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ASSESSMENT AND MONITORING OF POTATO PLANTER PERFORMANCE

by

(C) EDWARD JOHN HAUCK

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(SIGNED) Edward J. Hauck

PERMANENT ADDRESS:

13903 88 Avenue

Edmonton, Alberta

Canada. T5R 4J1

DATED February 9, 1987

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ASSESSMENT AND MONITORING OF POTATO PLANTER PERFORMANCE submitted by EDWARD JOHN HAUCK in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

K. W. Domier
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Supervisor

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Date March 12, 1987

Abstract

The metering aspect of potato planter performance was investigated in a set of experiments designed to determine the nature of pick-type metering mechanism interaction with seed potato pieces. Inconsistent delivery of seed pieces was identified as the primary factor behind the non-uniform planting patterns that have been identified with suppressed yields and inferior crop quality. Seed piece size and shape were determined to be critical factors in planter performance and seed piece yield potential.

In order to characterize the nature of pick-type planter metering performance, a laboratory experiment was conducted to study the effect of metering rate, and seed piece shape and size in relation to metering errors. Metering rates of 3, 6, and 9 plants/s were studied in combination with 45 g and 60 g seed pieces having 1, 2, or 3 cut surfaces. Higher metering rates were found to significantly decrease the occurrence of metering errors in the pick-type planter studied. Compatibility between seed material and the pick-type metering mechanism was also affected by seed shape and size. Blocky 3-cut pieces resulted in fewer metering errors when compared to the more rounded 2-cut and 1-cut pieces. Whole seed and 60 g seed pieces resulted in poor metering performance at metering rates below 6 plants/s. Consecutive metering error distributions are presented, for the performance factors studied, to facilitate the assessment of potato yields as

affected by planting patterns.

As a further step to understanding and improving potato planter performance, the design and development of a planter monitoring system was undertaken. The M6809 microprocessor-controlled potato planter monitor, with 2K of ROM and 2K of RAM, successfully employed a dual-sensor, event-triggered system to detect the occurrence of metering errors. Performance feedback to the operator included; immediate visual indication of metering errors for each planter row; intermittent visual display of performance statistics for each row; visual indication of drive train and sensor malfunction and audio indication of defective metering elements. The monitoring system performed to expectations on a potato planter simulation unit. Sensor positioning was determined to be critical for reliable performance.

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Table of Contents

List of Tables

List of Figures

Figure Page

1. INTRODUCTION

The Andes region of Peru and Bolivia between altitudes of 1,200 and 1,800 m is thought to be the potato's native home. History's first record of the potato, *Solanum tuberosum*, coincides with the Spanish conquistadors presence in Peru around 1524. The potato was first introduced to Spain somewhere between 1565 and 1580 and from there spread throughout the European continent reaching England by 1586. In the years spanning 1650 to 1840 the potato became a vital part of the Northern European diet, a fact brought to bear when the Irish potato famine struck during the 1840's. The first recorded evidence of the potato entering Canada was in 1623 at Port Royal, Nova Scotia where an English trading ship presented a barrel of potatoes to Acadian settlers (Thornton and Sieczka 1980). Since that time, potato production has flourished on Canadian soil.

On a world scale, potato production is increasing rapidly in the tropics and sub-tropics and is declining gradually in temperate zones (van der Zaag and Horton 1983). *Per capita* potato production estimates indicate that Eastern Europe (including Russia) is the largest consuming region but, unlike other regions, much of their crop is used as fodder. World consumption patterns indicate that 45 percent of the potato crop is utilized for human consumption, 31 percent as feed stock, 14 percent as seed, and 2 percent for starch (van der Zaag and Horton 1983).

Five year averages of Agriculture Canada (1985) statistics between 1980 and 1984 indicate that the total area under potato production in Canada is approximately 112,169 ha with an average yield of 26.2 t/ha. The yearly production of 2.9 million tonnes of potatoes has an estimated farm value of 306.1 million dollars. Approximately 78.2 percent of Canada's potato production takes place east of Manitoba with Prince Edward Island accounting for 28.6 percent of the national total. Alberta produces only 7.3 percent of the national total but has the third highest yield per unit area (26.6 t/ha).

The potato produces more edible energy and protein per unit area than most other crops and has a high level of daily energy and protein production (van der Zaag 1976). This high energy output is coupled with a very large energy input requirement that is exceeded only by that of irrigated rice. Today's production methods involve complex and highly specialized activities that have evolved over many years. Improvements in production practices have occurred in two ways: through reduction of production costs per unit area while maintaining yield, or by increasing yield without increasing production costs per unit area. Early potato research centered around cultivar trials, plant nutrition, disease-free seed production and the effect of spatial relationships on yield. In the 1950's the demand for processed potato products, such as French fries and chips (crisps), began to emerge and producers were encouraged to adopt market-specific production practices. Plant density concepts became more significant as grower desire for higher yields and consumer demand for product quality grew. Three factors of note in Glotzbach's (1973) assessment of European production trends between 1960 and 1970 during which time yields rose and area in production decreased were: changes in the production methods particularly in the control of weeds and potato blight by chemicals; the use of improved varieties and the use of high quality seed.

Aside from harvesting, stand establishment is the most expensive production operation for many crops. This is especially true where individual seeds must be isolated and placed at regular intervals (Harriott 1970). Since the late 1960's, potato planter performance studies have concentrated on improving irregular planting patterns and the rate of seed delivery as part of an overall desire to improve utilization of the agricultural resource base. As production methods intensified, the availability of agricultural labour and the ability to maintain a high work rate became increasingly important. To meet these demands, planter designs shifted from slow-speed, hand-fed planters to high-speed automatic units.

Plant stand surveys in the late 1960's (Andrew 1968) identified poor planter performance, as typified by inconsistent delivery of seed and irregular planting patterns, to be a major stumbling block for yield improvement. As the relationships between crop and planter performance became clearer, researchers began to investigate how properties of seed pieces affected yield from both an agronomic and planting operations point of view. Andrew and Domier (1978) believed the quality and yield of potato could be improved if relationships between potato seed, seed pieces, and planting techniques were better understood. Jarvis (1978) advocated that "any attempt to improve yield or otherwise increase the efficiency of the production process must be made with the requirements and limitations of mechanized systems in mind."

In light of the current understanding of potato planting operations, three objectives were set for this project:

1. To review planting parameters significant in establishing uniform and desired planting densities and to assess the planting density relationship to yield
2. To investigate the effect that metering rate, seed piece size and seed piece shape have on pick-type planter performance, and
3. To design a planter monitoring and data acquisition system capable of providing performance feedback to operators and for better evaluation of planting operations.

2. LITERATURE REVIEW

2.1 Seed Potatoes

Unlike many other vegetable crops, potato crops are usually established by vegetative propagation. Therefore, seed potatoes refer to the flesh of the previous generation. Due to the widely held preference for planting seed potatoes rather than potato seed, or true seed, the term seed will be considered synonymous to seed potato. One of the main reasons for not seeding true seed centers around the potato's diverse genetic constitution which represents a combination of 160 wild species and 20 cultivated species (Thornton and Sieczka 1980). No farmer can afford the uncertainty associated with such diversity on today's markets.

Next to the Netherlands, Canada is the largest seed potato exporter in the world with a distribution network extending to more than fifteen countries (Cameron 1984). Canada's cold winter climate offers some control over the spread of insects and diseases. Long-warm summer days and short-cool nights offer ideal conditions for high quality seed crops. The Canadian seed production system has six controlled and inspected tiers starting with pre-Elite I and II through to Elite I, II and III to Foundation, Certified, and ending with table grades (Agriculture Canada 1985). Of 65 licensed cultivars listed by Agriculture Canada (1985), Russet Burbank (formerly Netted Gem) is by far the most popular. Production estimates for 1984 indicate that Russet Burbank accounted for 37 percent of Canadian-grown seed. Developed in 1872 by Luther Burbank, Russet Burbank makes outstanding chips, is the standard for French-frying, bakes well, boils well, stores well, and is an all-time favorite. It is not surprising therefore to find a large proportion of North American potato research to be centered around Russet Burbank.

Seed potatoes are often the single highest input cost for potato producers. In South America and tropical Africa, seed potatoes represent 20 to 40 percent of production costs, in Asia, 30 to 55 percent and central America, 50 percent. European and North American producers spend approximately 20 percent of input costs on seed, 8 to 16 percent on labour, and 66 percent for other agricultural inputs according to van der Zaag and Horton (1983). Allen's (1978) estimates of seed costs in England are slightly higher at 30 to 50 percent of total growing costs. Seed quality is therefore a prime consideration in the production cycle. Aside from being disease free, quality parameters for seed lots include their physiological age and size distribution (Svensson 1977; Lidgett 1983).

The long-standing debate on the relative merits of planting whole seed *versus* cut seed originates from fundamental differences in North American and European production systems. To many European potato growers, the thought of cutting whole seed seems outrageous. The major criticism of cutting seed is the potential for spreading disease by means of contact with a contaminated cutting mechanism. Problems associated with seed cutting have been overlooked in light of the two major reasons for cutting seed.

Firstly, the majority of North American potatoes are grown on lighter soils (sandy loams, silt loams) that warm up rapidly in spring and have good drainage properties. Wetter, European soil conditions are more likely to cause cut seed to decay prematurely. The second reason has to do with the primitive state of the North American seed industry.

Canadian seed industry standards apply to all provinces whereas United States standards are set in each state. Although Canada is noted for quality seed, no designated seed producing areas are defined and control over the supply of seed is nonexistent. This implies two things to the seed grower: 1) the crop might not meet seed standards and, 2) if it does, it might be surplus to seed requirements (Rowberry and Howells 1979).

In both cases the most appealing alternative is to dispose of the crop as table-stock and this requires a minimum size of approximately 110 g. Seed of this size is too large to plant and must be cut into two, four or six pieces using a mechanical seed cutter. Rowberry and Howells (1979) concluded that given these conditions it seemed highly unlikely that North American producers would shift towards planting whole seed.

Molnar (1978) argued in favor of planting whole seed *versus* cut seed. His findings indicated whole seed had a greater total and marketable yield compared with cut seed of the same weight class. Total yield refers to the total harvested yield whereas marketable yield is the portion of total yield that falls within the standards set for different grades of marketable potatoes. The increased production of smaller potatoes was seen as advantageous, especially for seed production, even though this would necessitate alterations in planting practices, such as installing smaller chains on potato harvesters and slowing down the harvesting operation. Andrew and Silva (1983) demonstrated that cut end pieces from whole Russet Burbank potatoes had a marketable yield superior to whole seed tubers. Rempel's (1978) report agrees with this trend. Although Molnar (1978) predicted a significant shift from cut seed to whole seed on the Canadian prairies, the change, if any, has been slow to emerge.

The attention given to the description of seed material in planter performance studies ranges from nonexistent to excellent. Studies with poor or inadequate descriptions of seed make comparisons difficult. Unfortunately this aspect of planter performance has fallen victim to lack of experimental standards.

Svensson (1973) argued that productivity of potato seed would be improved by encouraging homogeneity within seed lots. Similarly, Thornton *et al.* (1983) suggested uniformity within seed lots would allow planters to perform more consistently.

2.2 Potato Growth Parameters

The complex nature of potato growth has been investigated from many angles with the objective of identifying significant growth parameters and their relationship to tuber yield. It is not the author's intention to detail all growth relationships as they are now understood. Rather, in pursuit of a more complete understanding of planter performance, an appreciation of the potato's agronomic relationships is necessary to realize the extent to which the planting process predisposes production potential.

