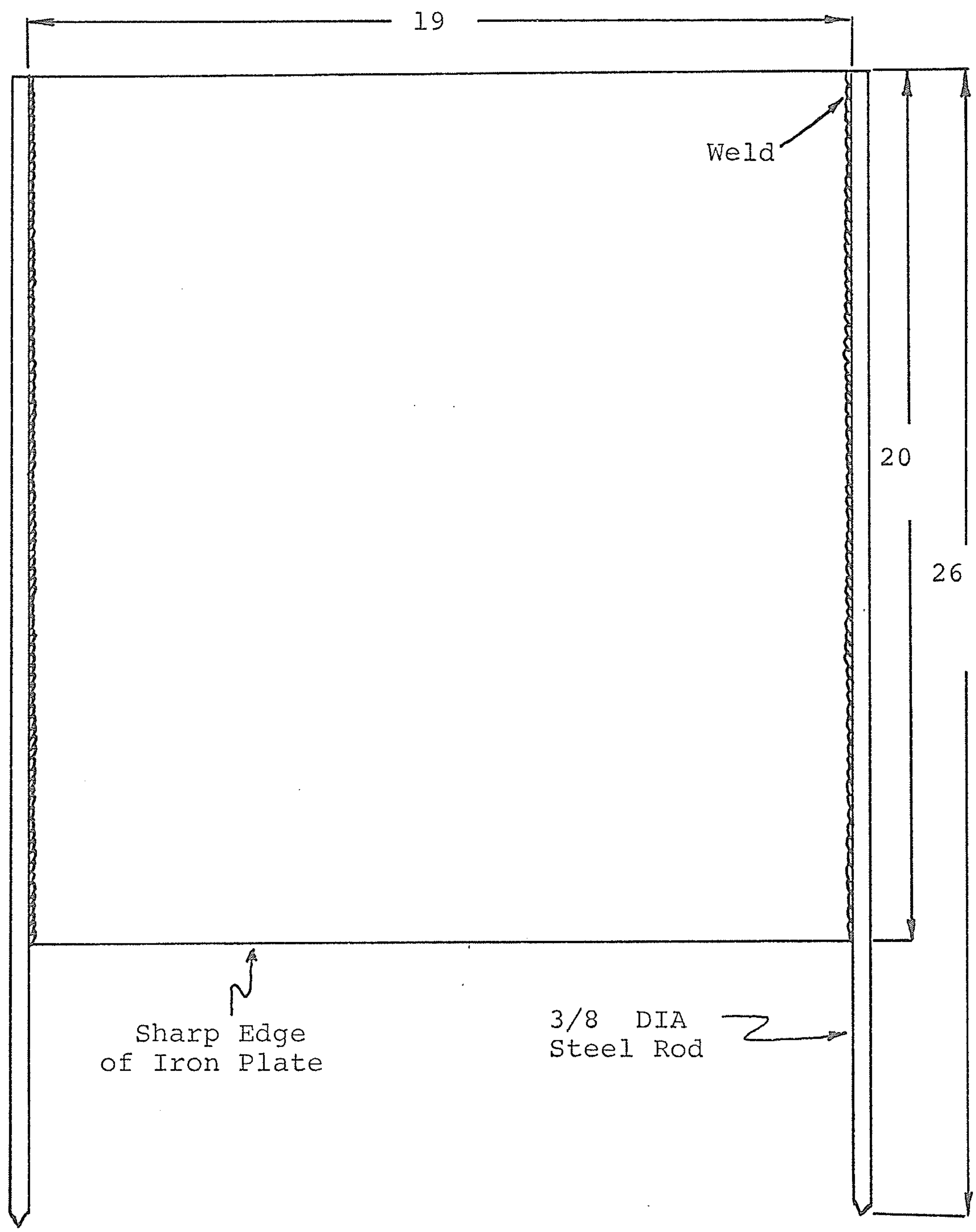
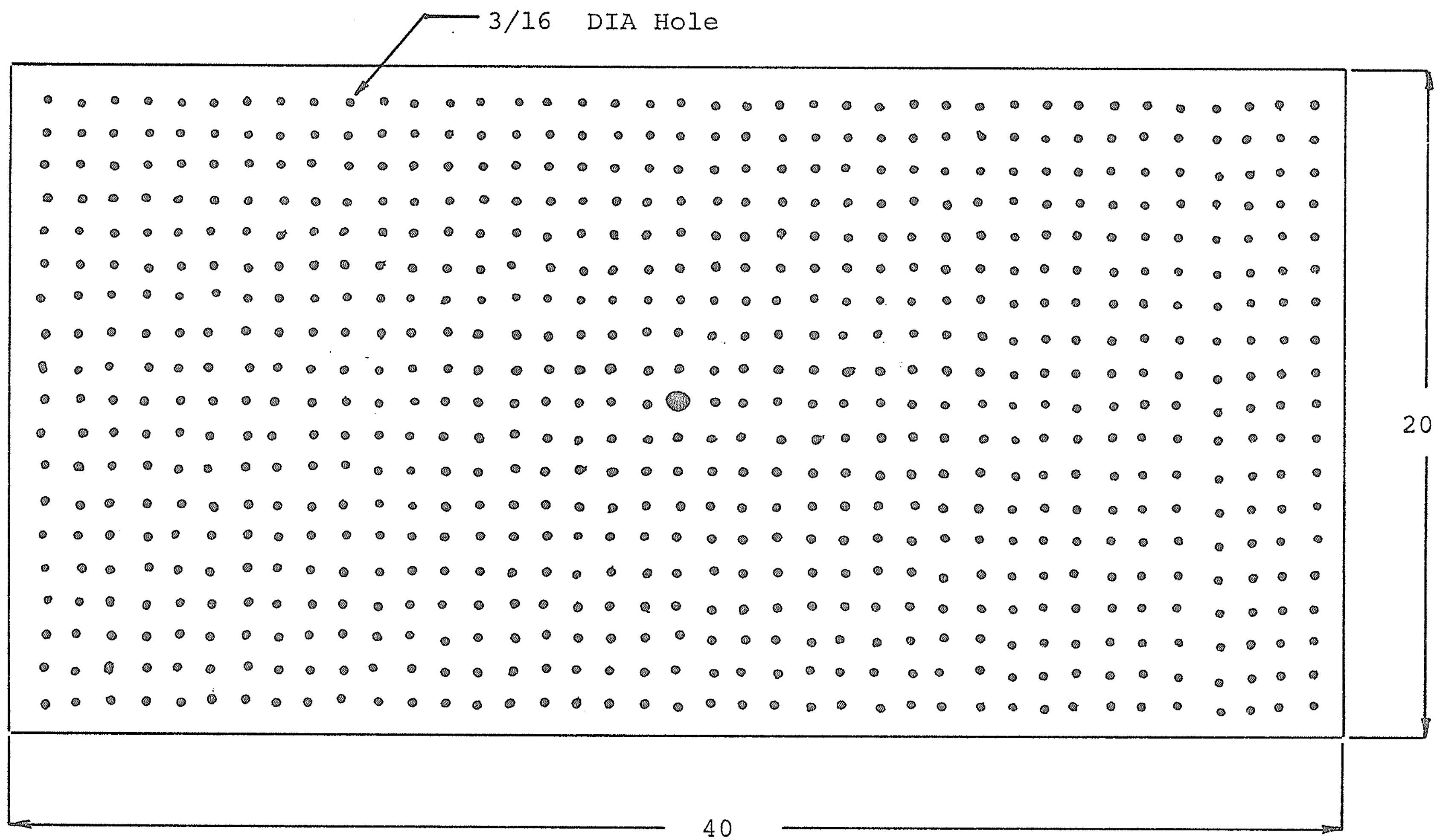


Figure 3.7. Side Plate
(Mat. 3/16 inch Black Iron)

Figure 3.8. Cover Plate
(Mat. 3/16 inch Black Iron)



potatoes were fixed in their positions by driving into the ground 3/32 inch diameter steel welding rods pointed at one end. Small rubber stops were used on the welding rods to prevent them passing through the cover plate when soil was washed out.

4. Steel tape: a 6 foot steel tape was used for the measurements of the potato locations.

5. Sludge pump assembly: a hand operated sludge pump equipped with 2 inch diameter plastic pipe on the inlet and the outlet was used to remove the soil and water slurry.

6. Sledge hammer: a 5 pound sledge hammer was used to pound the steel side plates into the ground.

3.2.2 Procedure

The tops of the selected plant were cut off with a sharp knife. Two side plates, 10 inches from the main stem on either side were pounded into the ground. The cover plate was placed on the side plates in such a position that the center of the cover plate was directly above the main stem. An identifiable welding rod was driven into the ground to locate the main stem. The other welding rods were driven into the ground all around the main stem on a 2 inch square grid out to 8 inches. It was hoped that the welding rods would fix each and every potato in position, on the plant. The high pressure water (50 to 80 psi, depending on soil conditions) was used to wash out the soil from the potatoes (Figure 3.9). The soil and water slurry was

Figure 3.9. Potato Distribution Set Up.

removed by the sludge pump from the washing area. The washing was continued until all the potatoes on the plant were clear of soil. Potatoes not pierced by a rod were located by driving an additional welding rods during washing. The welding rods which did not pierce any potatoes were removed after washing. Figure 3.11 shows the potato distribution after the washing was completed.

3.2.3 Measurements

The following measurements were taken and recorded for each plant:

1. Height of cover plate from top of hill (H) (Figure 3.10),

2. Hill height (h), (Figure 3.10),

3. The co-ordinates of center of gravity each potato along the row (Y), and across the row (X) were noted from the cover plate, by counting the number of holes on each axis from the central point,

4. The distance of center of gravity of each potato from cover plate (Z), was measured with steel tape (Figure 3.10 and 3.11),

5. The length and cross-section of an average potato in the sample.

3.3 Determination of Crop Yield

Five different rows were selected at random for yield sampling. On each row a length of 13.76 feet (see

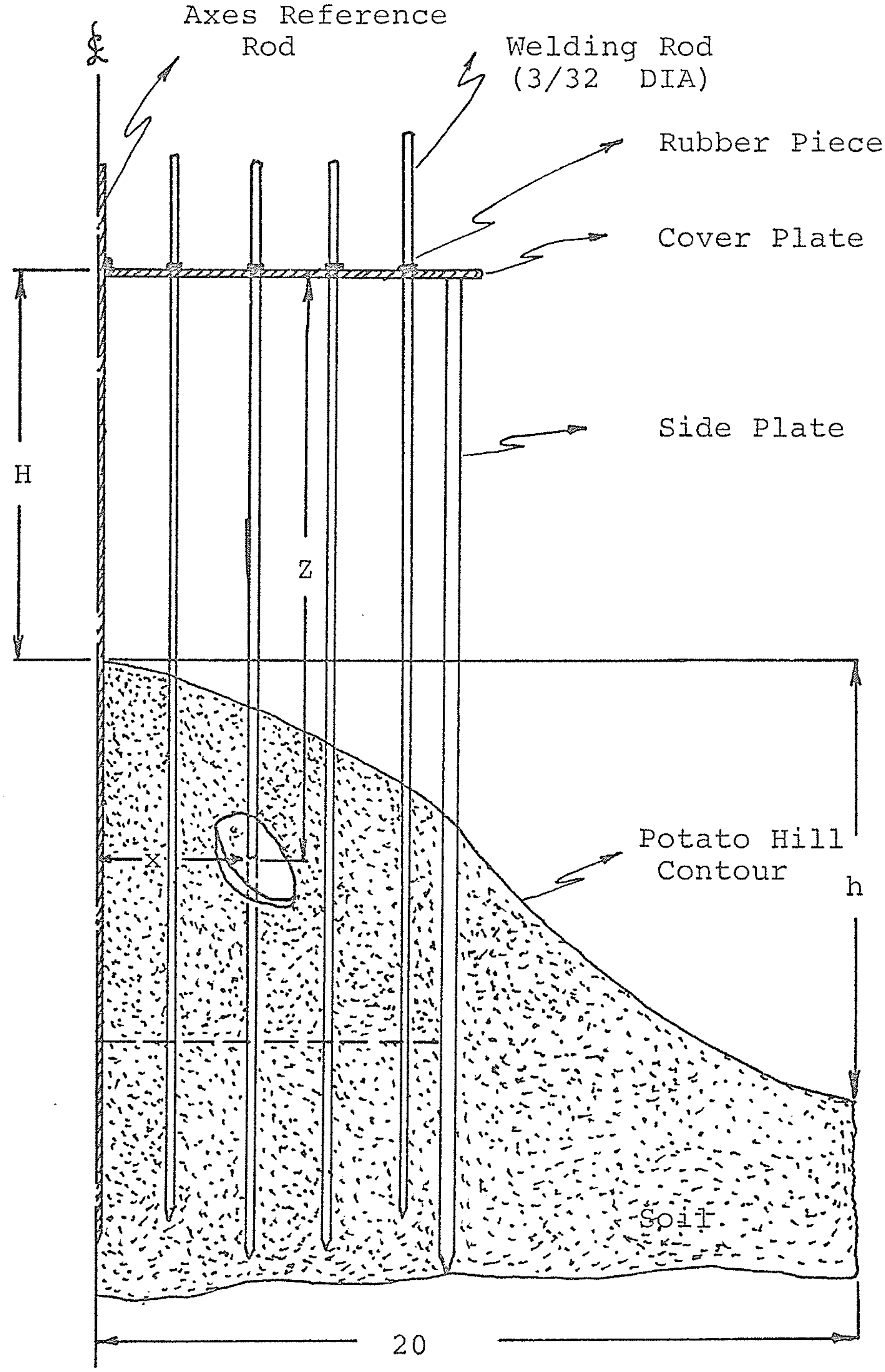


Figure 3.10. Half-section of Side View Showing Potato Distribution Measurements.

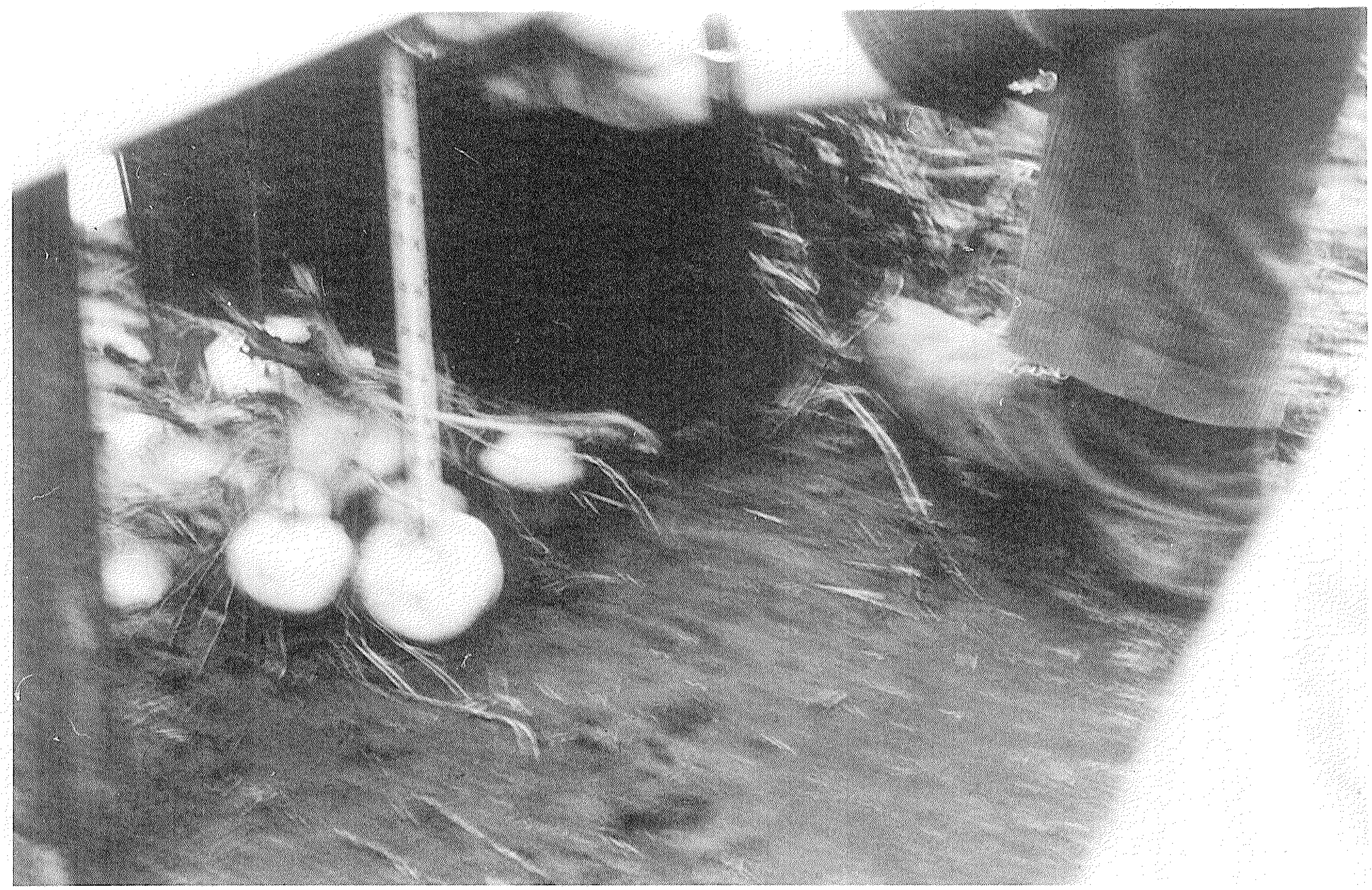


Figure 3.11. Measurement of Potato Depth.