A brief examination of potato morphology and anatomy is necessary to appreciate production relationships. The potato tuber is an underground stem that contains all the characteristics of a normal stem. Potato seed tubers possess a number of buds, or potential growing points, that are grouped together in eyes that tend to be concentrated at the apical end of the tuber (furthest from the seed). The buds at the apical end of a tuber exert apical dominance and normally sprout first at the end of dormancy. These buds are often referred to as the apical complex. Apical dominance is altered when a seed tuber is cut into pieces. The apical complex no longer exerts control over the whole tuber and this encourages sprout development from all pieces. Cut seed therefore has more main stems per unit weight than whole seed. Thornton and Sieczka (1980) suggest main stems from cut seed pieces tend to have a more uniform rate of emergence.

The number of buds that develop into stems depends also on the size and condition of the parent tuber (Allen 1978). Individual stems rely on the parent tuber to sustain growth for some time after emergence. Once stems become established, competitive interference for growing space and agronomic resources takes over.

Silva and Andrew (1985) point out the difficulty in achieving uniform potato crops. Up to 14-fold differences in tuber yield per hill were observed by these authors. Control over planting density has proven critical for establishing high yielding potato crops.

2.2.1 Population Density

Planting density can be manipulated by altering row or in-row spacing, seed piece size or shape, or seed conditioning. Therefore, the unit of density appropriate for describing the potato's yield response needs to be established. The most useful measures of planting density from Allen's (1978) perspective were the number of main stems/ha and weight of seed/ha. Iritani *et al.* (1983) considered main stems per unit area to be of limited value as a measure of density unless seed rate was also stated.

2.2.1.1 Seed Rate

Seed rate (t/ha) is the weight of seed planted per unit area and is equivalent to the number of tubers planted multiplied by the average seed piece weight. This is the unit of density most familiar to growers and has been used as the density scale in many existing density experiments (Allen 1978). Boyd and Lessels (1954) demonstrated how higher seeding rate increased yield. Their results also revealed distinct yield response curves for different sized seed grown in plots with identical seed rates.

A traditional method of assessing potato crops is the plant stand survey which compares the actual number of plants to the intended number of plants within a sample area. The resulting ratio, expressed as a percentage, is termed the plant stand. A plant stand survey conducted by Andrew (1968) over two years on 26 Alberta farms revealed plant stands ranging from 37 to 93 percent with an average of 74 percent. Further analysis of Andrew's 1968 stand survey was presented by Andrew (1971) and revealed that 60 percent of the factors responsible for reduced plant stands were attributed to missing seed pieces. An additional 19 percent of factors associated with poor plant stands fell into the wrong spacing or misplaced piece category. James *et al.* (1975) used aerial photography to assess plant stands in New Brunswick and found an average of 32 percent misses. Of the 1000 misses investigated, 88 percent were attributed to missing seed. Sieczka *et al.*'s (1986) three-year plant stand study again confirmed the failure to deliver seed as the major reason for missing hills and reported the average plant stand in New York State to be 83 percent. These studies appear to indicate that seed rates are substantially less than intended.

2.2.1.2 Main Stem Density

Holliday (1960) suggested that the main stem be considered the true unit of potato plant populations. A main stem was defined by Krijthe (1955) as a stem growing directly from the seed tuber. A positive relationship between the number of main stems per unit area of soil surface and yield was noted by Reestman and De Wit (1959). Another interesting observation from this study occurred at wide plant spacings where yield increased with the number of main stems per seed tuber and the total potato skin surface area. Results indicated a linear relationship existed between number of main stems per tuber and the tuber skin surface area. Both Bleasdale (1965) and Holliday (1960) claimed the stem number per seed piece was directly proportional to the number of eyes per seed piece and not related simply to skin surface area as suggested by Reestman and De Wit (1959). Wurr (1974) also reported a linear relationship between number of main stems per seed tuber and the number of sprouts before planting.

Allen and Wurr (1973) discussed methods of recording main stem densities in growing crops and conclude that differences between above-ground stems (includes auxiliary stems) and main stem counts were very small and unlikely to affect the relationship between yield and main stem density. A study by Iritani *et al.* (1983) confirmed this relationship.

Bleasdale (1965) claimed that the number of main stems per unit area influenced potato size distribution. Main stem densities from different sized seed tubers showed a continuous relationship for both total and graded yield whereas seed rates from different sized seed produced distinct yield response curves.

Wurr (1974) established a relationship between graded yield and main stem density. As main stem density increased, the total number of tubers was found to increase but the number of tubers per main stem, and the average tuber size, decreased due to greater inter-stem competition. The number of main stems produced by each seed tuber was found to be cultivar-dependent. Wurr, therefore, asserted that the larger the grade of potatoes over which yield is considered, the lower the main stem population required to give maximum yield in that grade. However, Lynch and Rowberry (1977a) reported that low main stem densities resulted in a higher proportion of deformed tubers.

Lynch and Rowberry (1977a) studied two reciprocal polynomial models for predicting main stem density/yield relationships over a wide range of densities (1.8-20 plants/m^2). The Bleasdale and Thompson (1966) model

$$y^{-\theta} = \alpha + \beta\rho \qquad \ldots (2.1)$$

where y = yield/plant
ρ = stems/m^2
α, β, θ = fitted parameters

appeared to give the most reasonable representation of the main stem density/yield relationship. Parameters α and β were associated with individual seed tuber sizes. Lynch and Rowberry (1977a) demonstrated that seed size did not influence the α and β parameters in cut and whole seed lots and, thus, they concluded that yield is a direct function of main stem density. Holliday (1960) identified the existence of an asymptotic relationship between the main stem density and total yield, and a parabolic relationship between marketable yield and main stem density. These findings were verified by Lynch and Rowberry (1977a) and are illustrated in Figure 2.1. The θ parameter in the Bleasdale and Thompson model was thought to characterize the

The title of Figure 2.1 is "Predicted yield/population density response curves for total and marketable yield in Russet Burbank (Lynch and Rowberry, 1977a)". This figure has been removed because of the unavailability of copyright permission. — (Page 15) relationship between marketable and total yield since it represented a ratio of the weight of plant parts to the weight of the whole plant relative to changes in planting density. A value of one for θ represented the total yield response whereas a θ value of 0.5 was associated with the marketable response. The marketable yield response for growing conditions on the University of Guelph's experimental farm, as defined by Lynch and Rowberry (1977a), was 8.1 main stems/m^2 (Figure 2.1). Shotton (1976) also presented a marketable yield response curve that conformed to the Bleasdale and Thompson (1966) model.

Wurr and Morris (1979) found small tubers gave greater main stem densities per weight of tubers planted but the resulting marketable yield was not distinguished from total yield. However, they pointed out that the number of main stems produced from identical seed varies in different growing areas and suggested that causes of variation of main stem number per seed tuber be given a high research priority. Lynch and Rowberry (1977b) suggested that high planting densities reduced the rate of tuber growth due to increased intra-hill competition for available mineral and carbon assimilates. A growth analysis study by Collins (1977) found that, in plants with identical spacing, the growth rate of tubers from plants with two and four main stems were higher than those of single main stem plants. The resulting number of main stems and the average tuber weight proved to be higher for plants with four main stems.

Jarvis and Shotton (1971) realized that theoretical considerations of main stem density were of limited use unless the actual number of main stems produced in the field could be accurately predicted.

2.2.1.3 Seed Conditioning

Manipulation of seed tuber behavior can influence both the quantity and quality of yields. The term physiological age is often associated with seed conditioning and has been defined as "the physiological state of a tuber at any given time" (Iritani and Thornton 1984). Seed material is living plant tissue and, therefore, ages with time. The physiological age of seed potatoes influences emergence, main stem number, growth rate, maturity, tuber size and ultimately, crop yield (Knowles *et al.* 1985). Although the relationship between physiological age and main stem density is recognized, the lack of a precise definition and criteria for measurement make this concept difficult to quantify. The aging factor used by Fishman and Talpaz (1984) and Fishman *et al.* (1985) in their potato growth model was derived from commercial field data but showed considerable variation from crop to crop. A possible explanation for inconsistent derivation of the aging factor was attributed to its sensitivity to cultivation practices.

Iritani and Thornton (1984) suggest that the rate of aging depends on the growing environment of seed, storage environment, and field conditions during germination. Iritani *et al.* (1983) found the number of main stems per seed piece increased with higher storage and germination temperatures and with later planting dates. Knowles *et al.* (1985) reported that apical dominance, shoot vigor, percent plant stand, and total tuber yield all declined as seed tubers progressed in age past five months.

In Europe, pre-sprouted seed often is used in Europe to encourage early crop emergence. Experiments conducted by Shotton (1973) demonstrated a yield increase of 3.5 to 5 t/ha using pre-sprouted seed. Sprout damage is thus considered an important planter performance parameter in Europe.

Chemical applications to seed material can be used to augment or suppress the number of main stems per seed. Applications of napthalene acidic acid (NAA) at 100 mg/L to eight and twenty month old seed tubers was reported to increase yields by 8 and 11 t/ha respectively (Knowles *et al.* 1985). NAA applications to younger seed increased yield of larger tubers by reducing the number of shoots per tuber. Holmes *et al.* (1970) studied the effect of growth regulators on apical dominance and found that treating seed with gibberelic acid increased yield of seed-sized tubers by up to 70 percent due to an increased main stem number. Slomnycki and Rylski (1964) stated gibberelic acid affects whole and cut seed differently because gibberelic acid uptake through skin occurs at a much lower rate than through exposed flesh.

2.2.1.4 Seed Size

Many early potato experiments were concerned with the growth response of different seed tuber sizes. Recent seed-size research has focussed on the effect that seed mass per main stem has on graded yields. The degree of seed size variability in commercial planting operations and the limitations of seed cutters have led some extension programs to focus on the value of reducing size variability (Schotzko *et al.* 1984).

Würr (1974) and Lynch and Rowberry (1977a) describe the relationship whereby larger seed pieces give a greater number of main stems per seed piece. Iritani *et al.* (1972) studied the relationship of yield to seed size, spacing, and main stem numbers using Russet Burbank potatoes. Identical main stem densities from different seed size spacing combinations were found to give variable proportions of U.S. No. 1 potatoes (112 g and over) and undersized potatoes. Larger seed spaced further apart averaged fewer main stems/unit area but produced a high marketable yield, superior plant stands and larger sized plants. A highly positive correlation (0.98) was established between weight of seed piece/main stem and total yield. The yield of different tuber grades as influenced by main stem number per seed piece (Figure 2.2) was reaffirmed by subsequent research (Iritani *et al.* 1983). Entz and LaCroix (1984) also found that crops grown from larger seed pieces with wide plant spacing had a higher marketable yield.

The initial rate of plant growth depends on the size of the seed piece and the rate at which the seed piece substrate is utilized (Milthorpe and Moorby 1979). In a growth analysis experiment, Dawes *et al.* (1983) showed that, once planted, seed piece weight decreased linearly with time reaching a 2 g residual mass 30 to 40 days later. Davies (1984) studied seed piece reserves as a limiting factor in potato sprout growth. His results indicated that, as the number of sprouts per seed tuber increased, the dry weight per sprout decreased due to increased intersprout competition. Wiersema and Cabello (1986) conducted research on comparative performance of different sized seed tubers. Increasing seed tuber weight decreased the time required for 90 percent emergence, increased the number of main stems per plant, increased the number of tubers per plant but decreased tubers per main stem, and increased total yields. Rowell *et al.* (1986) reported that use of 40-g to 60-g tubers resulted in

The title of Figure 2.2 is "Effect of main stem number per seed piece on yield of different sizes of Russet Burbank (Iritani and Thornton, 1984)." This figure has been removed because of the unavailability of copyright permission.

(Page 21)

yields 50 percent better than true potato seed possibly due to differences in early growth and emergence.

A seed piece survey by Andrew and Silva (1983) presented a range of average seed piece weights for different types of seed pieces found in seed lots on Alberta farms. For Russet Burbank, seed with one cut surface had a weight distribution between 34.1 and 66.0 g, seed with two cut surfaces were between 39.4 and 80.9 g, and seed having three cut surfaces fell between 41.8 and 90.3 g. A seed piece survey conducted by Schotzko *et al.* (1982) in Washington State found 15.5 percent of pieces weighed less than 28 g. The recommended seed piece size for Alberta conditions is 42 to 56 g (Andrew *et al.* (1976). The importance of defining seed piece size distribution rather than average seed size was stressed by Schotzko *et al.* (1984).

2.2.1.5 Seed Shape

The practice of cutting seed potatoes dissects the spherical-to elliptical-shaped whole tuber into a number of more blocky shaped seed pieces. As the size of the seed tuber increases, the number of seed pieces/tuber increases if an average seed piece size is maintained. However, the average skin surface area per piece decreases (Pitts and Hyde 1985).

Jarvis *et al.* (1976) concluded that spacing irregularity is best defined by the coefficient of variation (CV), consequently the CV is the most often used planter performance statistic. As defined by Steel and Torrie (1980) in equation 2.2, the CV represents a quantity that provides a relative measure of variation independent of the unit of measurement.

$$CV = \frac{s}{\bar{X}} 100 \qquad \ldots (2.2)$$

where CV = coefficient of variation
s = sample variation
$\bar{X}$ = sample mean

Andrew and Silva (1983) investigated the influence of seed portion on main stem number. The term portion referred to place of origin on the parent tuber and, by implication, the number of cut surfaces or shape of seed piece. With Russet Burbank potatoes from three experimental sites, the average number of main stems on 1-cut (end) pieces was 3.3 compared with 2.4 main stems for 3-cut pieces. The coefficient of variation (CV) and plant stand were 52.5 percent and 66.7 percent respectively for 3-cut pieces compared to 33.0 percent and 95.0 percent for 1-cut pieces. These statistics are especially relevant considering that production costs for low yielding and high yielding hills were similar (Andrew *et al.* 1983). A cutting index developed by Silva and Andrew (1984) included a factor which diminished seed lot quality as the number of cut surfaces increased. Andrew *et al.* (1983) indicated that a greater proportion of high-yielding pieces could be achieved if more attention was given to adjustment of cutting equipment. Cutting related aspects of seed shape are discussed in section 3.3.2.

2.2.1.6 Planting Pattern

Row and plant spacings are chosen in light of many growth-influenceing factors. The ideal planting pattern would encourage vigorous and uniform crop development by providing the spatial arrangement of plants most suited for optimal utilization of agricultural inputs. However, defining and achieving the ideal planting pattern is indeed a difficult task.

Traditionally, row spacing was chosen for convenience and compatibility with the planter's power source. Row widths of 700 mm were used with horse powered cultivation but modern cultivation methods require 760 to 910 mm row spacing (Jarvis and Shotton 1972). Jarvis (1972) compared 760 and 910 mm row spacing and found total yields to be approximately equal but marketable yield was slightly higher at 910 mm spacing due to less wastage from tuber greening. With 910 mm rows, harvesting work rates improved by 16.7 percent and slightly lower levels of tuber damage were recorded. North and Proctor (1973) noted also that wider row spacing saved time during planting and harvesting operations and required lower depth of tilth to form the final ridge.

Choice of plant spacing is usually considered in conjunction with other population density parameters. Recommended in-row plant spacing in Alberta is 230 to 460 mm with wider spacing being more suitable where fertility and/or moisture are limiting factors (Andrew *et al.* (1976). Wilson (1970) investigated plant spacings between 300 and 510 mm in Maine and found total yield decreased as spacing increased. Marketable yield remained relatively constant due to an increase in tuber size and a decrease in tuber number.

Two contributing factors to irregular seed placement are failure to deliver seed, and inaccurate placement of seed. The discussion in section 2.2.1.1 established the extent of missing seed pieces in commercial crops. Discussion under section 2.6.1 examines the causes of irregular seed placement. This section considers the impact of irregular seed placement on yield.

Blodgett (1941) studied the reduction in crop yield due to diseased or missing plants. He established that plants adjacent to gaps, caused by missing seed, exerted a yield compensation effect. In a simulated gap study reported by Andrew *et al.* (1970) and Preston (1971), total and No. 1 yields from plants adjacent to as many as three consecutive gaps were progressively greater. No additional compensation was observed for 4, 5, or 6 consecutive gaps. Thus, yield reduction due to missing plants was not found to be proportional to the percentage of plant stand loss. Yield compensation was a result of increased tuber size, not tuber number. This was evident as total and marketable yields per unit area were lower when the number of consecutive gaps was increased. However the yield of No. 1 potatoes increased slightly with 1 or 2 gaps and then decreased gradually up to 6 gaps. James *et al.* (1973) and James *et al.* (1975) assessed yield reduction attributed to missing plants by examining losses due to reduced plant stands. The 1973 study concluded that 90, 80, and 70 percent plant stands in New Brunswick crops resulted in 0, 5.6, and 11.1 percent reduction in yield respectively.

Jarvis *et al.* (1976) investigated differences in total and marketable yields attributed to spacing irregularity at CVs of 0, 20, 40 and 60 percent, at three different population densities. Total yield decreased and marketable yield fell by 1.7 t/ha when the CV was increased from 0 to 60 percent. As the CV increased so did the proportion of large tubers. Although yield depressions were not large, they were thought to be economically significant. Pascal *et al.* (1977) and Entz and LaCroix (1984) disagreed, stating that a CV as high as 75 percent did not reduce yield.

Some sites in Robertson and Pascal's (1974) study suggested irregular planting patterns may even be beneficial to yield. Davies (1954) and Boyd and Lessells (1954) demonstrated irregular spacing had a negative effect on yield only at very wide mean spacings while Sieczka *et al.* (1986) stated that non-uniform distribution of seed depresses yield only when the CV exceeds 100 percent.

Bleasdale and Thompson (1966) studied the impact of one, two and three plants in the same hill and concluded that seed clumping had little effect on yield.

Therefore, non-uniform planting patterns appear to have the most significant impact when planters produce a consistent pattern of consecutive planting errors. This reduces both effective planting rate and the compensation effect of plants adjacent to misses. Hirst *et al*, (1973) and James *et al.* (1975) pointed out the importance of defining a frequency distribution for consecutive misses since yield reduction is a function of the frequency in each consecutive miss class.

2.2.2 Economic Assessment of Growth Parameters.

Schotzko *et al.*'s (1982) review of the economics of seed size and spacing assessed the value of attainable yield, as defined by van der Zaag (1984), lost due to non-uniform planting patterns on Washignton State potato farms at $400/ha. Using Alberta Agriculture's (1982) economic assessment of fresh potato production, this represents an increase in the return to management of 59 percent.

Sharpe and Dent (1968) studied the economics of planting density. The planting density for optimum economic returns occurred at the point where the cost of establishing a main stem and the marginal value product equalled one another. Costs per main stem are related to the price of seed and the average number of main stems per seed piece which, in turn, depends on the weight distribution of whole seed tubers, seed conditioning, and cutting. Schotzko *et al.* (1984) discussed the economic impact of Russet Burbank seed size and spacing using a typical processor contract. Their economic assessment of yield proceeded in much the same manner as Sharpe and Dent's (1968) analysis.

Jarvis *et al.* (1976) pointed out that small variations in main stem densities which produce maximum yields have little effect on marketable yield due to the flat-topped nature of the marketable yield response curve (Figure 2.3, point A.) However, the ability to compensate for small variations in main stem density is more sensitive at a lower density which defines the point of maximum economic returns (Figure 2.3, point B). This case becomes even more critical if the established main stem density is less than intended (Figure 2.3, point C), as appears to be the case on many North American potato farms.

The title of Figure 2.3 is "Economic assessment of the marketable yield response curve (Jarvis et al, 1976". This figure has been removed because of the unavailability of copyright permission. (Page 29)

2.3 Seed Handling

The degree of variability in seed size and shape together with the dynamic nature of interactions between seed and both planter and growing environment, make seed piece uniformity a primary objective of the cutting process (Thornton *et al.* 1983). Mass production of seed pieces can be viewed as two separate operations: the grading of whole tubers according to size, and the cutting of each size in an appropriate manner.

2.3.1 Grading

Potatoes are often graded on potato cutters to facilitate the cutting of seed tubers according to size. Grading is also used to separate potatoes into the market grades established by processors and marketing organizations. The potato's vulnerability to damage and its diversity in size and shape impose a strict set of demands on the grading process.

Most on-farm graders and potato cutters have a series of parallel rollers with variable apertures capable of separating tubers into small, medium or large sizes. The major problem with roll sizers is that sizing is done by the smaller tuber dimension rather than the larger one (Pitts and Hyde 1985). As the proportion of large tubers increases, the load factor on the cutter's sizing rollers also increases. This reduces the efficiency of separation and increases the amount of tuber damage (Klenin *et al.* 1985).

The maximum feed rate for roller graders was given by Klenin *et al.* as 3.0 to 5.3 kg/s per metre of width. Grader capacity was defined as

$$q = 3.6\ qo\ B \qquad \ldots (2.3)$$

where q = capacity of the grader (t/h)
qo = maximum feed rate (kg/s·m)
B = width of the grading surface (m)

Zhao *et al.* (1986) stressed the importance of sizer roller spacings for effective separation of seed tubers. A simulation model designed to study the effects of different cut widths and roller spacings illustrated the sensitive nature of sizer roller adjustments. For the chosen distribution of whole seed cut to standard widths, the proportion of desired seed (28 to 84 g) decreased by 5.4 percent and the oversized seed increased by a similar amount when sizer roller spacings were increased by 6 mm.

The shape of the potato is the most critical parameter when considering roller spacing (Zhao *et al.*, 1986). Johnston (1970) correlated whole tuber diameter with weight and found the relationship to be cultivar-dependent. Webster's (1970) shape index (equation 2.4) was significant at the 1 percent level when used to discriminate between cultivars.

$$\text{Tuber shape index} = \frac{Tl \times 100}{Tb} \qquad \ldots (2.4)$$

where Tl = tuber length
Tb = tuber breadth

Brown's (1973) shape index (equation 2.5) is based on all three tuber axes and, therefore, gives a slightly more accurate index for cultivar shape.

$$\text{Tuber shape index} = \frac{Lmax\ Lmin}{Ce^2} \qquad \ldots (2.5)$$

where Lmax = maximun length of circumference
Lmin = minimum length of circumference
Ce = equatorial circumference

McRae (1985) reviewed work by Kolchin and Semekhunov (1975) who concluded that tubers sorted by weight had a scatter of linear dimensions smaller than the scatter of weights when tubers were sorted by linear dimensions. Goryachkin (1974) also supported the idea of sorting tubers by weight rather than sorting by linear dimensions.