Appendix E) was marked. Potatoes hand dug from this length were identified as a yield sample and weighed. The average weight for 5 yield samples was calculated. The average weight (lb) was then multiplied by the appropriate yield factor, depending upon the row spacing, to obtain the yield in cwt per acre. Yield factors for common row spacing for potatoes in Manitoba are listed in Table 3.1.

Table 3.1

Yield Factors

Row Spacing (inches)	Yield Factors (cwt/acre-lb)
36	10.55
38	10.00
40	9.50

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Potato Damage Results

The percentage of potato damage in each category was calculated on a weight basis from the data collected from the eighteen different fields. The results are listed in Appendix C. Potato damage was assessed on a weight basis since potatoes are produced and marketed on a weight basis. Potato damage represents a crop loss and therefore loss due to mechanical damage is more accurately given on a weight basis rather than on a number basis. In Chapter 4 slightly damaged tubers will be considered as undamaged, moderate and severely damaged as damaged, unless otherwise stated.

The results listed in Table 4.1 show that on an average field 35.33 per cent of the potatoes were damaged by the time they were delivered to the truck during the 1970 potato harvest in Manitoba. Potato damage ranged from 16 to 56.6 per cent of the crop. Nearly all the farmers who co-operated used a pull-type, two row potato harvester with the exception of one who used a self-propelled, two row potato combine. The amount of damage done to potatoes where they left the potato combine was no less than for the pull-type potato harvester. The potato damage at harvesting time by the potato combine amounted to 20.77 per cent (see Table 4.1). Practically all of the potato tops were killed by a frost which occurred during the second week of September 1970. Therefore nothing can be said about the contribution to potato damage by mechanical or chemical top killing methods.

Table 4.1

Potato Damage Results when They Left the Potato Harvester

Field Number*	Potato Damage (per cent) Damaged	Undamaged	Remarks
14	35.33	64.67	Average Damage
9	56.60	43.40	Maximum Damage
17	16.00	84.00	Minimum Damage
6	20.77	79.23	Harvested by potato combine

*See Appendix A.

4.1.1 Variation in Damage between the Fields and Harvesting Stages

Analysis of variance techniques were used to determine the variation in damage between the fields and harvesting stages, (see Appendix D, Part I). The analysis of variance is given in Table 4.2. The F-ratio for fields is not significant; tabulated $F(0.05) = 1.92$ for 17 and 36 degrees of freedom. The evidence is not in favor of field differences with respect to potato damage. The F-ratio for harvesting stages* is significant, tabulated F(0.01) = 2.21 for 36 and 162 degrees of freedom. The evidence is in favor of harvesting location differences.

Table 4.2

Analysis of Variance Table for Potato Damage

Source of Variation	df	S.S.	M.S.S.	F
Fields	17	5,764.62	339.1	0.4
Harvesting Stages	36	3,091.76	855.33	8.07**
Replications in Stages	162	17,171.20	105.995	

**Significant at 1 per cent level.

To test the individual differences in damage between the three harvesting stages, the Student-Neuman-Keul's test technique was used (see Table 4.3). The test revealed that the damage done before lifting was significantly different from the damage done at soil-machine interface. The total amount of damage done to the tubers was significantly different than the amount of damage done to the tubers up to and including the soil-machine interface.

*Refers to sample locations for samples 1, 2 and 3.

Table 4.3

Average Potato Damage at Three Harvesting Stages

Harvesting Stages	Potato Damage (Per cent by weight)
Before lifting	4.88
At Soil-machine Interface	9.21
In the Potato Truck	28.68

4.1.2 Potato Damage before Lifting

The mechanical damage done to potatoes before they are lifted from the soil ranged from no damage to as high as 13.8 per cent. The main reasons for potato damage before lifting were found to be careless harvester steering, narrow row spacing, wide tractor tires and poor hills. Many of the damaged potatoes found in number one sample were either crushed or cut into halves. Crushed potatoes were the result of tractor tire riding over the side of the hills. The sharp serrated coulters on each side of the potato harvester cut the potatoes into halves. The farmer who used a self-propelled potato combine was able to do less damage before lifting than others using pull-type potato harvesters (see Appendix C). On the average damage done to potatoes before lifting amounted to approximately 5 per cent of the crop.

4.1.3 Potato Damage at Soil-Machine Interface

The mechanical damage done to potatoes at the soil-machine interface was found to be largely dependent on the harvesting depth, machine setting and shape of the hill. Many of the damaged potatoes in number two samples were either cut or severely bruised. The cut potatoes were the result of a shallow running harvester blade. The primary shaking chain of the harvester bruised the potatoes severely at soil-machine interface. The total mechanical damage done to potatoes at soil-machine interface ranged from zero per cent to as high as 21.1 per cent. The farmer using the potato combine did less damage to the potatoes at soil-machine interface by not damaging them before lifting (see Appendix C). It was observed that many tubers were damaged by sticking in the space between the harvester blade and primary chain. The total average damage done to potatoes at soil-machine interface amounted to approximately 9 per cent of the crop.

4.1.4 Total Machine Damage

The damage done to potatoes on the harvester was a function of the following variables:

1. Soil type and condition,
2. Harvestor ground speed,
3. Crop yield,
4. Miscellaneous.

Potato damage in fields having heavier soils was found to be less as compared to lighter soils (see fields 3 and 5, Appendix C). The heavier soils with adequate moisture formed a cushion for the tubers and did not separate quickly on the shaking chains. This reduced damage due to agitation. The harvester ground speed greatly influenced the amount of damage done to potatoes. The machine which travelled faster caused more damage to the tubers (see fields 9 and 5, Appendix C). Crop yield combined with soil conditions and harvester ground speed did affect the potato damage. Mechanical damage to potatoes in high yielding fields was found to be higher (see fields 10 and 14, Appendix C). The results show that 16 to 56.6 per cent of the potatoes were damaged by the time they left the potato harvester. On the average the damage done to tubers when they left the harvester amounted to approximately 29 per cent of the crop.

4.1.5 Damage Versus Size of Potato

From the data collected for the damage study the average weight of damaged and undamaged tubers was calculated and compared at the three harvesting stages (see Table 4.4). In all three varieties, the average weight of damaged tuber was found to be slightly less than the average weight of undamaged tubers before lifting time. It was observed that the bigger potatoes grow deeper and the smaller ones shallower in the soil. Therefore, the smaller potatoes received mechanical injury before lifting time. At the soil-machine interface the damaged tubers were 22.5 per cent heavier than the undamaged tubers. The most obvious reason for this was that the heavier potatoes had difficulty in getting onto the primary shaking chain and were bruised between the harvester blade and the primary chain. Furthermore, since the heavier potatoes grew deeper, some were sliced by the shallow running harvesting blade. As the potatoes went into the truck, the damaged tubers were 17.3 per cent heavier than the undamaged tubers.

Table 4.4

Potato Damage and Tuber Weight

	Average Weight of Damaged/Average Weight of Undamaged (lb)		
Variety	Before Lifting	At Soil-machine Interface	In the truck
Norland	0.37/0.39	0.44/0.36	0.37/0.36
Norchip	0.30/0.32	0.45/0.35	0.38/0.30
Netted Gem	0.33/0.36	0.36/0.31	0.37/0.31

4.2 Potato Distribution Pattern

The results of the potato distribution investigation for 4 varieties are depicted in Figures 4.1 - 4.12. These are the averages for six samples for each variety. Potato distribution in the hill was found to be more dependent on hilling, other cultural practices and rainfall intensity rather than variety. Hilling and cultural practices displace the main plant stem location either to the left or to the right of the hill center, causing non-symmetrical tuber distribution about the main stem. Heavy rainfall washed the loose soil from the surface, thus leaving the tubers in the top 3 to 4 inches of the soil. The variety did not affect the distribution pattern of potatoes in the hill. It was found that heavier potatoes grow deeper in the soil than the lighter potatoes.

4.2.1 Norland Variety

Tubers for this variety were few and small in size. The average numbers of tubers per plant was 9. They grew within a 16 inch space across the row and to a 7 inch depth in the soil (see Figures 4.1 and 4.2). The 7 inch depth is the distance from the top of the hill to the center of gravity of the deepest potato. An additional 1 inch must be added to determine the average distance from the top of the hill to the bottom of the deepest potato. Figure 4.3 summarizes the results of Figures 4.1 and 4.2.

4.2.2 Kennebec Variety

Potatoes for this variety tend to grow wider and shallower than the other three varieties. The average number of potatoes per plant were seven. On the average all the potatoes were found within an 18 inch space across the row and within 6 inch depth in the soil (see Figures 4.4 and 4.5). These tubers are white and round in shape. An

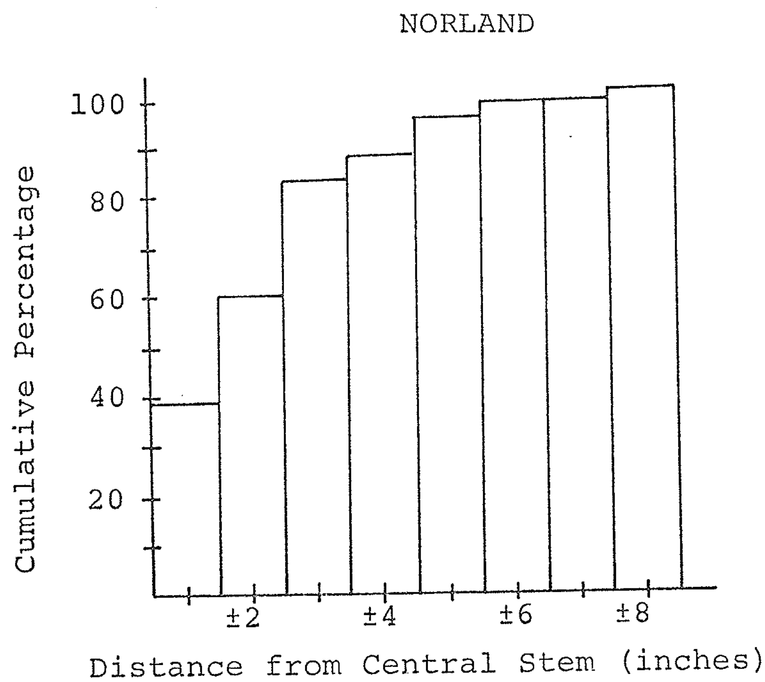


Figure 4.1. Horizontal Potato Distribution*

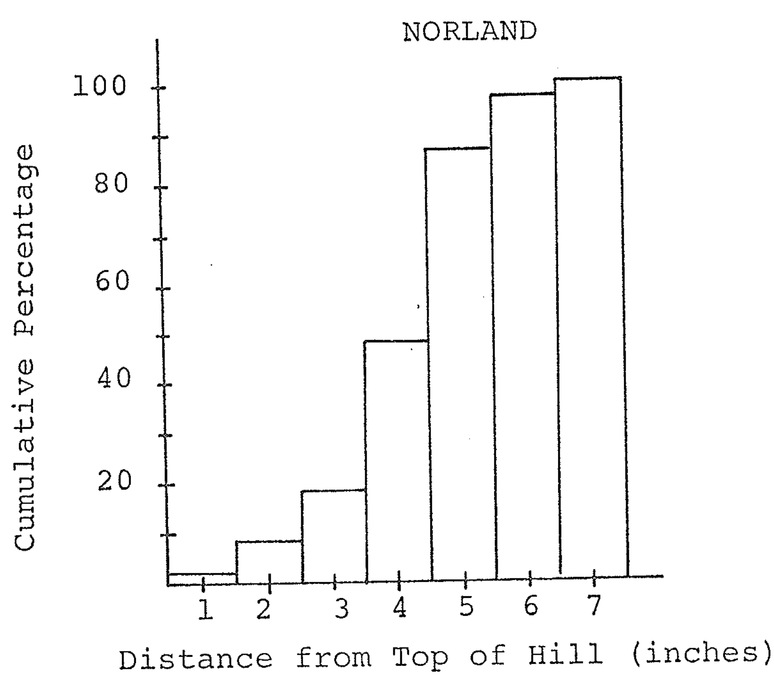


Figure 4.2. Vertical Potato Distribution

*Potato distribution across the row only.

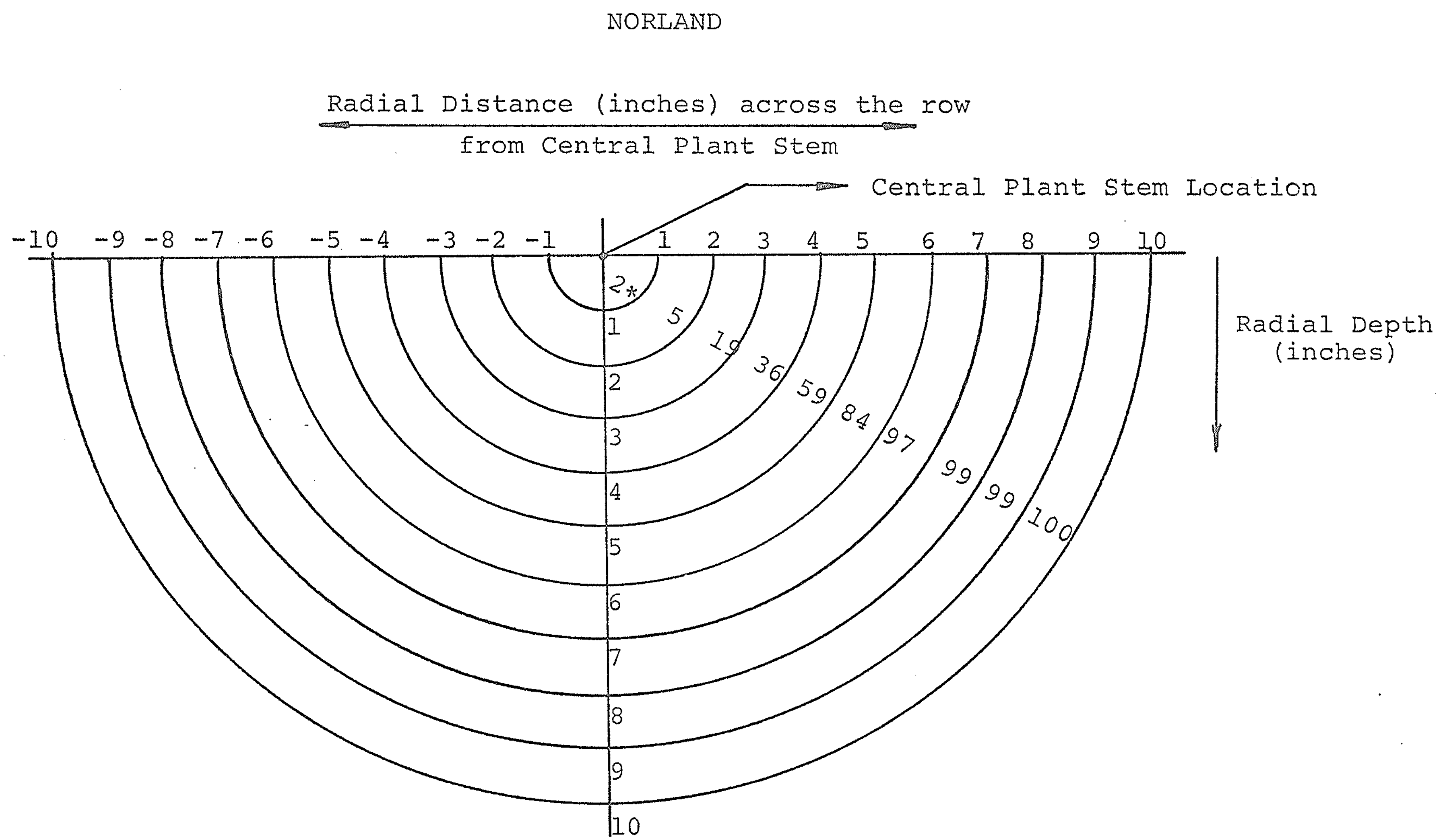


Figure 4.3. Two Dimensional Potato Distribution.
*Number representing per cent of potatoes inside the given radius.