McRae (1985) presented an equation for potato volume as

$$V = K\ a\ b\ c \qquad \ldots (2.6)$$

where V = potato volume
K = 0.524 for a true ellipsoid
a = length
b = breadth
c = thickness

Pitts and Hyde (1985) studied two ellipsoid-based models to predict volume, one considered all three axis and the other assumed the two larger axes to be equal. They concluded that the volume of a whole tuber can be calculated within five percent if the tuber length and width are known:

$$V = \frac{4 \pi a b2}{3} \qquad \ldots (2.7)$$

where V = tuber volume
a = 1/2 major axis
b = 1/2 minor axis

The Canadian seed tuber sizing schedule, in place as of 1983, had three size designations "A", "B", and Contract size. "A" sized tubers ranged from 113-340 g for round cultivars (e.g. Norchip) and 113-454 g for long cultivars (e.g. Russet Burbank). "B" sized tubers ranged from 42-113 g for both round and long cultivars. Contract size was defined as any size range agreed to by the buyer and seller. The proposed sizing regulations presented by Lidgett (1983) would see tuber sizing reported according to linear dimensions (based on the ability to pass through different sized square mesh) rather than weight. Equivalent sizes for the new long cultivars would see "A" sizes as 50-80 mm and "B" sizes as 40-50 mm. "A" sizes for round cultivars convert to 60-90 mm and "B" sizes to 40-60 mm. Another interesting aspect of the proposed changes is a minimum seed size of 25 mm for long cultivars and 28 mm for round cultivars (Lidgett 1983). These dimensions represent weights around 14 g and present an unexplored market for small seed.

Pascal *et al.* (1977) and Thornton *et al.* (1983) found closely graded whole seed resulted in a more uniform planting pattern. Planting graded seed (45-55 mm) was recommended by Eddowes (1986) for accurate seed spacing and depth of placement.

Sands and Regal (1983) introduced the concept of the tuber weight grading function to describe the distribution of weights of individual tubers. The grading function is a cumulative probability distribution function based on the assumption that tuber weights, in a population of mature potatoes, are normally distributed. As such, the grading function can be described by the population's mean and standard deviation. Each grading function has a corresponding probability density function which can then be used to predict the fraction of yield between any two weights.

The benefits derived from the grading process should also consider the cost of tuber damage due to handling (McRae 1980).

2.3.2 Cutting

Seed cutters were classified by French (1958) as automatic or non-automatic. Automatic cutters are self feeding and were further classified as "B" splitters or multiple sizer cutters. Non-automatic machines require an operator to position tubers prior to cutting. Most potato growers use high speed multiple sizer seed cutters to accommodate the cutting of large seed tubers into 2, 3, 4, or 6 pieces, depending on the tuber size.

Nomenclature for seed piece shape tends to vary and often reflects the researcher's focus. Andrew and Silva (1983) described seed pieces as whole, apical end, basal end, center cut, 3-cut, and quarter, all which imply a shape or position of origin on the parent tuber. Pitts and Hyde (1985) were concerned with optimizing cutting pattern for different sized tubers and chose seed piece names based on how many pieces a specific cutting pattern produced; 1-cut, 2-cut, and 4-cut. All naming schemes relate a pattern of increasing cut surface area and decreasing skin surface area, or, a change in shape from spheroid to blocky. Each shape influences the main stem number per seed piece and compatibility with the planting process. These relationships are central to an integrated perspective of planting operations.

The distribution of seed piece shapes and sizes within seed lots on Alberta potato farms (Andrew *et al.* 1983) showed substantial variation. This appears consistent with observations by Boyd and Lessells (1954) who noted considerable differences in weight of seed planted from farm to farm. Large ungraded whole seed contributes toward lack of seed piece uniformity (Johnston 1970; Hauck *et al.* 1982) as does the type of cutter and spacing of sizer rollers (Andrew *et al.* 1983).

According to French (1958) seed piece quality depends on the uniformity of seed piece size and the incidence of seed pieces without eyes. Leach *et al.* (1972) recommended that tubers over 280 g not be used for seed and, if they were, hand cutting was recommended. French (1958) reported that the cost of cutting seed depends on the percent of oversized tubers. Red Pontiac tubers cut into six pieces were found to be devoid of eyes 5 percent of the time whereas tubers cut into eight pieces had a 25 percent eyeless rate. Therefore, larger, longer, and less uniform seed decreases the homogeneity of seed piece size and shape (Pitts and Hyde 1985). Andrew *et al.* (1983) reported these conditions increased crop variability.

Optimal cutting patterns for different tuber sizes were derived by Pitts and Hyde (1985). As the number of seed pieces cut from one tuber increased from 2 to 7, the cut surface area to skin surface area ratio increased from 0.53 to 1.51. The volume of a seed piece as defined by Pitts and Hyde (1985) is given in equation 2.8.

$$SPVOL = \frac{\pi b^2}{N}\left(X - \frac{X^3}{3a^2}\right)\Bigg|_{X_{low}}^{X_{high}} \quad \ldots (2.8)$$

where SPVOL = seed piece volume
X_{high} = right end of seed piece
X_{low} = left end of seed piece
N = the number of cut surfaces
a = 1/2 major axis
b = 1/2 minor axis

The cut surface area of a seed piece as defined by Pitts and Hyde (1985) is given in equation 2.9.

$$CSA = \frac{\pi}{N}\, b\left(2 - \frac{X_{high}^2 + X_{low}^2}{a^2}\right) \quad \ldots (2.9)$$

where CSA = cut surface area

Skin surface area as defined by Pitts and Hyde (1985) is given in equation 2.10.

$$SSA = \frac{2\pi}{N}\, b\,\frac{\sqrt{a^2-b^2}}{a^2}\left(\frac{X}{2}\sqrt{\frac{a^4}{a^2-b^2} - X^2} + \frac{a^4}{a^2-b^2}\sin^{-1}\left(\frac{X}{a^2}\sqrt{a^2-b^2}\right)\right)\Bigg|_{X_{low}}^{X=X_{high}} \quad \ldots (2.10)$$

where SSA = skin surface area

Because a seed potato entering the cutting mechanism cannot be positioned accurately, the production of undersized seed pieces, or slivers, is inevitable. Slivers produce plants lacking vigor and therefore sliver removal devices should be used in conjunction with the cutting operation (Thornton *et al.* 1983).

Zhao *et al.* (1986) investigated two methods of reducing the variation in cut seed size: modification of seed cutters, and elimination of undersized seed pieces. They found that increasing the width between cutting blades increased the percent of desired Russet Burbank seed pieces to a maximum after which the proportion of desired seed dropped off rapidly. The criteria used to define desired seed pieces was based solely on weight (28-84 g) and ignored any shape effects. Adjustments to sizer roller spacings were shown to alter the size distribution of tubers approaching the cutting mechanisms. Although the optimum combinations of cut width and sizer roller spacings produced 90 percent desirable seed for an assumed seed size distribution, the optimum combination was noted to change with cultivar and size distribution of seed stock. Andrew *et al.* (1983) supported the view that growers can increase the proportion of desirable seed by adjusting cutting equipment according to seed lot size and shape. Implementing optimum settings in practical situations is difficult due to a combination of human error, inflexible cutter design, and the lack of proper indicator mechanisms for sizer roller spacings (Hauck *et al.* 1982).

The second part of Zhao *et al.*'s (1986) study examined the possibility of pneumatic separation of undersized seed pieces. Both percent loss of desired seed pieces (28-84 g) and percent separation of undersized seed pieces were measured as a function of air velocity in wind tunnel experiments. For the size distribution of seed pieces studied, the best results were achieved at an air velocity of 24.4 m/s where 80 percent of the undersized seed was separated with less than 4 percent of desirable seed lost. Factors which proved significant to seed terminal velocity were the height of end pieces, and mean diameter of half pieces. The terminal velocity of middle pieces (27.4 m/s) was well above the optimum separation velocity (24.4 m/s).

Seed cutting invariably is done at the storage site either at the time of planting or prior to planting to allow sufficient time for seed pieces to suberize in storage. Suberization refers to the healing process that takes place on freshly cut seed piece surfaces. Cutting seed at the time of planting is acceptable if soil conditions are favorable for healing cut surfaces and has the added advantage of preventing cut seed from rotting in storage should a stretch of inclement weather interrupt planting operations (Thornton and Sieczka 1980). Timm *et al.* (1973) concluded that healthy seed pieces with uniform respiration rates could be produced if seed potatoes were cut well in advance of planting to allow for suberization to take place. Their recommendation for cut seed storage was a shaded and ventilated environment with a temperature of 25°C to 30°C. Thornton's and Sieczka's (1980) recommendations are slightly different as they suggest suberization is best achieved by holding cut seed for three to five days at temperatures between 12.8°C to 18.4 °C with a relative humidity of 85 percent. Properly cut and stored seed pieces are reported to keep for two or three weeks without losing vigor (Rowberry and Howells 1979).

If a fungicide is required, the application is usually in powder form and is applied as pieces leave the cutter or in the field just prior to planting. One of the factors attributed to irregular planter performance is the tendency for seed pieces with greater cut surface area to stick to one another and to planter components (Likhyani *et al.* 1981). Research on the interaction between seed delivery systems and freshly cut *versus* suberized seed piece does not appear to have been studied.

2.4 Potato Planters

2.4.1 Types

Commercial potato crops in Europe and North America are planted by mechanical planters which open the soil, place the seed at the desired depth and spacing, and then cover and firm the seed bed. Planters usually have two, four, or six rows. Some one and two row planters use a three-point tractor hitch and utilize the tractor power takeoff to drive the metering mechanism. However, most planters rely on ground driven wheels to power the metering mechanism.

Planter operation, maintenance, and adjustment are more significant to planter performance than the type or make of planter (Andrew and Preston 1969). The basic components of the potato planter as outlined by Breece (1975) are: carrying and drive wheels; seed hopper; fertilizer hopper; fertilizer disk opener; fertilizer feed mechanism; platform; furrow opener shoe; covering disks; markers; and planting and feeding mechanisms. A brief examination of planter components will provide an overview of the planter's function.

Towed planters have two drive wheels that provide power to the fertilizer and planting mechanism. Wheel hubs are usually bolted to the drive axle with shear bolts to avoid damage to the planter should the metering mechanism jam. Carrying wheels are often found on six and eight row planters. The flow of seed from the hopper to picker chamber is controlled by adjustable gates. A platform on the back of many planters provides a space for an operator to monitor planter performance and to carry out duties dictated by planter design. Furrow openers consist of a set of opening disks and a wedge shaped opener shoe mounted on an undercarriage with hydraulic depth control. Planting action creates a furrow 75 to 100 mm wide in the seed bed. A set of covering disks for each row are located on the rear of the planter. These disks cover the seed and hill the row according to pitch and height adjustments relative to furrow openers.

Potato planters are most often classified according to their metering or feeding mechanism. Reference categories, based on operator labour requirements, refer to planters as manual, semi-automatic, or automatic (Jarvis 1978). Metering mechanisms are classified broadly as positive or non-positive mechanisms (Maunder 1983) depending on whether seed is individually selected and released or merely dispersed.

Early hand-fed planters required an operator for each row to select a potato from trays or bulk hoppers before dropping the seed down the planting tube. Planting rate was governed by ground speed and operator work rate. Improvements to hand-fed units included conveyance devices with compartments that transferred seed to the soil surface at regular intervals. Spacing was a function of both operator efficiency and conveyance speed relative to ground speed.

Cup-type planters select seed from the seed reservoir with cups mounted on an endless chain or belt. As the belt or chain travels through the planting tube, seed is conveyed toward the soil surface on the back of the preceding cup. Early planters used steel cups while some recent models offer plastic cups and inserts to meet different sizing requirements. The cups on many early models were designed to pick up only one seed. In some models, a compensation mechanism was used to release seed when a miss was encountered. Later models had larger cups capable of picking up more than one seed. Extra seed was displaced back to the seed reservoir with a removal device. Further developments included two to four rows of cups for each row planted. This allowed the belt to travel at slower speeds and resulted in superior metering performance. Spacing was determined by the speed of the belt or chain relative to ground speed.

Flat-belt planters direct the flow of seed from the hopper to a metering mechanism which feeds tubers onto a set of horizontal belts. The belts then discharge the tuber backwards onto the soil surface. Spacing proved to be a function of feed rate onto the belts and consistency of delivery.

Moulded-belt planters function in a similar manner to flat-belt planters. The belt consists of a series of moulded cups each capable of holding one tuber. Operators are required on the planter to ensure proper filling of cups.

Tuber unit planters combine both cutting and planting tasks. Belts travelling at different speeds align whole tubers before they are cut and then dispense the resulting pieces.

Pick-type planters usually have two vertically-mounted picker wheels for each row. The six to eight picker arms on a picker wheel each have a set of picks that pierce seed ~~pieces as~~ the arms rotate through the seed reservoir. When picker arms approach the planting tube, a cam activated stripper pushes the seed piece off the picks allowing the seed to fall down the planting tube and into the furrow.

Variation in pick length and arrangement offers some flexibility in accommodating different seed characteristics. Spacing is controlled by varying picker wheel speed relative to ground speed. A potential problem with this type of planter is the spread of disease from successive puncturing of seed pieces.

The new fully automatic Smallford Setronic potato planter developed by the Scottish Institute of Agricultural Engineering (Carruthers *et al*. 1984) combines many existing design concepts and adds microprocessor control to the seed delivery system. Plant spacing is push-button selected and achieved by microprocessor control of the hydraulic motor driving the planting belt in relation to ground speed. Three sets of belts are used for each row. A feed belt travels through the hopper in a direction perpendicular to the furrow filling the six moulded cups arranged across its width. The set of six seed tubers are then transferred intermittently onto a planting belt traveling toward the back of the planter. Each tuber falls into a separate flight on a planting belt and then is transferred to the point of release. Photo cells at the point of transfer between feed and planting belts detect empty cells which then are filled when make-up belts on the downstream side of the planting belt are activated. An infra-red detector above the make-up unit ensures that a tuber is available by indexing until a tuber is detected.

2.4.2 Safety

Safety concerns surrounding potato planters are focused on planter operators and their prescribed tasks. Semi-automatic planters require the operator for each row to pick and place the seed into the metering mechanism whereas automatic planters are more likely to have an operator standing on a rear mounted platform acting as a trouble-shooter and communication link to the tractor driver. In Murphy's (1980) unsafe behavior model, relationships between operator conditioning, rare event, and decision making are outlined. Operator conditioning relies on the principle of reinforcement. The belief that an accident will not occur encourages the operator to make the decision perceived to be of greatest utility. For the planter operator this could mean ensuring a constant seed feed by disrupting bridging action with a poke stick, or knocking doubles from metering elements, or perhaps by fishing stones from the seed reservoir bowl as the planter proceeds down the field. Prairie Agricultural Machinery Institute (PAMI) evaluation reports E1077 (1978a) and E1178A (1978b) both mention the importance of using a suitable poke stick to avoid injury to the operator.

Monitoring systems on field machinery enable operators to shift their attention away from simple tasks which can be tedious and time consuming. Design innovations "to improve the degree of personal safety during operation and application of products and materials" are part of the agricultural engineer's responsibility (Davis 1980). Electronic monitoring of problem areas would reduce the need for planter operators and, therefore, accidents are not as likely to occur.

2.5 Planting Operations

A majority of North American potato farms plant potato pieces cut from whole tubers using picker arm planters (Sieczka *et al.* 1986). The ability to perform at high planting rates with a minimum labour requirement accounts for the pick-type planter's popularity. Cup-type planters are gaining in popularity and are the planter of choice on most seed farms where disease control and regular planting patterns are critical. European producers prefer cup-type or belt-type planters to accommodate the planting of whole and, often, sprouted seed.

Date of planting varies between regions and years depending on soil moisture, soil temperature, and target market. Suggested minimum soil temperature at planting depth is 7°C (Andrew *et al.* 1976; Thornton and Sieczka 1980). Cold and wet conditions may contribute to seed piece decay and result in poor plant stands. Dates for planting in Alberta vary from early to late May depending on local conditions. High market prices for early crops provide incentives for producers to accept the risk of early planting and intensive management techniques.

Careful soil preparation is necessary to provide favorable growing conditions and facilitate ease of soil separation during harvest operations. Pre-planting cultivation is done just prior to planting. Cultivators with vertically rotating blades are often used because they have good depth control and provide the desired qualities of a fine textured seed bed with small aggregates (Poesse *et al.* 1973).

Insufficient planting depth results in tuber greening if tubers are exposed to sunlight. Suggested depth of planting is 80 to 130 mm below level ground (Andrew *et al.* 1976). If the height of the hill is considered, seed tubers should lay 150 to 200 mm below the top of the hill (Thornton and Sieczka 1980). Irregular depth control is often a problem with wide planters on hilly terrain.

From the farm management perspective, potato planting is noted for its slowness compared to other crops. The importance of planting rate is emphasized by the negative effect delayed planting has on yield. Increased planting rates enable machinery and labour to be reassigned to other seasonal demands. The higher potential output of modern planters requires that more attention be put to non-productive activities such as refilling the hopper (Jarvis 1978; Rowberry and Howells 1979). In Britain, traditional methods of filling the planter's seed hopper can account for up to 50 percent of planting time. Maunder (1983) studied seed handling systems in Great Britain. Seed in bulk containers resulted in planter filling rates of 3-5 man-min/t whereas handling seed in trays took 10-20 man-min/t. North American filling practices usually make use of a self-unloading potato truck and a towed transfer conveyer mounted at right angles to the truck's direction of travel.

The labour force required to run a smooth planting operation is dependent on the capacity and labour demands of planting machinery together with the size and type of farm operation and management style. Shotton's (1976) evaluation of different types of potato planters mentions an association between planter type and labour usage. However, due to the diversity in management styles and labour costs, the type of planter did not determine labour requirements. If minimum labour requirements for the planter are considered, clearly an advantage lies with larger, more automated planters.

2.6 Planter Performance

Concern over planter performance became firmly established when planter design shifted from hand-fed to automatic units. Sieczka *et al.* (1986) stated that "the primary reason for poor plant stands was the misplacement or failure to plant seed pieces." With increased work rates and faster planting speeds, new planter designs created questions about acceptable levels of irregular spacing and stimulated the investigation of performance factors. Maughan

(1973) saw performance data as a means to compare machines and as a reference point for decision making. According to Maughan, performance assessment should study the ability to segregate individual seeds from the seed reservoir and the suitability of soil-working parts. Maughan concludes "it is, however, unwise to study one of the aspects without due consideration of the other."

The approach to planter performance studies has evolved through the years. Studies by Pascal and Provan (1969), Jarvis and Palmer (1973) and Robertson and Pascal (1974), correlated planters and planter trials with yields. Although measures of planter performance were given, control over variations in planting, growing, and harvest phases of production were very difficult and results often were inconsistent or incomplete. Studies by Pascal and Langley (1971), Johnson and Vogt (1973), Carruthers (1975), Klassen (1977, 1980), Misener (1979, 1982), Likhyani *et al.* (1980), and Sieczka *et al.* (1986) used seed position in the furrow as a basis for performance comparisons. Knowing the pattern of seed distribution enabled yield response to be inferred from studies on growth response to spatial arrangement.

Halderson (1981) suggested a suitable approach for row-crop planter evaluation involving a separate analysis of metering and placement performance. Metering performance gives a measure of the metering mechanism's ability to engage a single seed at every opportunity whereas placement performance relates the effectiveness of seed transfer from the planter to its intended resting point in the furrow. Hyde *et al.* (1979) and Hyde and Thornton (1980) collected metering performance data using stationary planters driven by a variable speed electric motor. The dynamics of seed placement were presented in a paper by Bufton *et al.* (1974). Andrew and Domier (1978) and Pitts and Hyde (1985) suggested that consideration should be given to an integrated view of the planting process where interactions between seed, planter, and planter operating conditions determine performance. Jarvis (1978) stated that "an awareness of the nature of the general problems associated with the potato crop is a necessary adjunct to the planning of any research and development project on the crop."

2.6.1 Irregular Seed Spacing

One of the traditional measures of planter performance is the uniformity of the planting pattern. Several different statistics and methods of assessing spacing uniformity appear in planter performance literature. These include the coefficient of variation (CV), partial frequency distributions based on intended spacing, a performance index based on performance limits, and graphical renditions of successive seed spacing. These measures are based on the distribution of spacings between successive seed pieces and thus are a combined measure of metering and placement performance.

2.6.1.1 Measures of Uniformity

Jarvis *et al.* (1976) noted that, with hand-fed and cup-type planters, gaps between plants had a normal distribution and, therefore, irregularity of spacing could be defined in terms of the standard error of mean spacing except when the degree of irregularity is high and mean spacing is low. The standard deviation of a mean is often called the *standard error* (Steel and Torrie 1980). Jarvis *et al.* state further that assessments of crops planted at different mean spacings with the same planter suggested the standard error of the distribution of spacings varied with the mean spacing although this is not clearly established. However, other studies do not support the claim that the standard error of the spacing varies with mean spacing. For instance, Misener (1979) found that an increase in plant spacing decreased the frequency of doubles and skips for cup-type and pick-type planters. Likhyani *et al.* (1981) demonstrated that plant spacing did not significantly alter cup-type, and pick-type, planter performance.

If spacing errors do not necessarily vary with the mean spacing, then using the CV as a means of comparing performance trial results is invalid, unless, trials are conducted with identical plant spacings. This is so because the CV varies inversely with the sample's mean spacing. Therefore, larger spacing results in smaller

CVs, given a constant standard deviation of spacing. This point can be illustrated using data from Carruthers's (1975) planter trials. Both mean spacing and CV for planter trial runs are recorded. Knowing these statistics, the standard deviation of the spacing can be calculated using equation 2.2. For Pentland Dell graded to 32-37 mm, a spacing of 303 mm gave a CV of 37.5 percent and a standard deviation of 114 mm. However, an almost identical standard deviation of 112 mm at 390 mm spacing gave a CV of 29.2 percent. Although the standard error of seed placement is virtually identical for both trials, the CV indicates the 390 mm spacing is more uniform, and this is clearly not the case.

Performance studies by Misener (1979), Sieczka *et al.* (1986), Pascal and Robertson (1975), Pascal and Langley (1971), Carruthers (1975), and the Prairie Agricultural Machinery Institute (PAMI) (1978a, 1978b, 1978c, 1979, 1980) also used CV as a measure of spacing uniformity.

Likhyani *et al.* (1980) and PAMI publications (1978a, 1978b, 1978c, 1979, 1980) report irregular spacing as a frequency distribution using spacing categories. Four spacing categories are considered: doubles, singles, misses, and double misses. Likhyani *et al.* (1980) defined doubles as seed pieces less than half the intended spacing away from the preceding piece, singles are between half and one half the intended spacing, misses occur at one and a half to twice the intended spacing, and double misses at greater than twice the intended spacing. Misener's (1979) definitions differ. A miss is defined as a gap equal to or greater than twice the intended spacing and a double as a gap less than 70 mm. Again, caution has to be exercised when using these statistics to compare planter trials with different plant spacing. In the definition of a single, the acceptable deviation from the mean will change by half the change in the intended spacing. Thus, larger intended spacings will have a greater number of singles and doubles and fewer misses and double misses. Likhyani *et al.* (1981) acknowledged this, stating that the difference between 59.9 percent singles for pick-type planters and 44.2 percent singles for cup-type planters can not be considered significant because different spacings were used. The definitions of the above-mentioned spacing categories are inconsistent in PAMI potato planter performance reports. This makes performance comparisons difficult.