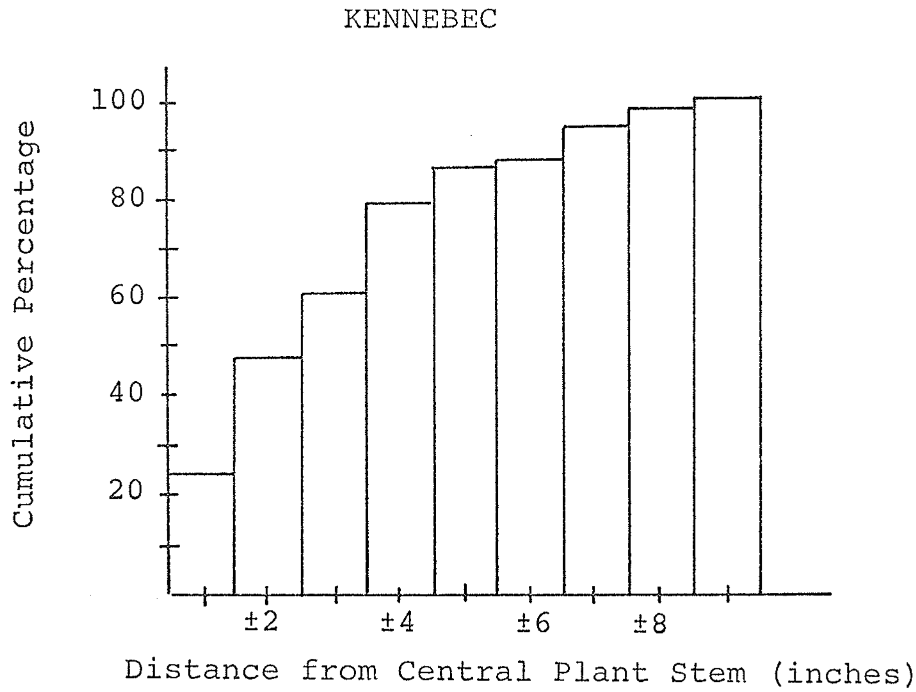


Figure 4.4. Horizontal Potato Distribution.

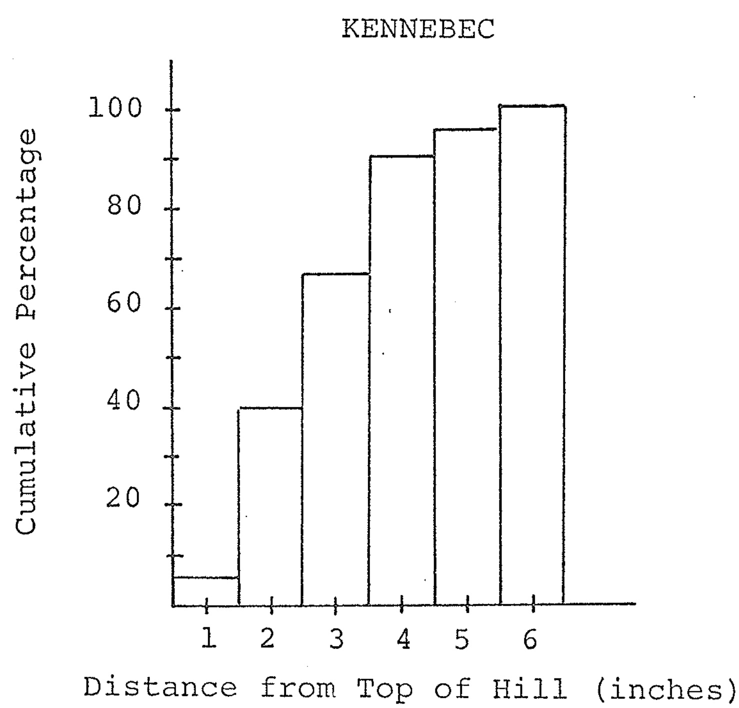


Figure 4.5. Vertical Potato Distribution.

additional 1 inch must be added to 6 inch distance to estimate the average distance from the top of hill to the bottom of the deepest potato. Figures 4.6 summarizes the results of Figures 4.4 and 4.5.

4.2.3 Norchip Variety

This variety had on the average 15 potatoes per plant. The tubers tend to grow close to the stem but deeper than the other three varieties. All the potatoes based on the six samples collected were found within an 18 inch space across the row and within an 8 inch depth in the soil (see Figures 4.7 and 4.8). Tubers of this variety are ellipsoidal in shape and white in color. An additional 1 inch must be added to the 8 inch distance to estimate the average distance from top of the hill to the bottom of the deepest potato. Figure 4.9 summarizes the results of Figures 4.7 and 4.8.

4.2.4 Netted Gem Variety

This is a high yielding variety and the tubers have good baking quality. The tubers sometimes grow so big that they weigh over 1 pound. The average number of tubers per plant was nine. This variety tends to grow wider than the other three varieties and reaches a depth of 7 inches from the top of the hill (see Figure 4.11). All the potatoes can be found within 20 inch spaces across the row (see Figure 4.10). This variety yields tubers oblong in shape and usually placed at an angle in the soil as contrast to other

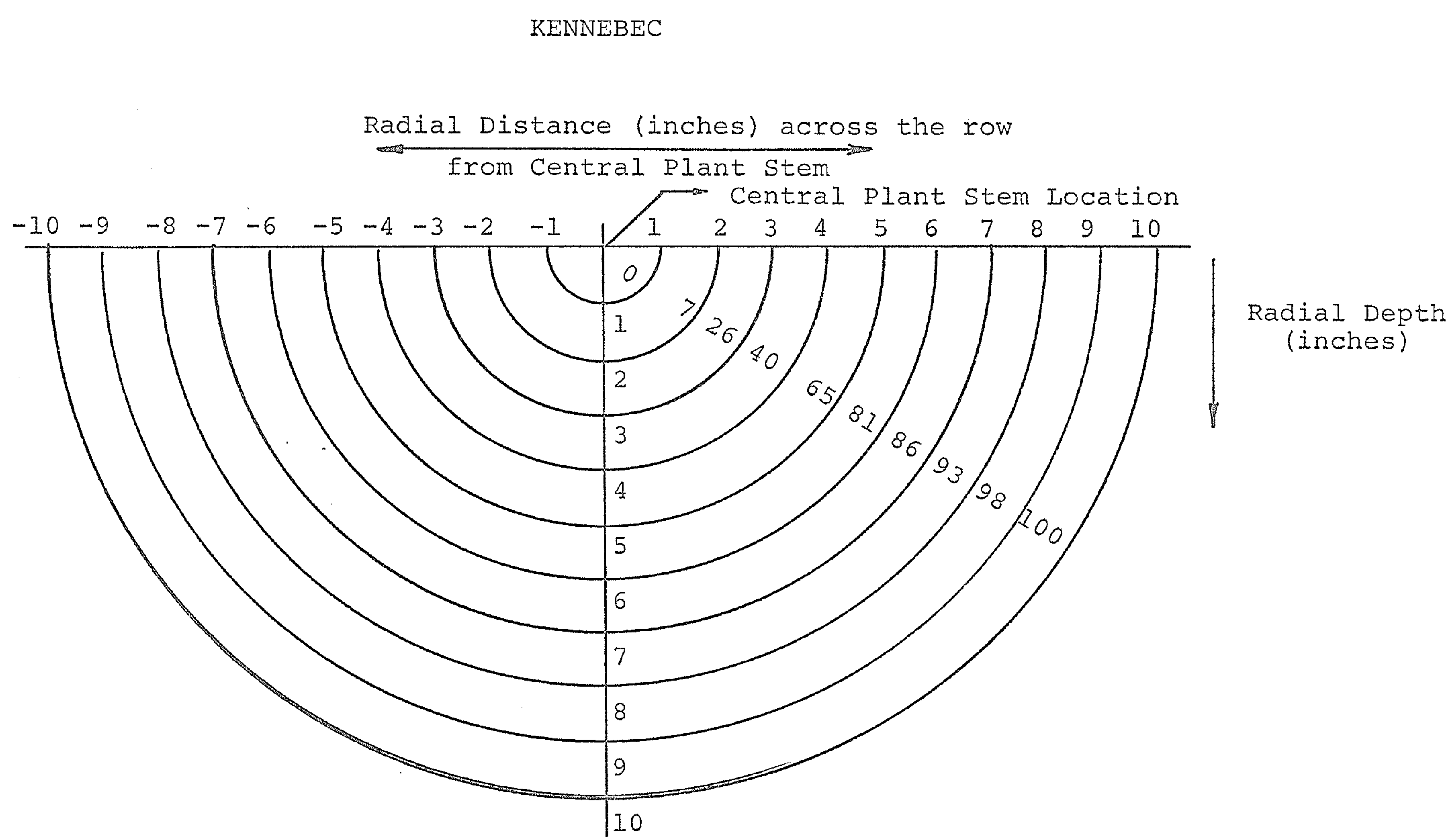


Figure 4.6. Two Dimensional Potato Distribution.

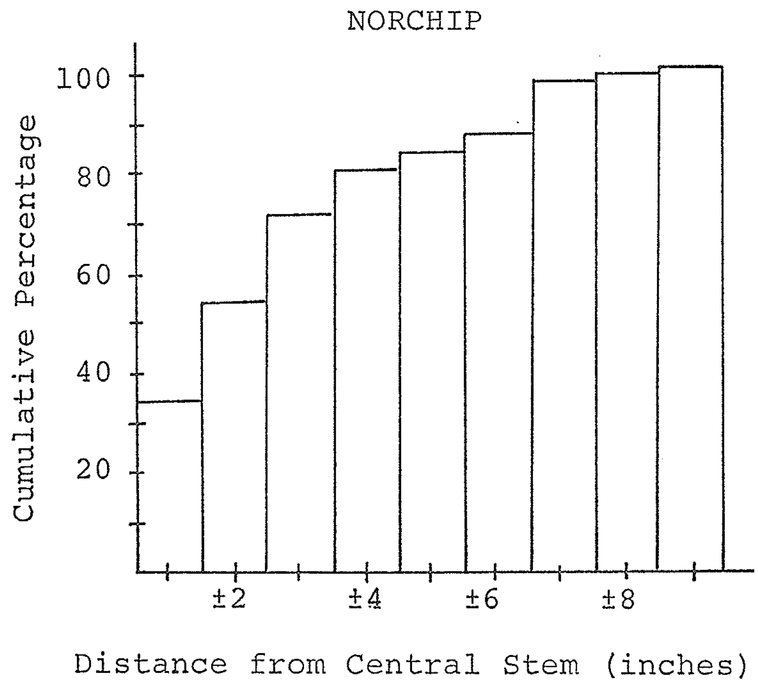


Figure 4.7. Horizontal Potato Distribution.

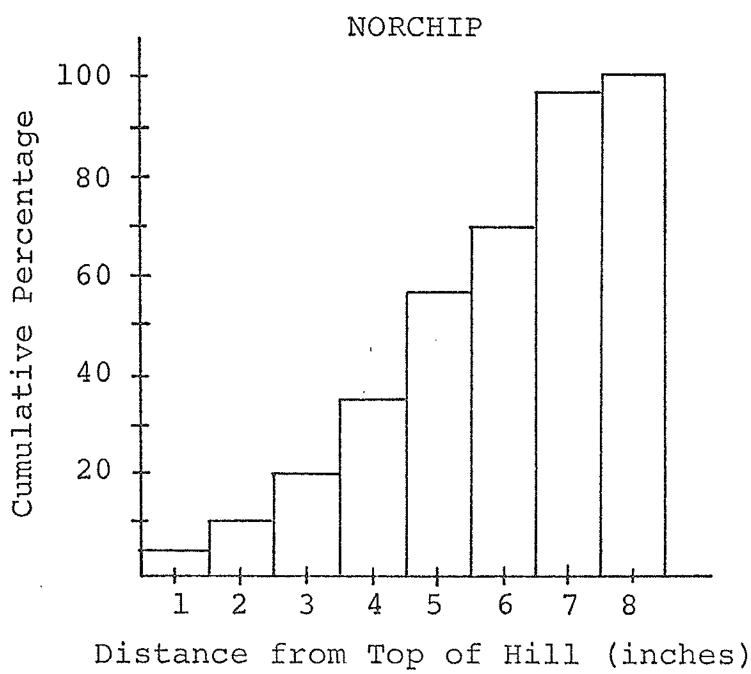


Figure 4.8. Vertical Potato Distribution.