A study conducted by Johnson and Vogt (1972) used a performance index to evaluate planters. This index penalized the planter for wrong spacing and delivery of more or less than the intended number of seed. Unfortunately, the derivation of index values was not discussed.

Performance studies by Klassen (1977, 1980) give a graphical rendition of successive seed spacing. The pattern generated when the distance between seed pieces was plotted for consecutive seed pieces provided an effective method of illustrating placement pattern but is statistically inconclusive.

2.6.1.2 Accuracy Standards

Arbitrarily established standards for planting uniformity have been used to set acceptable limits to spacing variability. In Sweden, the recommended planting accuracy (Larsson 1986) allows for a maximum of 2 per cent gaps, 5 per cent doubles and a CV for plant spacing in the 20 to 40 per cent range. A CV of less than 40 percent is the acceptable level of seed placement uniformity in PAMI's (1978) evaluation reports. Johnson and Vogt (1973) suggested that 90 percent of seed should be within 76 mm of intended spacing and that 95 to 105 percent of the intended amount should be delivered. Of twelve planting operations surveyed by Johnson and Vogt, not a single operation met these standards. Experimental work by James *et al.* (1973) suggested that a seeding rate achieving a 90 percent or better plant stand is satisfactory.

2.6.1.3 Planter Type

Planters vary in their ability to maintain consistant plant spacing. Table 2.1 lists planter performance (CV), in the literature cited, according to planter type.

Pick-type planters tend to plant fewer doubles and at low spacings have less misses compared to cup-type planters (Misener, 1979). Investigations by Shotton (1976) indicated that high delivery rates are possible with belt-type planters but often at the expense of greater variation in seed spacing. Jarvis and Palmer (1973) compared yields from cup-type and belt-type planters to hand-fed planters. Compared to hand-fed planters, Jarvis and Palmer (1973) found that cup-type planters reduced yields by 1.6 t/ha and, belt-type planters were associated with a 2.6 t/ha yield reduction.

2.6.1.4 Planting Speed

The effect of speed on row crop planting patterns varies with seed material and the type of metering mechanism (Hofman *et al.* 1986). An evaluation of 8 planters over 196 trial runs by Misener (1979) demonstrated that ground speeds from 4 to 8.8 km/h reduced accuracy of cup planters but pick-type planters did not exhibit the same sensitivity to speed. Averages from 64 trial runs conducted by Likhyani *et al.* (1981) supported these findings and although an increase in

Table 2.1 A review of potato planter performance according to planter type

Planter type	Seed type	CV(%) range	CV(%) average	Source
Hand-fed	Whole	15-59	33.1	English Agricultural Development and Advisory Service (1975)
	Whole	20-30		Jarvis (1978)
Belt-type	Whole	55-86		Pascal and Langley (1975)
	Whole	20-30		Jarvis (1978)
Moulded-belt	Whole	24-55	35.6	English Agricultural Development and Advisory Service (1975)
Flat-belt	Whole	29-90	46.9	English Agricultural Development and Advisory Service (1975)
Tuber-unit	Cut	48-71		Misener (1982)
Cup-type	Whole	15-41	33.1	English Agricultural Development and Advisory Service (1975)
	Whole	15-25		Jarvis (1978)
	Whole		66.0	Prairie Agricultural Machinery Institute (PAMI), (1979)
	Cut	59-87		Misener (1979)
	Cut		64.0	PAMI (1979)
	Cut		70.9	Likhyani et al. (1981)
Pick-type	Whole	48-69		Sieczka et al. (1986)
	Cut		31.0	PAMI (1978a)
	Cut		28.0	PAMI (1978b)
	Cut		38.0	PAMI (1978c)
	Cut	55-69		Misener (1979)
	Cut		61.0	Likhyani et al. (1981)
	Cut	43-70		Sieczka et al. (1986)

speed from 5 Km/h to 8 Km/h was not significant, the number of singles increased by 2.2 percent for pick-type planters but decreased by 10.2 percent with cup-type planters. The pick-type planter's apparent performance improvement with higher speeds was attributed to the greater penetrating force exerted by the picks.

Laboratory studies by Hyde and Thornton (1980) reported that cup-type planters tend to deliver more than the intended number of pieces at low ground speeds. The pick-type planter examined by Hyde and Thornton showed no effect of speeds below 5 Km/h but increasing the speed to 8 Km/h resulted in a significant increase in seed spacing.

In planting trials conducted by Sieczka *et al.* (1986), three pick-type planters were observed at various ground speeds under 6.5 Km/h. Although planter operation varied considerably, no distinct pattern emerged. One planter was tested for uniformity of spacing with whole seed. At 4.5 Km/h, the CV was 48 percent but at 6.5 Km/h the CV increased to 69 percent. This decrease in uniformity was attributed to seed bouncing off picker arms rather than being properly pierced and released.

A performance study on a belt-type planter using whole seed (Pascal and Langley 1971) indicated that increasing speeds from 7.2 to 10.4 Km/h increased both spacing CV and mean spacing. The belt-type planter developed by the Scottish Institute of Agricultural Engineering, as described by Carruthers (1975), was also reported to increase mean spacing at higher speeds.

2.6.1.5 Seed Size and Shape

Observations by Johnson and Vogt (1973) indicate that planter performance can be affected by the geometric characteristics of seed pieces, especially when using cup-type planters. The first description of cut seed piece shape related to planter performance appears in a study by Likhyani *et al.* (1981). Hand cut potato pieces, from Norland (round) and Russet Burbank (long) cultivars, weighing 40 g and 60 g had shapes described as end pieces or center cuts.

Most performance studies describe seed as whole or cut and if cut, whether cut by hand or by machine. Studies which fail to give an accurate account of seed characteristics included Klassen (1977; 1980), and the 1968 and 1969 trials reported by Sieczka *et al.* (1986). In trials conducted during 1970 and 1971, Sieczka *et al.* (1986) recognized the importance of controlling seed size and used hand-cut tuber pieces weighing 57 g. Johnson and Vogt (1973) used seed pieces weighing greater than 56 g and acknowledged that size and shape of seed pieces had an undetermined influence on their results. Hyde *et al.* (1979) gave a tuber mean weight of

36.4 g and noted seed was smaller than desired for cup-type planter trials. Mean weight and standard deviation of cut seed are given by Hyde and Thornton (1980) as 42 g and 18 g. Misener (1982) gave a description of seed pieces used for each planter tested. Mean weights ranged from 33.1 g to 50.1 g and standard deviation ranges from 12.0 to 17.6.

Carruthers (1975) categorized whole seed according to cultivar shape (flat round, oval, long oval) and grade (32-44 mm; 44-57 mm; and 32-57 mm). Pascal and Langley (1971) used tubers graded either to 34-42 mm or 42-51 mm and describe cultivar shape as round or long-oval.

The PAMI potato planter evaluation reports E1077 (1978a), E1178A (1978b), and E1178B (1978c) use seed with an average weight of 40.0 g. PAMI report number E0579 (1979) deals with cut and whole seed with an average weight of 60 g. In PAMI report E0480 (1980), average cut seed weight was 70 g. All PAMI trials used Russet Burbank potatoes.

Misener (1982) noted the importance of matching seed piece and cup sizes on cup-type planters after observing a decrease in misses and doubles with larger seed. A pick-type planter's level of spacing uniformity appeared to be not as sensitive to seed size. Tuber unit planters produced more misses when planting large whole tubers. Likhyani *et al.*'s (1981) investigation on the effect of seed piece size and shape found no significant difference in performance between 40 g and 60 g seed pieces. The shape of seed piece proved to be highly significent with end cut pieces averaging 59.8 percent singles as opposed to 43.8 percent for center cut pieces. Both Klenin *et al.* (1985) and Pitts and Hyde (1985) stated that irregular seed placement is greater for seed pieces with non-uniform size distributions.

Effect of whole seed size on spacing uniformity with belt-type planters was proven to be insignificant by Carruthers (1975). Pascal and Langley (1971) also reported that whole tuber shape had no apparent effect on mean spacing for belt-type planters. Misener (1982) suggested that accuracy of seed placement improves in cup and pick-type planters when planting whole seed. In Siecczka *et al.'s* (1986) planting trials, whole seed tubers planted with a a pick-type planter gave the best seeding rate but also resulted in the least uniform seed distribution pattern. The seed shape and planting speed interaction is discussed futher in section 2.6.4 under placement performance.

2.6.2 Seeding Rate

The ability to deliver the desired amount of seed over a given area is more important than the uniformity of seed spacing (Sieczka *et al.* 1986). Seed rate (t/ha) can be used to measure a planters ability to meet the desired seed spacing if the average seed size is known.

Factors such as wheel slip on drive wheels, large numbers of misses and doubles, broken or damaged metering elements, and bridging action in the hopper or feed mechanism all contribute to deviations from desired seed rate. Consequently, the actual average seed spacing often differs from the intended spacing. Theoretical seeding rate is defined by equation 2.11 given by Hunt (1986).

$$P = \frac{10,000\ N\ R}{2\pi\ r\ (1-s)\ w} \quad \ldots (2.11)$$

where P = the number of seed pieces/ha
N = the number of metering elements per revolution of the metering mechanism
R = the ratio of revolutions of the metering mechanism for every revolution of the drive wheel
r = effective radius of drive wheel (m)
s = drive wheel slippage (decimal)
w = effictive row width (m)

The actual seeding rate can be calculated by multipling the theoretical seeding rate by the ratio of successful metering events to total metering events.

The results from planting surveys by Sieczka (1986) and Klassen (1980) indicated that actual seed spacing was 40 mm greater than intended. The five PAMI potato planter evaluation reports (1978a, 1978b, 1978c, 1979, 1980) report average spacing deviated from the 460 mm intended spacing by

30, -20, 5, -10, 15 mm. All but one evaluation indicated that average spacing increased with speed. Hyde *et al.* (1979) noted that mean seed spacing increased with speed, lower picker bowl levels and location of picks closer to the picker wheel. The plant stand surveys discussed in section 2.2.1.1 lend support to the fact that seed application rates are generally lower than intended.

2.6.3 Metering Performance

If factors contributing to irregular planting patterns are partitioned according to planter function, then a separate analysis of metering and placement performance is in order. Expressing metering performance as a function of metering rate is quite acceptable, however, relating metering performance in terms of ground speed means little without stating levels of other significant planting parameters.

Four methods of assessing metering performance are reported in the literature cited. Burema *et al.* (1975) used a moving sticky belt below a mounted precision planter to gather spacing data. Slow motion 16 mm movies were used by Sieczka *et al.* (1986) to observe the planting process. Hyde *et al.* (1979) used a photo cell and light source at the drop chute to detect a falling seed. A 16 lobed cam was attached to the picker wheel drive shaft such that each passing picker arm closed a cam-switch. Electrical pulses from both sensors were connected to a chart recorder allowing metering statistics to be collected.

Compatibility between metering elements and seed material is of primary importance to regular seed delivery. Pick arrangement was determined to be significant by Hyde *et al.* (1979). The three different pick arrangements studied produced deviations from the intended spacing of -9.0 mm, 6.7 mm, and 23.2 mm. Johnson and Vogt (1973) found a three-pick arrangement to deliver 97 percent of intended seed compared to 88 percent for a two pick arrangement. Klenin *et al.* (1985) found that optimal clearance between picker spoons and the side plate of the feed hopper depended on the mass of the seed tuber. Clearance between the outer edge of the metering elements and the bottom of the feed hopper influence the amount of seed piece damage. Recommended clearance values were 3-5 mm.

Hyde and Thornton (1980) examined sprocket and roller idlers and three different idler spring tensions on cup-type planters. Both idler types delivered less seed as spring tension was increased. This was especially evident with the sprocket idler, which agitated the cup chain more vigorously.