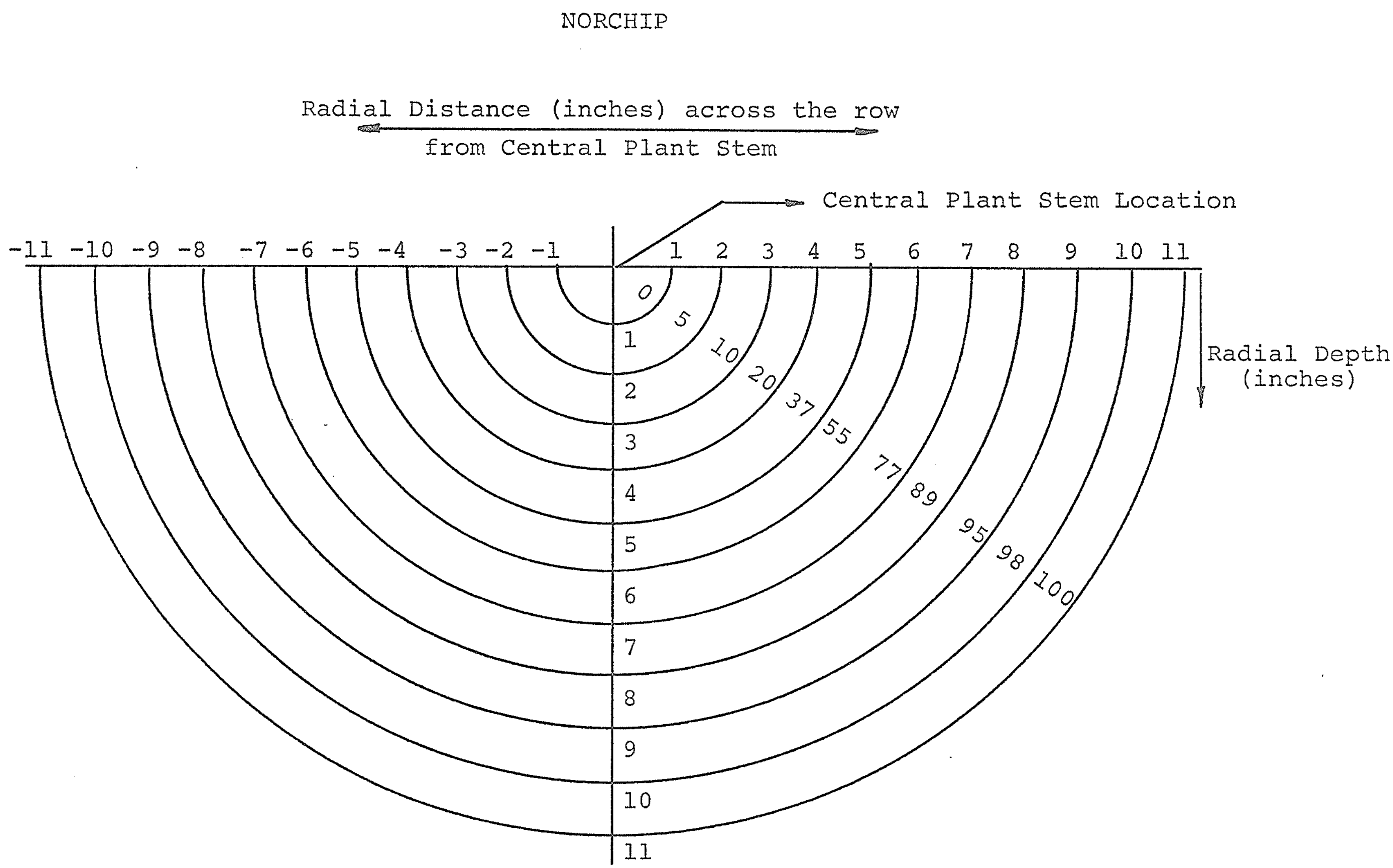


Figure 4.9. Two Dimensional Potato Distribution.

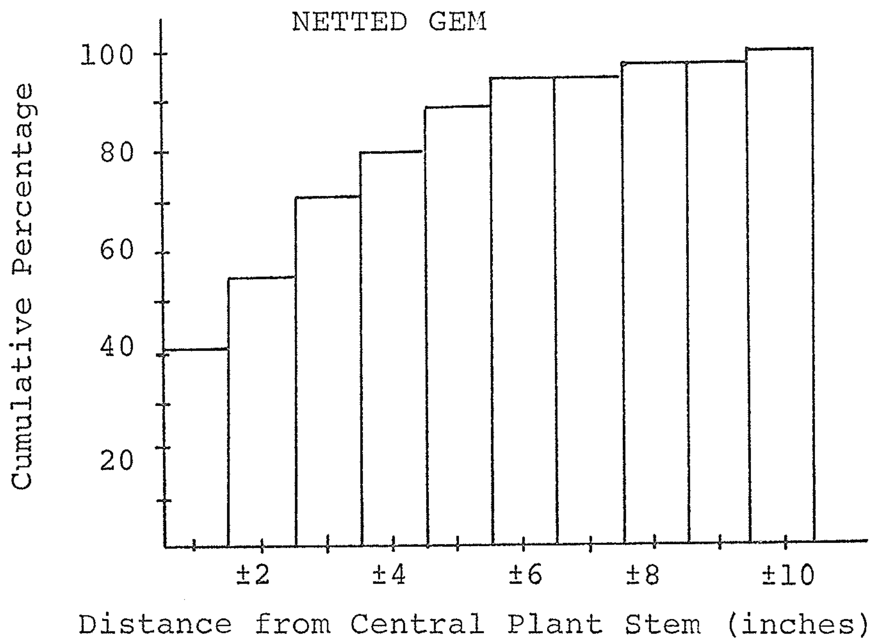


Figure 4.10. Horizontal Potato Distribution.

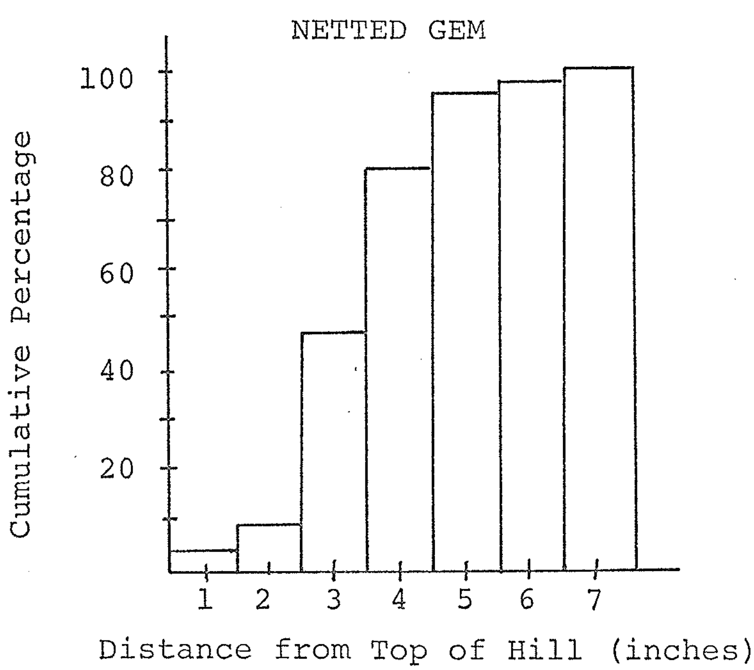


Figure 4.11. Vertical Potato Distribution.

varieties which have tubers lying flat in the soil. An additional 1.5 inches must be added to the 7 inch depth to determine the average depth of the bottom of the deepest potato from top of the hill. Figure 4.12 summarizes the results of Figures 4.10 and 4.11.

4.3 Distribution Variation Among Varieties

Analysis of variance techniques were used on the measurement data to determine the distribution variation between the four varieties (see Appendix G, Part I) both horizontally and vertically. The results of the analysis of variance are listed in Tables 4.4 and 4.5. The tabulated F(0.05) is 2.6 for 3 and 239 degrees of freedom. Upon checking the F-ratio for both horizontal and vertical distribution, the evidence is not in favor of varietal differences with respect to tuber distribution from the main stem. Although the F-ratio for horizontal potato distribution is close to the tabulated F(0.05), individual differences between two varieties across the row were tested by using the Student-Neuman-Keul's test (see Appendix G, Part II). The test shows that the difference between Kennebec and Norland varieties is significant at the 5 per cent level.

In order to further confirm that the four varieties do not differ significantly with regard to horizontal potato distribution in the soil, a X^2-test was performed using enumeration data (see Appendix G, Part III). The evidence is again not in favor of varietal differences with respect

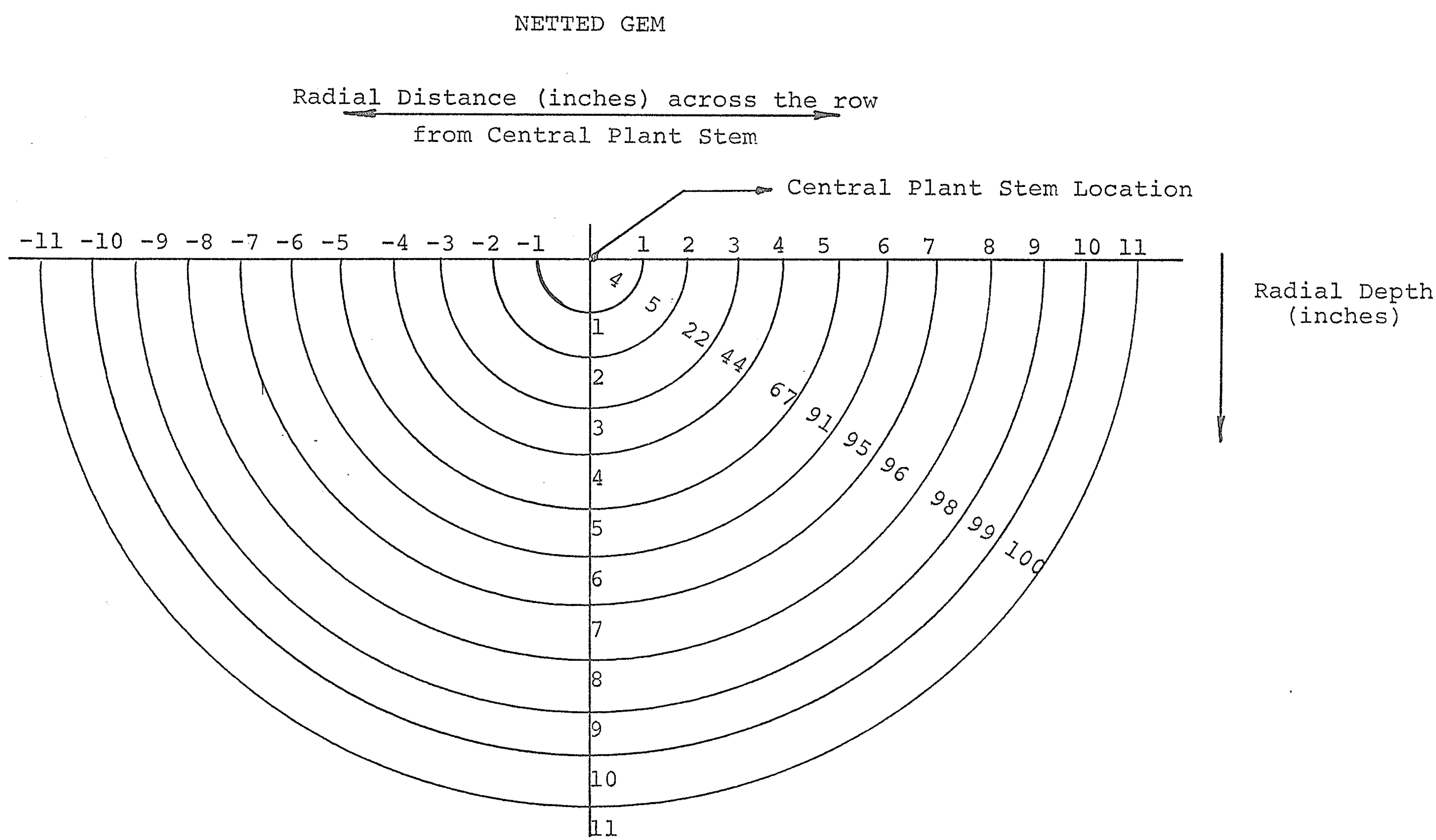


Figure 4.12. Two Dimensional Potato Distribution.

Table 4.5

Analysis of Variance for Horizontal Potato Distribution

Source of Variation	df	S.S.	M.S.S.	F
Among Varieties	3	31.54	10.51	2.26
Within Varieties	239	1,113.12	4.66	
Total	242	1,144.66		

Table 4.6

Analysis of Variance for Vertical Potato Distribution

Source of Variation	df	S.S.	M.S.S.	F
Among Varieties	3	10.16	3.39	0.254
Within Varieties	239	3,182.84	13.32	
Total	242	3,193.00		

to horizontal potato distribution in the soil.

Therefore it can be said, based on the samples surveyed, that there is no significant difference between four varieties with respect to both horizontal and vertical tuber distribution.

CHAPTER 5

CONCLUSIONS

From the results of this study, presented in Chapter 4, the following conclusions may be drawn:

1. On the average approximately 5 per cent of the potatoes were damaged before lifting. Tuber size did not have any effect on potato damage before lifting the crop. Potatoes were mostly damaged as a result of careless tractor steering, narrow row spacing, wide tractor tires and poorly shaped hills.

2. On the average approximately 9 per cent of the potatoes were damaged at the soil-machine interface. The average weight of the damaged tuber was 22.5 per cent higher than the undamaged tuber. The heavier potatoes were damaged between the harvester blade and the primary chain due to difficulty in getting onto the primary chain. These heavier potatoes were sliced by the shallow running harvester blade, because they grew deeper than the lighter potatoes.

3. On the average approximately 29 per cent of the potatoes were damaged by the time they reached the potato truck. The average weight of the damaged tuber was 17 per cent more than the undamaged tuber. The reasons for this were that the heavier potatoes were damaged at the soil-machine interface and on the shaking chains due to their

weight.

4. The difference in the field conditions did not have a significant effect on the amount of tuber damage.

The amount of damage at the three harvesting stages was significantly different for each stage, because at each stage an appreciable amount of damage was being done.

5. Potato distribution in the hill was found to be dependent on hilling and cultural practices and rainfall intensity. Potatoes for all four varieties tend to grow within a 16 to 18 inch space across the row, and 6 to 8 inch deep in the soil.

6. The results of the potato distribution study give indications of how deep the harvester must be set to avoid blade damage to the tubers. For nicely formed potato hills, harvesting depth should range from 6 to 8 inches to avoid blade damage and provide a sufficient earth cushion for the potatoes on the harvester.

7. Most of the potatoes for the four varieties grew at a depth of 2 to 5 inches measured from top of hill.

CHAPTER 6

SUGGESTIONS FOR FURTHER STUDY

Several studies have been conducted in the past to evaluate the damage at various stages of potato harvesting. The results indicate to the grower the losses involved and also suggest methods for reducing mechanical injury. The most important factor that has not been investigated so far is "cost". The cost of eliminating the last possible traces of mechanical injury may exceed the value of potatoes saved. Maximum yield and minimum damage do not necessarily mean maximum profit. It is important to compare the cost of eliminating each per cent of mechanical damage and the value of potatoes saved, in order to form a business policy which matches the concept of acceptable risk and profit return. Therefore, it is suggested that in future the cost involved in reducing each per cent of mechanical injury should be studied.

It is also suggested that this study could be carried further by comparing the mechanical injury received by potatoes under recommended harvesting and handling practices and prevalent potato handling practices. Mechanical damage to potatoes during post-harvest handling and on the processing lines should also be determined under prevailing Manitoba conditions. This will help to answer the question as to whether potato handling equipment needs improvement and if so where and how much.

In this study an attempt was made to investigate potato distribution without regard to cultural practices. It is suggested that the effects of seed placement and subsequent tillage practices and climatic factors should be investigated by running experiments under controlled and conventional conditions. It may also be interesting to study the distribution variation between individual plants of one variety under controlled conditions. Although it is concluded from this study that under Manitoba conditions intervarietal differences do not exist with regard to potato distribution, further studies would be worthwhile on additional varieties.

BIBLIOGRAPHY

1. Abraham, K. V. Systems engineering potato harvester damage, Unpublished M. Sc. Thesis, University of Alberta, 1969.

2. Alberta Department of Agriculture. Potatoes in Alberta, Queen's Printer for Alberta, Pub. No. 137, February, 1959.

3. Aspinwall, J. S., Hepherd, R. O. and Habblethwaite, P. A Method for the assessment of potato damage resulting from mechanical handling, J. Agr. Eng. Res., 7(1), 71, 1962.

4. Bailey, P. H. An investigation into the distribution of potatoes in the ridge, J. Agr. Eng. Res., 2(2), p. 146, 1957.

5. Canada Department of Agriculture. Potato growing in the Atlantic Provinces, Pub. No. 1281, 1967.

6. Dominion Bureau of Statistics, Field crop reporting series No. 20, Ministry of Trade and Commerce, Ottawa, Catalogue No. 22-002, November,18, 1970.

7. Dominion Bureau of Statistics, Quarterly bulletin of Agricultural Statistics, Ministry of Trade and Commerce, Ottawa, Catalogue No. 21-003, April-June, 1970.