The level of seed in the seed reservoir showed a positive correlation with the amount of seed delivered per unit time (Hyde *et al.* 1979; Hyde and Thornton 1980). Klenin *et al.* (1985) suggest that a seed depth 100 to 150 mm in the seed reservoir is needed to meet the metering demand and avoid excessive seed damage caused by higher levels.

The value of applying the kinematics of planting units to planter design is stressed by Bufton *et al.* (1974) as he states "where a forward speed is required which achieves an acceptable rate of work, optimization of the seed release conditions is only likely to be achieved by specific drill design to overcome the problems posed by metering mechanisms being unable to satisfactorily meter seeds at higher peripheral speeds."

2.6.4 Placement Performance

Seed displacement after impact with the soil surface depends on the nature of the soil surface, weight and shape of the seed piece, impact velocity, and impact angle (Bufton *et al.* 1974). Although an analysis of placement performance for seed potato pieces does not appear in the literature cited, sugar beet seed was among the seeds investigated by Bufton *et al.*

The interaction between seed velocity and the angle of impact indicated greater seed displacement with lower impact angles (relative to the soil surface) and higher seed velocities. Angles of impact above 40° resulted in a progressive decrease in mean seed displacement to a minimum which occurred between 75-80° for all seeds studied (Bufton *et al.* 1974). Lower angles of impact increased seed displacement, especially for spherical seeds and heavier irregular shaped seeds. Seed roll was more prevalent on packed *versus* sheared soil surfaces.

The horizontal component of seed velocity is the main factor behind seed piece roll and is equal to the horizontal component of the metering mechanism's peripheral velocity and the velocity of the planter. Pascal *et al.* (1977) substantiate the problem of greater seed piece roll at high planting speeds. If the soil working parts of the planting mechanism were designed to trap the seed piece at the point of impact, seed roll would be negligeable.

The kinematics of picker planting units, as presented by Klenin *et al.* (1985), are used to relate design parameters to field operating conditions. The kinematic index is defined by Klenin *et al.* (1985) as the ratio of the linear velocity at the extreme point of the metering mechanism to the speed of the machine (equation 2.12).

$$\lambda = \frac{u}{v} = \frac{2\,\pi\,R}{z\,s} \qquad \ldots (2.12)$$

where λ = kinematic index
u = linear velocity at extreme point of metering mechanism
v = ground speed of the planter
R = length of planter arm
z = number of metering elements
s = plant spacing

For a given spacing and planter speed, the number of cups or picker arms on the metering mechanism can be selected using the kinematic index. Ideally the kinematic index assumes a value of -1. In this case the horizontal velocity of the metering mechanism at the point of release is equal and opposite to the speed of the planter, thus, the horizontal component of seed velocity is zero. This condition minimizes the tendency of seed pieces to roll upon impact with the soil.

2.7 Planter Monitoring and Instrumentation

The production of agricultural commodities depends on the efficient use of resources. As critical resources become more expensive, producers need to assess alternatives and determine the implications of altering the production system (Smith *et al.* 1985; Holt and Schoorl 1985).

A historical review of instrumentation on agricultural equipment by Wilson (1983) noted that, until recently, this subject had gone virtually unnoticed and was not particularly well documented. The evolution of planter instrumentation and monitoring systems were given as examples of progress in this field. Mechanical switches activated by falling seed have now been replaced by infra-red light emitting diodes, photo transistors and magnetic and capacitive proximity sensors. Analogue circuits are now often supplemented with digital circuitry. Flashing lamps, needle gauges, and warning buzzers are no longer the exclusive means of indicating machine performance. Ongoing and user-requested performance levels now can be transmitted to the operator through an array of output devices which include alphanumeric displays.

Modern monitoring and control systems are based on microprocessor ability to analyse a series of events over a period of time: Wilkins (1979) discussed microprocessor control of precision planters.

Thornton *et al.* (1983) assert that an optimal set of planting parameters are difficult to identify considering the combinations of planter operating conditions and the variable nature of potato growth response. Performance feedback was identified as a means of encouraging satisfactory performance levels. PAMI evaluation report no. E0579 (1979) recommended that manufacturers provide the option of a planting monitor to accommodate the needs of a one-person potato planting operation. A microprocessor controlled modified belt-type potato planter developed by Carruthers *et al.* (1984) used an array of photo cells to detect and replace empty cells with potatoes from a secondary delivery system.

Other examples of electronic assistance in potato planting operations include seed flow and hopper level indicators (PAMI 1980), a microprocessor assisted system for grading potatoes (Carlow 1983), and an automatic load control system for conveyors (Hyde *et al.* 1983).

3. ASSESSMENT OF PICK-TYPE PLANTER METERING ERRORS

3.1 Objective

The objective of this experiment was to determine how metering rate, and seed piece size and shape, affect metering performance of pick-type planters.

3.2 Equipment and Experimental Facilities

Laboratory planting trials were conducted at the University of Alberta's Agricultural Engineering Research Station at Ellerslie.

A McConnell 555 single-row, ground driven pick-type planter (Figure 3.1), manufactured by McConnell Mfg. Co. Inc., Prattsburg, New York, formed the experimental unit. The pick-type metering mechanism had a picker wheel with sixteen picker arms. Each picker arm had two steel picks (Figure 3.2) that pierced seed pieces as the picker wheel rotated through the seed reservoir. Seed was released by the cam-activated stripper device on each arm.

The data collection system consisted of an IBM Personal Computer, a Datataker model DT100 data logger manufactured by Data Electronics (Aust.) Pty Ltd. and a sensor system capable of detecting successful and unsuccessful metering events. Picker wheel action and sensor positioning are illustrated in Figure 3.3.

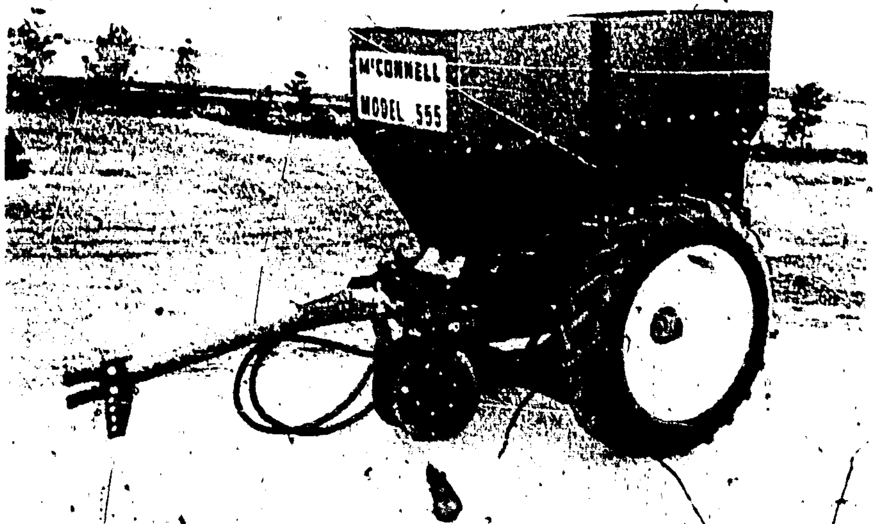


Figure 3.1 McConnell 555 pick-type planter

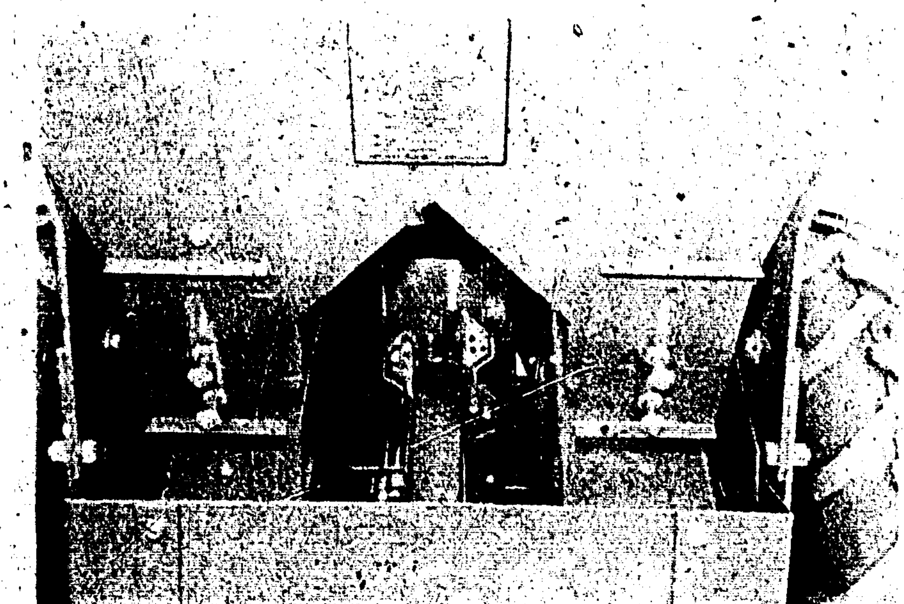


Figure 3.2 Pick-type metering mechanism

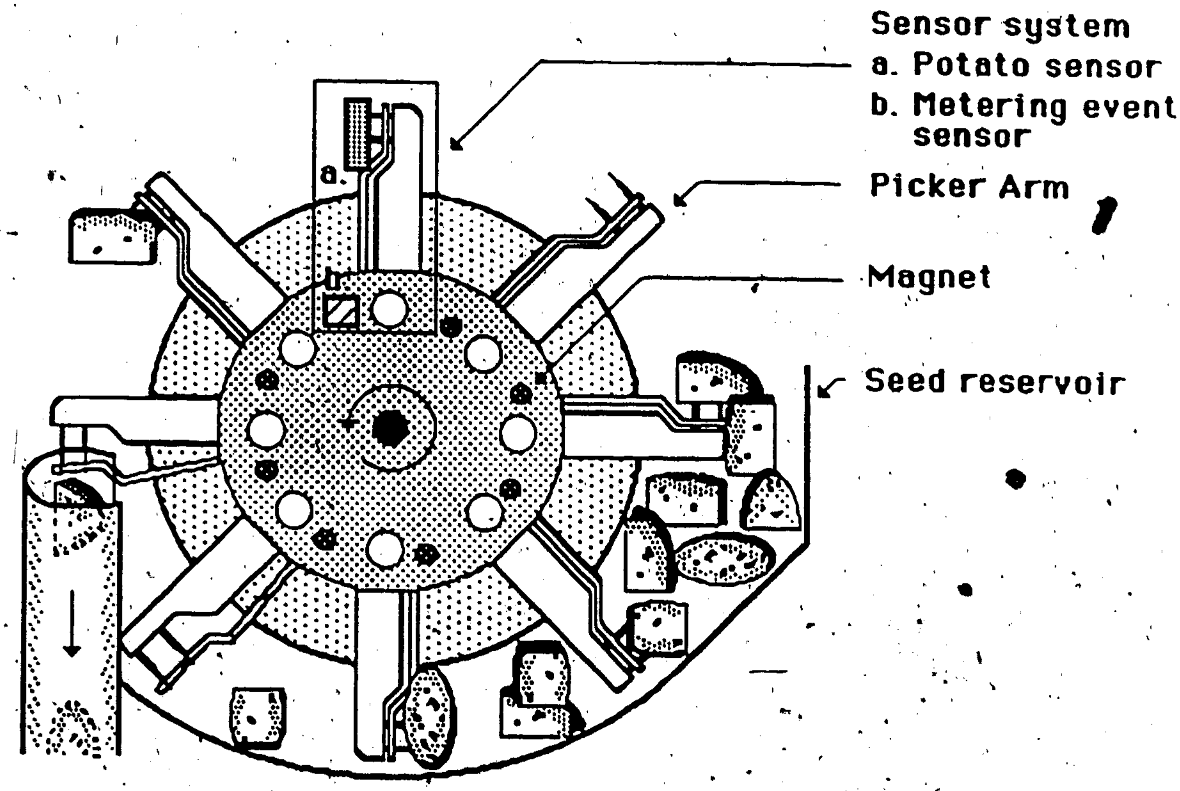


Figure 3.3 Picker-wheel action and sensor positioning

3.3 Experimental Procedure

A total of 105 laboratory metering trials were conducted using a McConnell pick-type planter, mounted on blocks and powered by a variable speed electric motor. Two experiments were conducted. The first experiment assessed metering performance of cut seed using a 3 x 3 x 2 factorial experimental design (randomized complete block, with five replications). Three metering rates were investigated in combination with three seed piece shapes and two seed piece sizes. Moderate to high metering rates were chosen with 3, 6, and 9 plants/s representing field speeds of 3.8, 7.6, and 11.4 km/h at 30 cm plant spacing. Seed shapes and sizes were chosen to be representative of seed found on Alberta potato farms. Shapes having one, two, or three cut surfaces were investigated in combination with seed sizes of 45 g and 60 g.