8. Dubetz, S. and Hobbs, E. H. Irrigation water--its use and application, Canada Department of Agriculture, Pub. No. 1199, 1966.

9. Eaton, F. E. and Hansen, R. W. Mechanical separation of stones from potatoes by means of rotary brushes, Paper presented at Annual Meeting of ASAE, W. Lafayette, June, 1969.

10. Feldman, M. Potato harvesting--damage, stone separation and present system, Engineering Research and Development in Agriculture, Ottawa, Issue No. 8, January, 1970.

11. Finney, E. E., Hall, C. W. and Thompson, N. R. Influence of variety and time upon the resistance of potatoes to mechanical damage, Am. Potato J., Vol. 41, p. 178, 1964.

12. Gilfilan, G. and Ramsay, A. M. A field study of potato and rubbish separation by hand, J. Agr. Eng. Res., 5(1) 3, 1960.

13. Glaves, A. H. and French, G. W. Increasing Potato-harvester efficiency, USDA, Agriculture Handbook No. 171, December, 1959.

14. Green, H. C. The susceptibility of fruit and potatoes to damage during handling, a Paper presented at an open meeting of I.A.E., London, January 28, 1965.

15. Green, H. C. Potato Damage, J. Agr. Eng. Res., 1(1), 56, 1956.

16. Green, H. C. An experiment with damaged potatoes, J. Agr. Eng. Res., 7(2), 165, 1962.

17. Green, H. C. Experiments on the storage of damaged potatoes, J. Agr. Res., 2(2), 141, 1957.

18. Green, H. C. Some experiments on the storage of washed and damaged potatoes, J. Agr. Eng. Res., 4(3), 255, 1959.

19. Hamblin, H. J. and Chalmers, G. R. An experiment on the mechanical harvesting of potatoes at slow forward speed, J. Agr. Eng. Res., 2(1), 81, 1957.

20. Hastings, R. C. Mechanical injury to potatoes and its eradicationin North Dakota, Am. Potato J. 8(5), p. 126, 1931.

21. Hawkins, J. C. The design of potato harvesters, J. Agr. Eng. Res., 2:14, 1957.

22. Hine, H. J. Mechanical damage to potatoes, J. Ministry of Agr., Vol. 65, p. 608, March, 1959.

23. Hine, H. J. Soil problems in potato mechanization, J. Ministry of Agr., Vol. 68, p. 20, April, 1961.

24. Hopkins, R. B. Effect of potato digger design on tuber injury, Agr. Eng., Vol. 37, p. 109, February, 1956.

25. Humphrey, E. Steps that can be taken to reduce mechanical damage to potatoes at harvest time, Idaho Agr. Exp. Sta., Bul. No. 278, June, 1950.

26. Iritani, W. M., Ohms, R. E. and Sparks, W. C. Potato vine killing in Idaho, Idaho Current Information Series No. 55, University of Idaho, August, 1967.

27. Jaruis, J. W. Handling potatoes, Dept. of Traffic Union Pacific Railroad, Omaha, Nebraska.

28. Larsen, F. E. External and internal (blackspot) mechanical injury of Washington Russet Burbank potatoes from field to terminal market, Am. Potato J., Vol. 39:249, July, 1969.

29. Mainprize, L. F. Reducing mechanical injury in potato handling, Ontario Department of Agriculture and Food, Pub. No. 184, 1969.

30. Manitoba Department of Agriculture, Farm and Home News for Manitoba, November 26, 1969.

31. Manitoba Department of Agriculture. 1969 Year Book of Manitoba Agriculture, Queen's Printer for Manitoba, 1970.

32. Manitoba Department of Agriculture. Manitoba Farm Outlook--1970, Queen's Printer for Manitoba, 1970.

33. Misener, G. C. and Kemp, J. G. Factors influencing potato damage during harvesting, Paper presented at Annual Meeting of CSAE, Ottawa, July 7, 1970.

34. Philipson, A. and Lawrence, D. C. Comparisons of potato damage assessment at different time intervals after harvesting, J. Agr. Eng. Res., 8(1), 31, 1963.

35. Prapuolenis, A. A. Method for determination of the distribution of potatoes in the soil, J. Agr. Eng. Res., 13(4), 370, 1968.

36. Preston, T. A. Potato harvesting damage survey, Agr. Bul. No. 7, Faculty of Agriculture, University of Alberta, p. 12, February, 1968.

37. Preston, T. A. Albertan harvesting problems, gaps, leavings, damage, Paper presented at Annual Meeting of Pacific Northwest Region of ASAE, Vancouver, B. C., October, 1969.

38. Principles and Practices of Commercial Farming, Faculty of Agriculture and Home Economics, University of Manitoba, II edition, 1968.

39. Robertson, I. M. The use of para-cresol for the detection of damage in potato tubers, J. Agr. Res., 6(2) 220, 1961.

40. Scott, M. L. and Roberts, J. A. Potato production studies in New Brunswick, Paper presented at Annual Meeting of CSAE, July 7, 1970.

41. Smith, N. and Sides, S. E. An evaluation of stone separation mechanisms for potato harvesters, Paper presented at Annual Meeting of the North Atlantic Region of ASAE, Montreal, August, 1969.

42. Snedecor, G. W. Statistical methods--as applied to experiments in Agriculture and Biology, Iowa State College Press, Ames, Iowa, 1956.

43. Sparks, W. C. Effects of mechanical injury upon the storage losses of Russet Burbank potatoes, Idaho Agr. Exp. Sta., Bul. No. 220, November, 1954.

44. Sparks, W. C. Mechanical injury to potatoes from harvester to consumer, Idaho Agr. Exp. Sta., Bul. No. 280, 1957.

45. Sparks, W. C. Injury to Russet Burbank potatoes by different harvesting machines, Idaho Agr. Exp. Sta. Bul. No. 218, July, 1954.

46. Sparks, W. C., Smith, V. T. and Garner, J. G. Ventilating Idaho potato storage, Idaho Agr. Exp. Sta., Bul. No. 500, p. 8, October, 1968.

47. Steel, R. G. D., and Torrie, J. H. Principles and procedures of Statistics, McGraw-Hill Book Company, Toronto, 1960.

48. Stone, G. E. Cost of production and fresh market preparation of Manitoba potatoes--1968, Unpublished M. Sc. Thesis, University of Manitoba, 1970.

49. Stone, G. E. Potatoe diseases in the field, storage and market, Paper presented at Annual Meeting of Vegetable Growers Association of Manitoba, p. 23, January, 1968.

50. Stone, G. E. Promising areas for vegetable crop production in Manitoba, Technical and Scientific papers at Annual Meeting of the Vegetable Growers Association of Manitoba, January, 1969.

51. Tavernetti, J. R. and Zahara, M. B. Mechanical potato harvesting, California Agriculture, p. 9, July, 1959.

52. Tavernetti, J. R. and Baghott, K. G. A study of potato harvesting at Tulelake, California, Am. Potato J. 37(1), p. 34, 1960.

53. The Potato Association of America, Potato Handbook--Machinery and Equipment Issue, New Brunswick, N. J., 1958.

54. Thornton, R. E. Problems and solutions on bruising of potatoes in harvesting and handling--importance and identification of bruising problem, Paper presented at Annual Meeting of Pacific Northwest Region of ASAE, Vancouver, B. C., October, 1969.

55. Weaver, M. L., Roberts, J., George, J. E., Jensen, M. and Sandar, N. Harvesting potatoes in water-tight bulk body, Am. Potato J., Vol. 42, p. 147, 1965.

56. Webb, E. G. and Scott, J. R. Reducing digger damage in potato harvesting, Ontario Agr. College, Revised Cir., No. 184, September, 1955.

57. West, W. J. Mechanization of potato harvest in the U.S.A., J. Agr. Eng. Res., 3(2), 172, 1958.

58. William, C. M. King Edward potatoes--impact and mechanical damage at lifting time, Am. Potato J. Vol. 40, p. 286, August, 1963, Erratum 40:332, September, 1963.

59. Wilson, A. G. Primary aspects of potato marketing in Manitoba, Faculty of Agriculture and Home Economics University of Manitoba, Res. Rpt. No. 8, March, 1961.

60. Wilson, E. B., Sparks, W. C., Peterson, C. L., and Orr, P. H. Developments in mechanization, post-harvest handling and preservation of potatoes and onions, Rural Manpower Center, Mich. State University, Rpt. No. 16, p. 191, 1969.

61. Zahara, M., McLean, J. C. and Wright, D. N. Mechanical injury to potato tuber during harvesting, California Agriculture, p. 4, August, 1961.

APPENDICES

APPENDIX A

Table 1. Yields, Varieties, Machine Speed and Operating Depth for Test Fields (1970 Potato Damage Study in Manitoba)

Fields	Name and Address of Farmer	Crop Yield and Variety (cwt/acre)	Machine Ground Speed (MPH)	Harvesting Depth (Inches)[a]	Remarks
1	Hugh Ronald, Box 1002, Portage la Praire, Manitoba	265.5 Norland	1.68	4	Soil was med., wet and sticky, 6 persons on crew.
2	Steve Kiminski, P. O. Box 70, Carnation Foods Ltd. Carberry, Manitoba	117.7 Netted Gem	2.24	6.25	Dry sandy soil, 5 persons on crew.
3		164.2 Netted Gem	2.69	5.5	Dry sandy soil, 5 persons on crew.
4		158.0 Netted Gem	1.52	5.5	Med. soil, lots of weeds and trash, 2 persons on crew.

[a] Vertical distance measured from top of hill to harvester blade in harvesting position.

Appendix A, Table 1 (Continued)

Fields	Name and Address of Farmer	Crop Yield and Variety (cwt/acre)	Machine Ground Speed (MPH)	Harvesting Depth (Inches)	Remarks
5		184.9 Netted Gem	2.02	6.0	Heavy soil, not many weeds, 2 persons on crew.
6	Suderman Brothers Ltd., R. R. 1, Winkler, Man.	182.3 Netted Gem	1.06	4.75	Heavy clody soil, with lots of weeds, 4 persons on crew.
7		184.9 Netted Gem	1.84	6.5	Heavy soil, fair amount of weeds, 2 persons on crew.
8	W. R. Laycock, P. O. Box 130, Carman, Manitoba	200.0 Norchip	4.27	5.5	Med. and dry soil, med. weeds, 1 person on crew.
9		192.4 Norchip	4.24	4.8	Heavy and dry soil with med. weeds, 1 person on crew.
10		240.9 Norchip	4.54	4.5	Heavy and wet soil with slods and weeds, 1 person on crew.

Appendix A, Table 1 (Continued)

Fields	Name and Address of Farmer	Crop Yield and Variety (cwt/acre)	Machine Ground Speed (MPH)	Harvesting Depth (Inches)	Remarks
11		160.6 Norland	4.54	4.3	Med. soil, ideal harvesting conditions, 1 person on crew.
12		167.4 Norland	4.54	4.3	Med. dry soil, med. weeds, 1 person on crew.
13		168.6 Norland	4.39	5.9	Med. soil, opt. moisture, 1 person on crew.
14	Kroeker Seeds Ltd., Box 415, Winkler, Manitoba	77.2 Netted Gem	1.33	4.5	Heavy cloddy soil, wet and sticky, 4 persons on crew.
15		74.8 Netted Gem	1.36	4.5	Heavy cloddy soil, dry, difficult to work with.

Appendix A, Table 1 (Continued)

Fields	Name and Address of Farmer	Crop Yield and Variety (cwt/acre)	Machine Ground Speed (MPH)	Harvesting Depth (Inches)	Remarks
16	Gem Growers c/o Carman Vegetable Growers Association, Carman, Manitoba	118.2 Netted Gem	3.11	6.3	Med. soil, ideal harvesting conditions, 2 persons on crew.
17		124.1 Netted Gem	2.79	6.3	
18		122.3 Netted Gem	2.96	6.5	

APPENDIX B

RAW DATA COLLECTED

PART I

Damage Study Data

			Sample No. 1			
		Sample	Mechanical Damage (wt./count)			
Fields	Trial No.*	Weight** (lbs)	SL	ME	SE	UD
	1	13.13	1.31/4	0.44/1	2.31/4	11.69/34
1	2	14.38	1.75/3	0.44/1	1.19/3	11.81/29
	3	9.38	0.38/2	0.00/0	0.88/3	8.13/26
	4	11.88	1.31/2	0.00/0	0.69/2	9.88/4
	1	3.38	1.06/3	0.44/2	0.44/2	1.31/6
2	2	2.69	0.69/4	0.31/2	0.00/0	1.56/10
	3	4.81	0.69/4	0.00/0	0.00/0	2.94/11
	4	4.00	0.94/4	0.00/0	0.00/0	2.81/14
	1	4.88	0.25/1	0.19/1	1.09/2	3.00/9
3	2	5.88	0.31/1	0.00/0	0.00/0	5.69/19
	3	4.59	0.94/4	0.00/0	0.47/1	2.78/13
	4	9.75	1.63/3	0.81/2	0.00/0	6.66/24
	1	8.88	1.50/5	0.38/2	0.00/0	6.25/14
4	2	7.06	1.63/7	0.00/0	0.31/1	4.56/17
	3	6.00	0.94/3	0.31/1	0.00/0	4.31/15
	4	7.69	0.44/2	0.00/0	0.00/0	6.44/16
	1	7.25	0.88/2	0.00/0	0.00/0	5.44/10
5	2	5.38	1.19/2	0.38/1	0.00/0	4.19/16
	3	8.88	2.38/3	0.00/0	0.00/0	6.19/13
	4	3.81	0.00/0	0.50/1	0.00/0	3.31/10
	1	4.38	0.00/0	0.00/0	0.00/0	4.19/15
6	2	2.81	0.00/0	0.00/0	0.00/0	2.50/5
	3	2.31	0.50/2	0.00/0	0.00/0	1.63/7
	4	1.25	0.19/1	0.00/0	0.00/0	0.88/7
	1	5.00	0.88/2	0.00/0	0.00/0	3.94/12
7	2	3.63	0.00/0	0.00/0	0.22/1	3.25/11
	3	3.38	1.16/3	0.00/0	0.00/0	2.06/6
	4	5.25	1.00/1	0.00/0	0.00/0	4.19/12

*There were four trials on each field.

**Sample weight is weight of sample collected before testing for damage.

SL = slightly damaged SE = severely damaged
ME = moderately damaged UD = undamaged

PART I - Damage Study Data (Continued)

Fields	Trial No.*	Sample Weight** (lbs)	Sample No. 1 Mechanical Damage (wt./count) SL	ME	SE	UD
8	1	7.69	1.13/2	0.38/1	0.38/1	5.75/20
	2	9.75	1.50/4	0.38/1	0.00/0	7.75/25
	3	9.25	0.88/1	0.00/0	0.00/0	8.16/16
	4	8.94	1.06/4	0.00/0	0.41/1	7.50/16
9	1	6.25	1.25/3	0.19/1	0.38/1	4.44/14
	2	7.94	1.06/5	0.38/1	0.44/1	5.13/22
	3	6.44	2.31/6	1.50/5	0.38/2	2.38/11
	4	6.44	2.59/5	0.41/1	0.22/1	3.19/9
10	1	5.56	1.25/2	0.00/0	0.00/0	4.25/19
	2	5.50	1.06/4	0.00/0	0.25/2	3.50/10
	3	3.69	0.50/2	0.00/0	0.00/0	3.13/12
	4	5.50	0.63/2	0.00/0	0.00/0	4.75/17
11	1	5.81	0.44/1	0.00/0	0.38/1	4.63/12
	2	5.19	0.31/1	0.00/0	0.00/0	4.50/14
	3	6.63	0.94/2	0.00/0	0.00/0	5.56/14
	4	5.19	0.63/3	0.00/0	0.00/0	4.56/16
12	1	6.25	0.94/2	0.00/0	0.38/2	4.88/14
	2	6.94	0.31/1	0.00/0	0.31/1	6.31/13
	3	6.19	0.00/0	0.00/0	0.63/1	5.44/21
	4	8.63	1.06/2	0.00/0	0.50/1	7.00/20
13	1	9.19	0.00/0	0.00/0	0.38/2	8.25/21
	2	7.75	0.63/1	0.00/0	0.00/0	7.00/15
	3	6.63	1.00/2	0.00/0	0.31/1	5.25/20
	4	8.38	0.88/2	0.00/0	0.00/0	7.43/19
14	1	2.88	0.00/0	0.00/0	0.00/0	2.63/13
	2	3.88	0.38/1	0.41/1	0.50/1	3.00/16
	3	2.38	0.00/0	0.00/0	0.44/1	1.88/11
	4	5.38	0.81/2	0.00/0	0.00/0	4.31/23
15	1	3.75	0.38/1	0.00/0	0.00/0	3.19/14
	2	1.75	0.38/1	0.00/0	0.00/0	1.38/9
	3	4.50	1.25/4	0.00/0	0.50/1	2.81/22
	4	2.56	0.50/2	0.00/0	0.00/0	2.06/8

PART I - Damage Study Data (Continued)

Fields	Trial No.*	Sample Weight** (lbs)	Sample No. 1			
			Mechanical Damage (wt./count)			
			SL	ME	SE	UD
16	1	4.94	0.00/0	0.00/0	0.00/0	4.31/16
	2	5.50	1.06/2	0.00/0	0.00/0	4.31/16
	3	5.31	0.56/1	0.00/0	0.00/0	4.50/20
	4	6.56	0.63/1	0.00/0	0.00/0	5.88/28
17	1	6.13	0.69/1	0.00/0	0.00/0	5.31/23
	2	6.06	1.44/4	0.00/0	0.00/0	4.63/16
	3	5.63	1.25/3	0.00/0	0.00/0	4.44/18
	4	5.50	0.63/2	0.00/0	0.00/0	4.75/20
18	1	3.69	0.31/1	0.00/0	0.00/0	3.31/26
	2	4.94	0.19/4	0.00/0	0.00/0	3.81/25
	3	4.94	0.25/1	0.00/0	0.00/0	4.69/22
	4	6.19	0.75/6	0.00/0	0.41/1	5.06/30

PART I

Damage Study Data

Fields	Trial No.*	Sample Weight** (lbs)	Sample No. 2			
			Mechanical Damage (wt./count)			
			SL	ME	SE	UD
1	1	6.00	0.38/1	0.00/0	0.00/0	5.63/13
	2	1.88	0.63/3	0.00/0	0.63/4	0.63/2
	3	4.88	0.56/1	0.00/0	1.31/2	3.00/2
	4	11.75	0.31/1	0.69/1	0.44/1	10.31/34
2	1	2.06	1.13/3	0.00/0	0.00/0	0.69/6
	2	3.50	0.81/3	0.19/1	0.00/0	2.26/14
	3	4.44	1.25/6	0.00/0	0.00/0	2.94/11
	4	4.44	2.81/13	0.00/0	0.31/1	1.06/7
3	1	4.25	0.88/3	0.00/0	0.38/2	2.31/6
	2	6.75	0.56/2	0.00/0	0.00/0	5.63/15
	3	7.25	1.22/4	0.00/0	0.50/2	4.88/15
	4	6.00	0.50/5	0.38/2	0.56/1	3.69/13
4	1	3.00	0.63/3	0.44/1	0.44/1	1.00/2
	2	6.88	1.69/4	0.44/1	0.00/0	4.44/16
	3	5.44	1.00/4	0.31/2	0.69/1	2.88/9
	4	9.38	1.00/2	0.81/1	1.00/2	5.38/14
5	1	7.94	0.81/4	0.00/0	0.00/0	7.00/28
	2	6.13	3.13/5	0.00/0	0.00/0	3.00/8
	3	4.31	0.00/0	0.00/0	0.00/0	4.19/10
	4	9.75	1.63/5	0.00/0	0.38/1	7.13/16
6	1	9.75	3.38/7	0.25/1	0.00/0	5.38/19
	2	4.13	0.00/0	0.00/0	0.00/0	3.56/4
	3	10.38	3.44/10	0.94/1	0.94/2	4.13/15
	4	2.44	1.13/3	0.00/0	0.00/0	1.19/4
7	1	6.63	1.69/4	0.00/0	0.38/1	4.25/10
	2	5.38	1.00/1	0.00/0	0.00/0	1.13/8
	3	6.63	1.94/4	0.00/0	0.44/1	4.00/9
	4	4.25	1.31/5	0.00/0	0.38/1	2.69/7
8	1	9.88	0.88/2	0.69/1	0.38/1	8.16/22
	2	8.06	1.44/3	0.00/0	0.00/0	6.44/18
	3	10.00	1.13/2	0.38/1	0.00/0	8.44/23
	4	6.63	1.63/3	0.69/2	0.00/0	4.63/14

PART I - Damage Study Data (Continued)

Fields	Trial No.*	Sample No. 2 Sample Weight** (lbs)	Mechanical Damage (wt./count) SL	ME	SE	UD
9	1	5.44	0.88/2	0.38/1	0.38/1	4.06/17
	2	8.19	2.06/6	1.50/3	0.63/2	4.13/15
	3	7.38	1.63/4	0.81/1	0.31/1	4.44/15
	4	8.63	1.53/3	0.94/1	0.38/1	5.75/19
10	1	4.94	1.19/3	0.00/0	0.19/1	3.50/11
	2	5.25	0.16/1	0.00/0	0.31/1	4.44/14
	3	5.25	0.75/3	0.00/0	0.19/1	4.25/22
	4	6.31	0.44/2	0.00/0	0.75/2	5.19/14
11	1	4.56	0.38/1	0.00/0	0.25/1	3.88/15
	2	6.25	0.75/2	0.00/0	1.13/3	4.13/15
	3	5.44	0.50/2	0.00/0	0.63/2	4.56/13
	4	6.44	1.38/3	0.00/0	1.81/4	3.22/13
12	1	7.13	1.06/1	0.00/0	0.59/1	5.44/18
	2	6.00	0.69/2	0.00/0	0.19/1	5.13/17
	3	6.94	0.94/1	0.00/0	1.13/3	5.06/17
	4	7.38	0.84/2	0.00/0	0.00/0	6.44/19
13	1	7.94	0.75/2	0.00/0	1.38/4	5.50/17
	2	5.75	0.00/0	0.00/0	0.00/0	5.44/14
	3	7.63	0.00/0	0.00/0	0.75/2	5.38/21
	4	7.13	0.00/0	0.00/0	1.19/2	5.81/24
14	1	1.94	0.38/2	0.00/0	0.00/0	1.44/8
	2	1.19	0.13/1	0.00/0	0.38/1	0.63/6
	3	2.19	0.41/1	0.00/0	0.00/0	1.63/11
	4	3.50	0.44/1	0.00/0	0.25/1	3.19/20
15	1	2.06	0.56/2	0.00/0	0.38/1	1.00/6
	2	1.06	0.25/1	0.00/0	0.00/0	0.69/6
	3	2.69	0.56/2	0.00/0	0.69/3	1.63/7
	4	1.75	0.44/1	0.00/0	0.00/0	1.31/7
16	1	6.75	1.38/3	0.00/0	0.00/0	5.25/20
	2	3.75	0.63/1	0.00/0	0.31/1	3.13/12
	3	7.31	1.25/2	0.00/0	0.38/1	5.63/24
	4	4.19	0.38/1	0.00/0	0.38/1	3.50/17
17	1	5.50	0.88/3	0.00/0	0.00/0	4.75/19
	2	4.75	0.41/1	0.00/0	0.00/0	4.50/21
	3	7.44	1.00/3	0.00/0	0.00/0	6.19/29
	4	6.38	0.38/3	0.00/0	0.00/0	5.00/19
18	1	3.56	0.94/4	0.00/0	0.25/1	2.63/14
	2	3.69	0.94/2	0.19/1	0.00/0	2.50/7
	3	5.75	0.34/1	0.00/0	0.00/0	5.25/24
	4	6.31	0.47/2	0.00/0	1.19/7	4.44/31

PART I

Damage Study Data

Fields	Trial No.*	Sample Weight** (lbs)	Sample No. 3			
			Mechanical Damage (wt./count)			
			SL	ME	SE	UD
1	1	12.88	1.13/2	0.19/1	0.31/1	11.44/29
	2	11.13	2.13/5	0.38/1	1.38/2	6.75/16
	3	14.63	3.00/8	0.13/1	0.50/2	11.00/30
	4	12.56	4.31/8	0.38/1	0.00/0	7.88/22
2	1	6.38	4.13/16	1.13/4	0.38/1	0.63/1
	2	8.50	5.75/16	0.13/1	0.00/0	0.31/2
	3	4.94	4.19/14	0.38/1	0.00/0	0.19/7
	4	6.06	4.38/20	0.00/0	1.06/5	0.44/2
3	1	8.38	4.38/10	2.13/4	1.13/4	0.31/1
	2	6.06	3.44/12	1.38/4	0.31/2	0.44/3
	3	9.06	5.19/17	1.13/5	1.25/3	1.13/5
	4	9.69	6.25/18	1.63/4	0.75/2	0.50/3
4	1	8.75	2.81/7	0.50/2	1.06/4	3.69/15
	2	5.31	2.63/7	0.00/0	0.00/0	2.50/9
	3	7.06	2.63/9	0.38/1	1.63/2	2.00/10
	4	5.25	1.75/4	0.38/1	1.13/3	1.88/8
5	1	6.25	2.25/7	1.19/2	0.56/2	2.13/8
	2	4.94	1.38/5	0.38/1	1.00/2	2.69/9
	3	5.38	2.31/7	0.56/1	0.81/2	1.81/6
	4	5.06	3.00/9	1.00/1	0.31/1	0.94/3
6	1	6.75	3.06/10	1.63/4	0.44/1	1.19/3
	2	6.13	2.63/5	0.00/0	0.38/1	3.13/8
	3	7.69	3.31/11	0.75/2	0.75/1	2.69/10
	4	9.13	4.94/15	1.50/4	0.63/3	1.75/10
7	1	4.81	2.44/7	0.94/2	0.75/3	0.81/3
	2	8.06	2.38/7	1.75/5	3.44/7	0.44/2
	3	8.38	3.94/7	1.38/2	1.63/2	1.19/2
	4	8.06	4.59/6	0.56/1	0.81/1	2.31/3
8	1	6.88	1.78/7	2.00/5	0.78/2	2.88/10
	2	8.00	1.88/5	1.31/3	0.88/2	4.34/13
	3	7.94	2.19/7	1.38/4	0.94/2	4.06/16
	4	8.13	1.81/3	1.06/3	2.88/4	3.13/11
9	1	3.94	0.25/1	1.25/3	1.25/3	1.44/6
	2	5.13	0.81/3	1.81/6	1.56/6	0.38/3
	3	7.06	0.41/1	2.25/7	2.00/7	2.56/12
	4	7.94	2.13/6	1.56/4	1.16/3	3.06/12

PART I - Damage Study Data (Continued)

		Sample No. 3				
		Sample Weight**	Mechanical Damage (wt./count)			
Fields	Trial No.*	(lbs)	SL	ME	SE	UD
	1	6.81	1.38/6	2.25/6	1.13/3	1.94/8
10	2	5.19	1.19/4	0.94/3	2.06/7	1.06/4
	3	6.63	1.38/3	0.00/0	0.44/1	4.94/14
	4	8.31	0.75/3	2.06/6	2.13/7	3.56/14
	1	6.94	0.69/1	2.13/6	0.88/3	3.50/12
11	2	5.50	1.50/2	1.56/3	0.25/1	.56/9
	3	7.31	1.50/3	0.59/1	2.81/6	2.31/12
	4	7.25	0.63/3	0.69/1	1.19/3	5.13/16
	1	6.50	0.50/2	1.88/5	2.06/4	2.19/8
12	2	6.56	0.94/2	1.69/5	1.56/7	2.56/7
	3	6.88	0.75/2	0.25/1	1.94/5	4.06/11
	4	5.25	0.81/2	1.25/4	0.63/2	2.12/9
	1	7.50	0.25/1	0.56/1	1.09/4	5.56/21
13	2	7.06	0.00/0	0.56/2	1.06/3	5.44/16
	3	6.88	1.13/3	0.88/2	1.75/5	3.31/11
	4	8.31	0.38/1	0.81/2	0.63/2	6.75/27
	1	3.63	0.63/2	0.56/2	0.69/3	2.06/9
14	2	4.44	1.13/5	1.69/7	0.50/2	1.56/7
	3	5.25	0.75/3	0.66/2	1.69/3	2.56/11
	4	5.81	1.50/6	0.81/3	0.69/3	3.47/15
	1	8.00	1.88/7	0.94/3	1.50/6	2.81/17
15	2	3.88	0.66/2	0.81/3	0.59/2	2.31/9
	3	4.00	1.13/4	1.06/4	0.63/2	1.94/10
	4	7.69	2.29/9	0.44/2	0.69/7	2.75/15
	1	8.63	3.81/10	0.94/3	2.47/10	2.38/11
16	2	7.88	3.06/9	1.44/4	0.94/2	3.19/13
	3	6.19	1.56/5	0.75/2	1.13/3	3.50/14
	4	6.81	2.38/6	0.38/1	0.38/1	4.44/28
	1	7.13	3.31/7	0.94/2	0.81/3	2.75/10
17	2	6.38	2.63/6	1.00/3	0.88/2	2.63/10
	3	7.56	3.38/9	0.00/0	0.38/1	4.25/14
	4	4.50	2.50/7	0.00/0	0.50/1	1.75/8
	1	7.50	4.19/13	0.38/1	0.94/2	2.69/9
18	2	6.06	2.31/10	1.44/3	1.06/3	1.75/6
	3	5.69	2.44/10	0.50/1	0.94/4	2.31/9
	4	6.63	3.00/10	0.69/2	0.88/5	2.44/11

PART II

Potato Distribution Data

Variety = Norland

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem X (Inches)	Y (Inches)	Z (Inches)
1	6.0	9.9	-2.0	0.0	15.5
			-3.0	3.0	14.0
			-5.0	-2.0	13.0
			-1.0	-4.0	14.0
			4.0	-1.0	13.0
			2.0	0.0	14.5
			-1.0	1.0	14.8
2	6.0	9.4	3.0	0.0	13.5
			-5.0	0.0	12.5
			0.0	-2.5	13.5
			-2.0	-2.0	13.0
			2.0	-1.0	12.5
			-4.0	1.0	13.0
			-3.0	0.0	13.8
			-3.0	-.5	13.5
			-2.0	-3.0	14.0
3	6.0	11.8	0.0	-7.0	16.0
			-1.0	-6.0	15.0
			0.0	-3.5	13.5
			3.0	-3.0	15.5
			3.0	-3.0	16.5
			5.0	-6.0	15.5
			-2.0	-2.0	16.0
			-0.5	-1.5	15.0
			-3.0	6.0	14.5
			-3.0	4.0	13.0
			0.0	6.0	14.5
			6.0	7.0	16.0
			0.0	3.0	14.5
			0.0	-2.0	14.5
			0.0	0.0	13.5
			0.0	0.0	14.5
4	5.0	11.7	-1.0	2.0	15.8
			-1.0	5.0	15.3
			1.0	2.0	15.4
			3.0	-5.0	13.5
			3.0	-5.0	15.8
			0.0	-3.0	16.5
			2.0	-2.0	16.0
			3.0	-1.0	16.3
			6.0	-2.0	15.4

PART II - Potato Distribution Data (Continued)

Variety = Norland

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem X (Inches)	Y (Inches)	Z (Inches)
5	5.0	10.8	-5.0	2.0	15.5
			-1.0	7.0	14.1
			0.0	5.0	12.8
			2.0	4.0	14.6
			-1.0	-1.0	15.3
			-3.0	0.0	14.1
6	5.0	11.1	-4.0	-1.0	16.1
			0.0	-2.0	11.9
			-2.0	-3.0	16.6
			-2.0	-5.0	16.8
			-8.0	-3.0	16.1
			2.0	-1.0	15.7
			3.0	-6.0	16.9
			2.0	1.0	15.9
			0.0	0.0	14.9
			0.0	0.0	17.4
			0.0	0.0	15.9

h = height of hill

H = height of cover plate from top of hill

X = potato co-ordinate across row

Y = potato co-ordinate along row

Z = vertical potato co-ordinate

PART II - Potato Distribution Data (Continued)

Variety = Kennebec

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem X (Inches)	Y (Inches)	Z (Inches)
1	5.8	15.9	-2.0	-10.0	17.0
			-4.0	-4.0	18.0
			8.0	-4.5	17.0
			3.0	5.0	16.9
			1.0	2.0	17.1
			2.0	-1.0	17.5
			-1.0	3.0	17.9
			1.0	1.0	20.2
			-2.5	2.0	21.2
2	5.8	15.9	9.0	-2.0	18.5
			5.0	-1.0	18.7
			6.0	-3.0	18.0
			-4.0	-2.0	18.4
			7.0	3.0	18.6
			-1.0	4.0	16.5
			-8.0	-1.5	17.6
			0.0	-2.0	17.0
3	5.8	15.8	7.0	-2.0	17.8
			5.0	-4.0	17.0
			2.0	-6.0	17.5
			1.0	-7.0	17.5
			3.0	-1.0	18.8
			2.0	-1.0	18.0
4	5.8	13.4	4.0	-3.0	14.4
			4.0	1.0	14.8
5	5.8	11.1	5.0	4.0	14.4
			3.0	0.0	13.9
			7.0	-5.0	14.6
			4.0	-4.0	14.6
			1.0	3.0	15.1
			4.0	-6.0	14.3
			2.0	-7.0	14.5
			0.0	-5.0	14.3
			3.0	-1.5	16.2
			-1.0	-2.5	14.8
6	5.8	10.8	2.0	-6.0	13.3
			1.0	3.0	12.0
			2.0	4.0	14.4
			-2.0	-2.0	12.4
			-4.0	-2.0	12.8
			-2.0	2.0	13.0
			-3.0	6.0	14.6
			-2.0	8.0	14.9

PART II - Potato Distribution Data (Continued)

Variety = Norchip

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem		
			(Inches)	Y (Inches)	Z (Inches)
1	6.0	9.5	-7.0	7.0	13.5
			-2.0	7.0	15.1
			-2.0	1.0	15.7
			-4.0	-3.0	16.0
			-1.0	-5.0	15.1
			2.0	-3.0	13.4
			3.0	4.0	12.8
			0.0	-2.0	15.6
			0.0	0.0	12.3
			0.0	0.0	16.4
			2.0	1.0	13.1
			3.0	1.0	15.9
			6.0	2.0	15.2
2	5.5	8.0	6.0	3.0	14.2
			8.0	-1.0	14.0
			4.0	1.0	14.3
			2.0	-2.0	12.5
			5.0	-2.0	13.9
			7.0	-5.0	13.0
			3.0	-3.0	14.2
			3.0	-4.0	12.9
			6.0	-4.0	14.7
			-3.0	-1.0	11.5
			-3.0	-1.0	13.8
			1.0	-5.0	14.8
			1.0	0.0	14.6
			-7.0	-1.0	15.1
			9.0	-6.0	14.2
			-7.0	-8.0	15.2
			-3.0	-3.0	12.2
			-3.0	-6.0	14.5
			-2.0	-4.0	14.1
			-4.0	-1.0	12.3
			-4.0	-1.0	14.3
			-1.0	-1.0	11.3
			-4.0	0.0	11.4
			-4.0	1.0	13.0
			-1.0	1.0	11.9
			-2.0	3.0	12.9
3	6.0	11.6	3.0	-2.0	12.4
			2.0	-1.0	13.9
			4.0	1.0	14.2
			4.0	1.0	12.4

PART II - Potato Distribution Data (Continued)

Variety = Norchip

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem X (Inches)	Y (Inches)	Z (Inches)
			4.0	3.0	13.3
			3.0	5.0	13.3
			0.0	4.0	13.9
			0.0	3.0	14.5
			-2.0	6.0	12.5
			-1.0	3.0	13.0
			-1.0	3.0	14.3
			-1.0	0.0	14.3
			-0.5	-0.5	12.7
			-3.0	-4.0	13.0
			-7.0	0.0	13.5
4	7.0	9.3	6.0	-1.0	13.1
			3.0	0.5	13.2
			3.0	-8.0	14.8
			2.0	-5.0	15.5
			-4.0	-6.0	13.0
			-2.0	0.0	12.3
			-1.0	2.0	14.2
			-7.0	2.0	14.1
			0.0	-2.5	11.8
			0.0	-2.5	14.1
			0.0	-5.0	13.9
5	7.0	11.4	2.0	7.0	16.9
			2.0	-2.0	16.7
			1.0	-1.0	18.2
			2.0	9.0	17.1
			2.0	5.0	17.8
			-1.0	2.0	15.5
			1.0	4.0	17.9
			-4.0	-1.0	15.0
			-3.0	0.5	15.5
			1.0	3.0	16.1
			1.0	3.0	17.9
			-3.0	1.0	18.0
6	7.0	11.4	7.0	0.0	16.9
			-1.0	2.0	15.2
			1.0	1.0	17.7
			-0.5	-0.5	16.7
			-0.5	-0.5	18.6
			1.0	-2.0	16.8
			2.0	-4.0	16.8
			-2.0	-5.0	15.4
			-1.0	-2.0	15.2
			-1.0	-3.0	17.6

PART II - Potato Distribution Data (Continued)

Variety = Netted Gem

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem X (Inches)	Y (Inches)	Z (Inches)
1	4.8	10.7	3.0	9.0	13.7
			2.0	-5.0	13.6
			0.0	-4.0	13.7
			-2.0	0.0	15.4
			4.0	4.0	14.5
			3.0	7.0	13.0
			-5.0	6.0	12.9
2	5.0	12.4	1.0	2.0	15.0
			0.0	4.0	15.5
			-1.0	-2.0	14.8
			-2.0	-4.0	15.5
			-2.0	3.0	16.0
			-4.0	2.0	16.2
			-2.0	0.0	16.8
			0.0	-1.0	13.9
3	6.0	11.2	10.0	3.0	16.5
			6.0	0.0	13.8
			2.0	2.0	13.6
			5.0	-4.0	13.6
			5.0	0.0	15.5
			4.0	-1.0	14.0
			3.0	-4.0	14.7
			1.0	-2.0	14.6
			-3.0	1.0	15.0
			0.0	0.0	13.6
			0.0	13.0	13.7
4	5.5	10.0	-8.0	8.0	13.4
			-3.0	-3.0	14.8
			0.0	-5.0	15.5
			0.5	-4.0	12.5
			6.0	1.0	13.9
			0.0	-10.0	16.5
5	6.3	12.2	-5.0	-6.0	14.8
			-1.0	-6.0	15.7
			0.0	-4.0	15.4
			0.0	-1.0	14.3
			0.0	2.0	12.9
			0.0	4.0	14.7
			1.0	3.0	15.4
			1.0	1.0	15.5

PART II - Potato Distribution Data (Continued)

Variety = Netted Gem

Sample No.	h (Inches)	H (Inches)	Potato Co-ordinates from Main Stem X (Inches)	Y (Inches)	Z (Inches)
			0.0	-1.0	13.1
			0.0	-1.0	15.6
			-1.0	1.0	15.4
			-1.0	2.0	16.5
			-1.0	1.0	16.6
6	6.8	11.2	-3.0	6.0	14.3
			-3.0	-4.0	14.1
			-2.5	-3.5	12.8
			-2.0	-7.0	15.5
			4.0	5.0	13.6
			5.0	0.0	14.0
			5.0	-2.0	14.4
			3.0	-2.0	14.0
			4.0	-7.0	14.7
			4.0	-9.0	15.1

APPENDIX C

Results of Potato Harvesting Damage
Study in Manitoba 1970

		Damage Classification (Per cent/Av. wt. of Tuber in Pounds)			
Fields	Sample*	Slight	Medium	Serious	Damage Free
	1	8.73/0.43	1.42/0.44	9.42/0.42	80.43/0.42
1	2	13.45/0.31	1.47/0.69	15.99/0.34	69.09/0.35
	3	20.86/0.46	2.23/0.27	4.69/0.44	72.21/0.38
	1	24.99/0.23	6.41/0.19	3.38/0.22	65.21/0.22
2	2	46.02/0.24	1.46/0.19	1.85/0.31	50.67/0.18
	3	80.32/0.28	7.03/0.27	6.02/0.24	6.63/0.22
	1	12.76/0.35	3.27/0.33	8.82/0.52	75.15/0.52
3	2	15.48/0.23	1.85/0.19	7.28/0.29	75.38/0.34
	3	61.24/0.34	20.60/0.37	10.59/0.31	7.57/0.20
	1	16.71/0.27	2.56/0.23	1.19/0.31	79.54/0.31
4	2	20.88/0.33	10.12/0.40	10.97/0.53	58.03/0.33
	3	39.95/0.34	4.83/0.31	14.92/0.42	40.30/0.24
	1	15.59/0.64	4.93/0.44	0.00/0.00	79.48/0.40
5	2	19.82/0.40	0.00/0.00	1.04/0.38	79.14/0.34
	3	40.31/0.32	13.91/0.63	12.04/0.38	33.74/0.29
	1	10.31/0.23	0.00/0.00	0.00/0.00	89.69/0.20
6**	2	30.66/0.40	3.18/0.59	2.49/0.47	63.68/0.34
	3	47.85/0.34	13.20/0.39	7.57/0.37	31.38/0.28
	1	18.39/0.51	0.00/0.00	1.59/0.22	80.03/0.22
7**	2	26.64/0.42	0.00/0.00	5.40/0.40	67.97/0.44
	3	45.75/0.49	16.15/0.46	21.99/0.51	16.11/0.47
	1	12.98/0.42	2.23/0.38	2.39/0.39	82.40/0.39
8	2	15.45/0.51	5.14/0.44	0.94/0.38	78.47/0.36
	3	23.05/0.35	17.62/0.38	16.09/0.55	43.23/0.39
	1	25.45/0.38	9.08/0.31	4.72/0.28	60.75/0.28
9	2	20.16/0.41	11.72/0.60	5.74/0.34	62.37/0.28
	3	14.08/0.33	30.10/0.34	26.60/0.31	29.21/0.23

*1 Before Lifting the Crop
2 At Lifting
3 Potato Truck

Appendix C (Continued)

		Damage Classification (Per cent/Av. wt. of Tuber in Pounds)			
Fields	Sample*	Slight	Medium	Serious	Damage Free
	1	17.56/0.34	0.00/0.00	1.30/0.13	81.14/0.13
10	2	11.21/0.28	0.00/0.00	10.49/0.49	78.30/0.26
	3	18.12/0.29	18.92/0.35	21.91/0.32	41.05/0.29
	1	10.28/0.33	0.00/0.00	1.74/0.38	87.98/0.38
11	2	12.81/0.38	0.00/0.00	15.91/0.38	71.28/0.28
	3	19.35/0.48	21.78/0.45	18.31/0.39	40.57/0.23
	1	8.03/0.46	0.00/0.00	6.74/0.36	85.23/0.36
12	2	12.79/0.59	0.00/0.00	6.83/0.38	80.38/0.31
	3	12.29/0.37	20.79/0.34	23.80/0.34	43.12/0.31
	1	8.52/0.50	0.00/0.00	2.28/0.23	89.20/0.23
13	2	2.46/0.38	0.00/0.00	11.83/0.41	85.71/0.29
	3	5.94/0.35	9.33/0.40	15.43/0.32	69.29/0.28
	1	6.17/0.40	2.39/0.41	7.66/0.47	83.79/0.47
14	2	15.93/0.27	0.00/0.00	9.94/0.31	74.13/0.15
	3	18.90/0.25	18.26/0.27	17.07/0.32	45.78/0.23
	1	19.79/0.25	0.00/0.00	2.74/0.17	77.46/0.17
15	2	25.01/0.26	0.00/0.00	10.89/0.27	64.10/0.17
	3	25.48/0.49	15.29/0.54	14.76/0.31	44.47/0.25
	1	10.12/0.56	0.00/0.00	00.00/0.00	89.88/0.50
16	2	15.44/0.52	0.00/0.00	5.36/0.36	79.19/0.24
	3	32.26/0.36	10.57/0.35	14.48/0.31	42.69/0.23
	1	17.23/0.40	0.00/0.00	0.00/0.00	82.77/0.38
17	2	13.21/0.32	0.00/0.00	0.00/0.00	86.79/0.23
	3	43.51/0.41	6.51/0.39	9.49/0.37	40.49/0.27
	1	7.61/0.13	0.00/0.00	1.65/0.41	90.74/0.41
18	2	16.07/0.30	1.31/0.19	6.51/0.18	76.11/0.19
	3	42.13/0.28	11.13/0.43	13.84/0.27	32.90/0.26

**Farmer used a two-row self-propelled potato combine.

APPENDIX D

PART I

Analysis of Variance as Applied to Damage Study Data

Field No. (i) i=1,18	Harvesting Stages (i,j) j=1,2,3	Replications (i,j,k) k = 1,2,3,4 k=1	k=2	k=3	k=4	$X_{ij.}$	$X_{i..}$
	1	17.46*	10.73	9.37	5.81	43.37	
1	2	0.00	33.33	26.90	9.62	69.85	140.49
	3	3.83	16.54	4.31	3.02	27.70	
	1	27.08	12.11	0.00	0.00	39.19	
2	2	0.00	5.85	0.00	7.42	13.27	104.65
	3	24.08	2.10	7.98	18.03	52.19	
	1	28.26	0.00	11.22	8.90	48.38	
3	2	10.64	0.00	7.58	18.32	36.54	209.70
	3	41.01	30.34	27.36	26.07	124.78	
	1	4.67	4.77	5.58	0.00	15.02	
4	2	35.06	6.70	20.49	22.10	84.35	178.37
	3	19.35	0.00	30.27	29.38	79.00	
	1	0.00	6.60	0.00	13.12	19.72	
5	2	0.00	0.00	0.00	4.16	4.16	127.65
	3	28.55	25.32	24.95	24.95	103.77	
	1	0.00	0.00	0.00	0.00	0.00	
6	2	2.77	0.00	19.87	0.00	22.66	105.75
	3	32.75	6.19	20.00	24.15	83.09	
	1	0.00	6.34	0.00	0.00	6.34	
7	2	6.01	0.00	6.90	8.68	21.59	180.48
	3	34.21	64.79	36.98	16.57	152.55	
	1	9.95	3.95	0.00	4.57	18.47	
8	2	10.58	0.00	3.82	9.93	24.33	177.65
	3	37.37	26.04	27.07	44.37	134.85	
	1	5.06	11.70	28.61	9.83	55.20	
9	2	13.33	25.60	15.58	15.35	69.86	351.88
	3	59.67	73.90	58.86	34.39	226.82	

*Entries in replication column represent the per cent of damaged potatoes (moderately and severely damaged).

PART I (Continued)

Field No. (i) i=1,18	Harvesting Stages(i,j) j=1,2,3	Replications (i,j,k) k = 1,2,3,4 k=1	k=2	k=3	k=4	$X_{ij.}$	$X_{i..}$
	1	0.00	5.20	0.00	0.00	5.2	
10	2	20.24	6.31	3.66	11.76	41.97	210.48
	3	50.37	57.14	6.51	49.29	163.31	
	1	6.97	0.00	0.00	0.00	6.97	
11	2	5.59	18.8	11.07	28.24	63.65	184.2
	3	41.81	46.77	47.16	24.61	113.58	
	1	6.13	4.59	10.38	5.84	26.94	
12	2	8.32	3.16	15.85	0.00	27.33	232.66
	3	59.43	48.58	31.29	39.09	178.39	
	1	4.4	0.00	4.73	0.00	9.13	
13	2	18.09	0.00	12.23	17.00	47.32	155.52
	3	22.12	22.95	37.2	16.8	99.07	
	1	0.00	21.21	18.97	0.00	40.18	
14	2	0.00	33.33	0.00	6.44	39.77	221.26
	3	31.73	44.88	41.52	23.18	141.31	
	1	0.00	0.00	10.96	0.00	10.96	
15	2	19.59	0.00	23.96	0.00	43.55	174.70
	3	34.22	32.04	35.50	18.43	120.19	
	1	0.00	0.00	0.00	0.00	0.00	
16	2	0.00	7.29	5.23	8.92	21.44	121.66
	3	35.52	27.58	27.09	10.03	100.22	
	1	0.00	0.00	0.00	0.00	0.00	
17	2	0.00	0.00	0.00	0.00	0.00	64.01
	3	22.41	26.33	4.74	10.53	64.01	
	1	0.00	0.00	0.00	6.59	6.59	
18	2	6.54	5.23	0.00	19.51	31.28	137.74
	3	16.10	38.11	23.26	22.4	99.87	

Analysis of Variance

Source of Variation	df	S.S.	M.S.S.	F
Fields (1)	(18-1)	$\dfrac{\sum_i X_{i..}^2}{3 \times 4} - C$	S.S./df	(1)/2
Harvesting Stages (2)	18(3-1)	$\dfrac{\sum_i \sum_j X_{ij.}^2}{4} - \dfrac{\Sigma X_{i..}^2}{12}$	S.S./df	(2)/(3)
Repetitions in Stages (3)	18(3)(4-1)	$\sum_i \sum_j \sum_k X_{ijk}^2 - \dfrac{\Sigma\Sigma X_{ij.}}{4}$	S.S./df	
Total	215	$\sum \sum \sum X_{ijk}^2 - C$		

$$C = (\sum_i \sum_j \sum_k X_{ijk})^2/18 \times 3 \times 4$$

Substitution of numerical values in above analysis of variance gives the following:

Analysis of Variance Table

Source of Variation		S.S.	M.S.S.	F
Fields	17	5764.6153	339.095	0.3965
Harvesting Stages	36	30791.7556	855.3265	8.0195**
Repetitions in Stages	162	17171.1982	105.995	
Total	215	53727.5691		

**Significant at one per cent level.

Calculating Average Damage at three Harvesting Stages.

Average per cent damage = Total per cent damage over all fields and replications/No. of fields x No. of replications.

(1) $\overline{X}_1$ = Average per cent damage before lifting = 351.66/72 = 4.8842

(2) $\overline{X}_2$ = Average per cent damage at lifting (soil machine interface) = 662.86/72 = 9.2064

(3) $\overline{X}_3$ = Average per cent damage in the truck (total machine damage) = 2064.7/72 = 28.6764

PART II

Student-Neuman-Keul's Test

$$W_p = q_\alpha \ (p_1 n_2) \ \overline{S}_x$$

$$\overline{S}_x = \sqrt{\frac{105.995}{72}} = 1.21332$$

$$q_{\alpha\ 0.05} \ (p_1 n_2) = 2.77 \quad \text{for } p_1 = 2$$

$$= 3.31 \quad \text{for } p_1 = 3$$

(A) <u>Comparing Harvesting Stages 1 and 2</u>

$$W_p = q\alpha(p_1 n_2) \ \overline{S}_x = 2.77 \times 1.21332 = 3.3609$$

$$|\overline{X}_1 - \overline{X}_2| = 4.3222$$

Since $|\overline{X}_1 - \overline{X}_2|$ is greater than W_p therefore 1 and 2 are significantly different.

(B) <u>Comparing Harvesting Stages 2 and 3</u>

$$W_p = q_\alpha(p_1 n_2) \ \overline{S}_x = 3.31 \times 1.21332 = 4.0160892$$

$$|\overline{X}_2 - \overline{X}_3| = 19.65$$

Since $|\overline{X}_2 - \overline{X}_3|$ is greater than W_p therefore 2 and 3 are significantly different.

(C) From (A) and (B), this can be concluded that 1 and 3 are significantly different.

APPENDIX E

Crop Yield Estimation

Y = yield - cwt/acre

W = sample weight - lbs

Rs = row spacing - inches

YF = yield factor

L = length of row to be dug - feet

Using unit factor

$$Y = \frac{W}{100} \times \frac{12}{Rs} \times \frac{1}{L} \times \frac{66 \times 660}{acre} \quad cwt/acre$$

$$= \frac{W}{Rs \times L} \times \frac{12 \times 66 \times 660}{100}$$

Assuming Rs = 38 inches

$$Y = \frac{W}{L} \times \frac{12 \times 66 \times 660}{38 \times 100} = \frac{66 \times 6.6 \times 1.2}{3.8} = 137.56$$

$$Y = \frac{W \times 137.56}{L}$$

Assuming L = 13.756 $\approx$ 13.76 ft.

Y = W x 10

Y = W x YF by definition of yield factor

YF = 10 for L = 13.76 feet

and Rs = 38 inches.

APPENDIX F

POTATO DISTRIBUTION RESULTS

(Graphically presented in Figures 4.1 - 4.12)

Variety: NORLAND

Horizontal Potato Distribution		Vertical Potato Distribution		Two-dimensional Potato Distribution	
X_i a/	Per cent Found	Z_i a/	Per cent Found	R_i c/	Per cent Found
X_1	39.66	Z_1	1.72	R_1	1.72
X_2	60.34	Z_2	8.62	R_2	5.17
X_3	82.76	Z_3	18.97	R_3	18.97
X_4	87.93	Z_4	48.28	R_4	36.21
X_5	94.83	Z_5	87.93	R_5	58.62
X_6	98.28	Z_6	98.28	R_6	84.48
X_7	98.28	Z_7	100.00	R_7	96.55
X_8	100.00			R_8	98.28
				R_9	98.28
				R_{10}	100.00

a/ Within ± i inches across the row.

b/ Up to i inches deep in hill measured from top of hill to center of gravity of deepest potato.

c/ Within a radius of i-inches with center at intersection of hill profile and main stem.

Variety: KENNEBEC

Horizontal Potato Distribution		Vertical Potato Distribution		Two-dimensional Potato Distribution	
X_i	Per cent Found	Z_i	Per cent Found	R_i	Per cent Found
X_1	23.26	Z_1	4.65	R_1	0.00
X_2	46.51	Z_2	39.53	R_2	6.98
X_3	60.47	Z_3	67.44	R_3	25.58
X_4	76.74	Z_4	90.70	R_4	39.53
X_5	83.72	Z_5	95.35	R_5	65.12
X_6	86.05	Z_6	100.00	R_6	81.40
X_7	93.02			R_7	86.05
X_8	97.67			R_8	93.02
X_9	100.00			R_9	97.67
				R_{10}	100.00

Variety: NORCHIP

Horizontal Potato Distribution		Vertical Potato Distribution		Two-dimensional Potato Distribution	
X_i	Per cent Found	Z_i	Per cent Found	R_i	Per cent Found
X_1	34.38	Z_1	3.45	R_1	0.00
X_2	54.02	Z_2	10.35	R_2	4.60
X_3	71.26	Z_3	19.54	R_3	10.34
X_4	83.91	Z_4	36.78	R_4	19.54
X_5	85.06	Z_5	54.02	R_5	36.78
X_6	89.66	Z_6	70.11	R_6	55.17
X_7	97.70	Z_7	96.55	R_7	77.01
X_8	98.85	Z_8	100.00	R_8	88.51
X_9	100.00			R_9	95.40
				R_{10}	97.70
				R_{11}	100.00

Variety: NETTED GEM

Horizontal Potato Distribution		Vertical Potato Distribution		Two-dimensional Potato Distribution	
X_i	Per cent Found	Z_i	Per cent Found	R_i	Per cent Found
X_1	41.82	Z_1	3.64	R_1	3.64
X_2	54.55	Z_2	7.27	R_2	5.45
X_3	70.91	Z_3	45.45	R_3	21.82
X_4	81.82	Z_4	81.82	R_4	43.64
X_5	92.73	Z_5	94.55	R_5	67.27
X_6	96.36	Z_6	98.18	R_6	90.91
X_7	96.36	Z_7	100.00	R_7	94.55
X_8	98.18			R_8	96.36
X_9	98.18			R_9	98.18
X_{10}	100.00			R_{10}	98.18
				R_{11}	100.00

APPENDIX G

PART I

Analysis of Variance for Potato Distribution Data

A = potato co-ordinate--equal to X for horizontal potato distribution and equal to Z for vertical potato distribution

n = number of potatoes for which measurements were taken.

Analysis of Variance

Source of Variation	df		M.S.S.	F
(1) Among Varieties	(4-1)	$\sum_{i=1}^{4} \left(\frac{X_{i.}}{ni}\right)^2 - C$	S.S./df	(1)/(2)
(2) Within Varieties	$\sum_{i=1}^{4} (n_i - 1)$	$\sum_{i=1}^{4} \sum_{j=1}^{ni} X_{ij}^2 - \sum_{i=1}^{4} \left(\frac{X_{i.}}{ni}\right)^2$	S.S./df	
Total	$\left(\sum_{i=1} n_i\right) - 1$	$\sum_{i=1}^{4} \sum_{j=1}^{ni} X_{ij}^2 - C$		

$$C = \frac{(\Sigma\Sigma\ X_{ij})^2}{\sum_{i=1}^{4} n_i}$$

Substituting numerical values, gives the following tables.

Analysis of Variance Table
(Horizontal Distribution)

Source of Variation	df	S.S.	M.S.S.	F
Among Varieties	3	31.538	10.513	2.257
Within Varieties	239	1113.118	4.657	
Total	242	1144.656		

Analysis of Variance Table
(Vertical Distribution)

Source of Variation	df	S.S.	M.S.S.	F
Among Varieties	3	10.157	3.386	0.254
Within Varieties	239	3182.8538	13.317	
Total	242	3192.9928		

Note:

Both F's are not significant.

PART II

Student-Neuman-Keul's Test

This test was carried out to test individual differences among varieties with regards to horizontal distribution only.

$\overline{X}$ = average measurement in inches along x-axis

$\overline{X}$ (Norland) = 2.147

$\overline{X}$ (Kennebec) = 3.267

$\overline{X}$ (Norchip) = 2.718

$\overline{X}$ (Netted Gems) = 2.436

Arranging all $\overline{X}$ in ascending order,

$\overline{X}$ (Norland), $\overline{X}$ (Netted Gem), $\overline{X}$ (Norchip), $\overline{X}$ (Kennebec)

$n_2 = 238$ ——> error degrees of freedom

P_1 is number of means involved in comparisons

P_1	——>	2	3	4
$q_\alpha(p_1 n_2)$	——>	2.77	3.31	3.63

$$Wp = [q_\alpha (p_1 n_2)] \times S$$

$$S = \sqrt{\text{error mean sum of squares}} \times \sqrt{\frac{1}{2}\left(\frac{1}{R_i} + \frac{1}{R_j}\right)}$$

R_i and R_j, number of measurements of two varieties respectively.

(A) <u>Comparing Norland and Netted Gems</u>

$P_1 = 2$ $R_i = 58$ $R_j = 55$

$q_\alpha\ (P_1 n_2) = 2.77,$ $S = 0.2871$

$Wp = 0.7953,$ $|\overline{X}_i - \overline{X}_j| = 0.289$

Since $|\overline{X}_i - \overline{X}_j|$ is not greater than Wp, therefore Norland and Netted Gems are not significantly different.

(B) <u>Comparing Norland and Norchip</u>

$P_1 = 3$ $R_i = 58$ $R_j = 87$

$q_\alpha\ (P_1 n_2) = 3.31,$ $S = 0.2585$

$Wp = 3.31 \times 0.2585 = 0.85567$

$|\overline{X}_i - \overline{X}_j| = 0.571$

Since $|\overline{X}_i - \overline{X}_j|$ is not greater than Wp, therefore Norland and Norchip are not significantly different.

(C) <u>Comparing Norland and Kennebec</u>

$P = 4$ $R_i = 58$ $R_j = 43$

$q_\alpha\ (P_1 n_2) = 3.63,$ $S = 0.3071$

$Wp = 1.11477$

$|\overline{X}_i - \overline{X}_j| = 1.12$

Since $|\overline{X}_i - \overline{X}_j|$ is greater than Wp, therefore test points out that Norland and Kennebec are significantly different. But it is doubtful that they are actually different, since F-ratio is not significant.

(D) Comparing Netted Gem and Norchip

$P_1 = 2$ $R_i = 55$ $R_j = 87$

$q_\alpha (P_1 n_2) = 2.77$ $S = 0.263$

$Wp = 2.77 \times .263 = 0.7284$

$|\overline{X}_i - \overline{X}_j| = 0.282$

Result: not significantly different.

(E) Comparing Netted Gem and Kennebec

$P_1 = 3$ $R_i = 55$ $R_j = 43$

$q_\alpha (P_1 n_2) = 3.31,$ $S = 0.3109$

$Wp = 1.029$

$|\overline{X}_i - \overline{X}_j| = 0.831$

Result: not significantly different.

(F) Comparing Norchip and Kennebec

$P_1 = 2$ $R_i = 87$ $R_j = 43$

$q_\alpha (P_1 n_2) = 2.77$ $S = 0.2847$

$Wp = 0.7885$

$|\overline{X}_i - \overline{X}_j| = 0.549$

Result: not significantly different.

PART III

Statistical Analysis of Underground Potato Distribution - Using Enumeration Data

Classification: - Horizontal

R_1 ⟶ 1 in. on each side of main stem

R_2 ⟶ 1.1 to 2 in. on positive side and 1.1 to 2 in. on negative and so on.

X^2 - test was only performed on horizontal potato distribution.

Norizontal

Region	Norland	Kennebec	Norchip	Netted Gem	Total ($n_{i.}$)
1	23	10	30	23	86
2	12	10	17	7	46
3	13	6	15	9	43
4	3	7	11	6	27
5	4	3	1	6	14
6	2	1	4	2	9
7	0	3	7	0	10
8	1	2	1	1	5
9	0	1	1	0	2
10	0	0	0	1	1
	58	43	87	55	243

X^2 - Test (for Horizontal)

Using $X^2 = (\sum_j (\sum_i n_{ij}^2/n_i)/n_{.j} - 1)/n_{...}$

Let $\sum_i n_{ij}^2/n_i = A_j$

$A_1 = (23)^2/86 + (12)^2/46 + (13)^2/43 + (3)^2/27 + (4)^2/14 + (2)^2/9 + (1)^2/5 = 15.3324$

$A_2 = (10)^2/86 + (10)^2/46 + (6)^2/43 + (7)^2/27 + (3)^2/14 + 1/9 + 3/10 + 2/5 + 1/2 = 7.9382$

$A_3 = (30)^2/86 + (17)^2/46 + (15)^2/43 + (11)^2/27 + 1/14 + (4)^2/9 + (7)^2/10 + 1/5 + 1/2 = 29.0109$

$A_4 = (23)^2/86 + (7)^2/46 + (9)^2/43 + (6)^2/27 + (6)^2/14 + 4/9 + 1/5 + 1 = 14.6492$

$$B = \frac{15.3324}{58} + \frac{7.9382}{43} + \frac{29.0109}{87} + \frac{14.6492}{55}$$

$$= 0.2644 + 0.1846 + 0.3335 + 0.2663 = 1.0488$$

$X^2 = (0.0488)243$ on 27 df

$= 11.8584$ on 27 df

From Tables

$X^2_{(27)}$ 0.05 = 40.1

Since calculated X^2 is smaller than tabulated X^2-, therefore they are not significant.