The experimental layout for whole seed metering trials was based on a single criterion of classification for groups of data with equal replication. Metering performance of 50-100 g whole seed at metering rates of 3, 6, and 9 plants/s was determined.

3.3.1 Seed Preparation

Whole Russet Burbank seed tubers with a mean weight of 178 g and a standard deviation of 68.7 g were hand cut into 6 seed lots weighing 45 kg (±5 kg). Each seed lot represented a seed shape and size combination. A seventh seed lot weighing 45 kg (±2.5 g) consisted of whole tubers between 50 g and 100 g. Seed piece shapes are described as 1-cut, 2-cut, or 3-cut to reflect the number of cut surfaces as illustrated in Figure 3.4 (a). Figure 3.4 (b) shows the portion of the parent tuber from where seed pieces of a particular shape originated. Seed piece shapes were cut to 45 g and 60 g (±2.5 g) sizes bringing the number of seed lot treatments to 6. Each whole seed tuber and the resulting pieces were individually weighed with a scale having accuracy to 0.1 g. Seed dimensions defined as variables in equation 2.8 (Pitts and Hyde (1985)) were measured with an accuracy of ±2.5 mm.

3.3.2 Planter Preparation and Instrumentation

The planter was mounted on blocks and the wheels were removed. A sprocket and chain drive assembly with a 5:1 reduction ratio was installed between the drive wheel hub and the output shaft of a 10:1 reduction gear box powered by a 0.75 kW variable speed electric motor (model 2BD-01154, Leeson) rated between 0 and 1750 rpm. A baffle board was placed below the point of seed release to deflect falling seed into a collection box used to recycle seed for metering trial replications.

Metering errors were detected using a dual-sensor, event-triggered system. Sensor system positioning and mode of operation are illustrated in Figures 3.3 and 3.5. A modulated infrared through-beam photoscanner (model MCS-651,

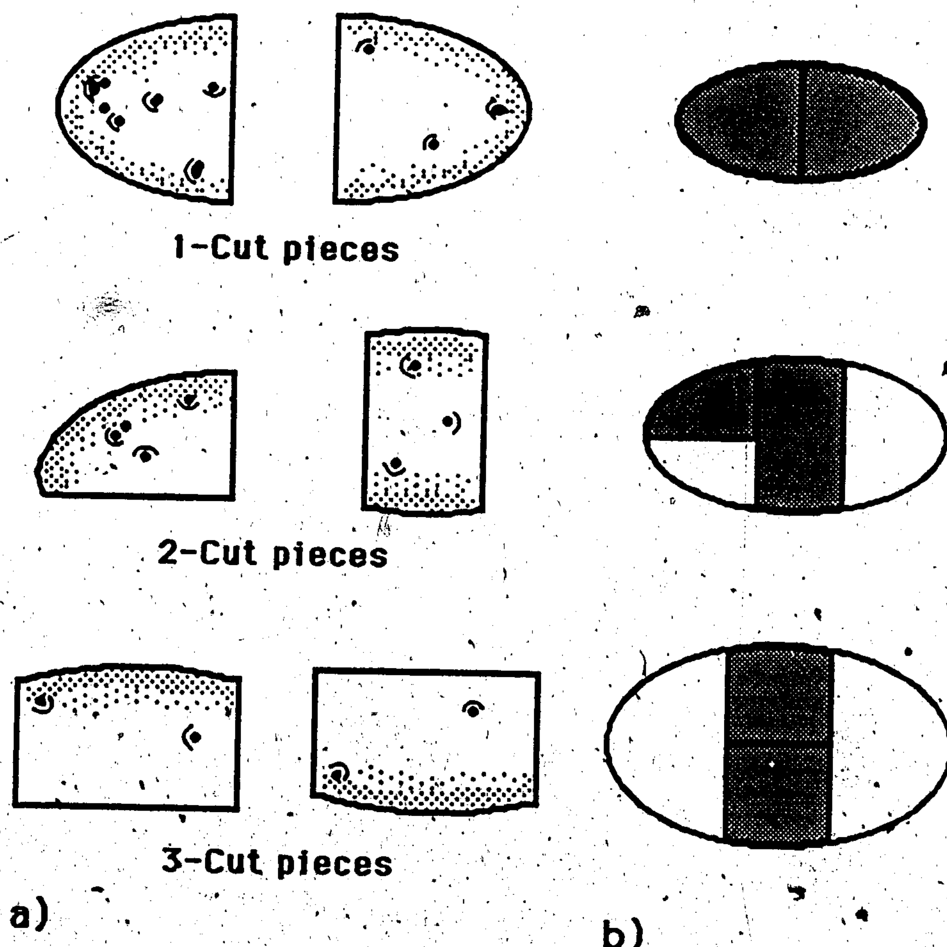


Figure 3.4 Cut seed attributes
a) Seed piece shape
b) Seed portion

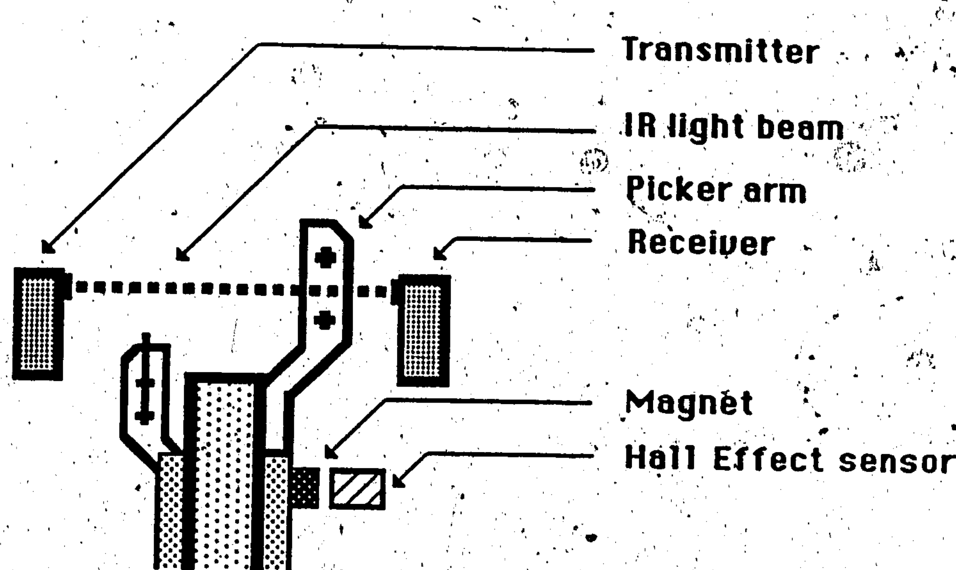


Figure 3.5 Sensor system

Warner Electric, Marengo, IL.) functioned as the potato sensor and was mounted so that the light beam intersected the plane of picker wheel rotation at right angles and passed halfway between the two picks on the picker arm. Permanent ceramic magnets 13 mm in diameter and 7 mm thick were bonded to the base of each picker arm, with the south pole facing outward, along a line extending from the mid point of the pick's length to the picker wheel hub. A Sprague 3019T Hall Effect switch (metering event sensor) was positioned so the leading edge of a passing magnet would create a pulse indicating the occurrence of a metering event at precisely the moment that picks on the picker arm passed through the potato sensor's light beam. A gap of 4 mm between the metering event sensor and the magnet gave very precise metering event signals. The sensitivity of the metering sensor was improved by bonding another magnet's north pole to a 5 mm thick plastic spacer which in turn was fixed to the back of the metering event sensor. This arrangement concentrated the magnetic field surrounding the Hall Effect switch and allowed the metering signals to be triggered from a greater distance.

Both the metering event sensor and the potato sensor were connected to the data logger which in turn was connected to the IBM PC. An on-off toggle switch (data log switch) completed the data acquisition circuit. Section 4.2.1.2 contains further sensor system discussion and Appendix E9 and E10 provide sensor circuit diagrams.

3.3.3 Collection of Metering Data

After a randomly chosen seed lot was placed in the seed hopper, data logging instructions were sent from the IBM PC to the data logger. Once the variable speed electric motor was set to the desired metering rate, a contact tachometer (Tak-Elete, model 1707, Power Instruments Inc.) was used to confirm picker wheel speed. Logging of metering data commenced when the data log switch was engaged. As the magnets on passing metering elements signalled metering events, logic circuitry on the light sensor was polled to determine if a potato piece was engaged (beam broken - logic 1) or if a metering error had occurred (beam intact - logic 0). Logic voltages then were logged. Any bridging action that threatened to disrupt the flow of seed was broken up with a stick, to ensure a constant feed rate. After a minimum of 100 metering events the data log switch was disengaged. Metering data was transferred from the data logger to a data file on disk and then the hopper and seed reservoir were emptied. This procedure was repeated for five replications of seed lot treatments.

3.3.4 Data Analysis

Seed piece data were analysed to determine the cut and skin surface areas as defined by equations 2.9 and 2.10 (Pitts and Hyde (1985)). The ratio of cut surface area to skin surface area gives a continuous measure of cut seed attributes as opposed to the number of cut surfaces which provides a discrete but less effective characterization of seed material.

A metering data analysis program written in BASICA (Appendix A) was used in conjunction with an IBM PC to analyse data files. The first three data points in each file were disregarded to eliminate inconsistency which may have resulted when the data logger was engaged. Each line in the data file contained a "1" or a "0" which represented either a successful or unsuccessful metering event. The total number of metering events and the number of successful and unsuccessful metering events were determined. A distribution of consecutive metering errors was established by recording the number of consecutive misses preceding each successful metering event.

3.4 Experimental Results and Discussion

Sensor positioning effects were not verified beyond comparing the observed metering performance and the metering error indication (a light emitting diode (LED) on the data acqusition circuit). Errors were more prevalent at lower metering rates. The overestimation of metering errors could have been avoided had the potato sensor been positioned to intersect the plane of pick rotation at the tip of the picks upon a metering event signal, rather than half way down the length of the pick.

No indication of sensor system malfunction was evident for over 20,000 recorded metering events.

3.4.1 Seed Piece Attributes

Seed piece dimensions were analysed to determine the seed piece volume (equation 2.8), cut surface area (equation 2.9), and the skin surface area (equation 2.10) as defined by Pitts and Hyde (1985). Unfortunately dimensions recorded with ±2.5 mm accuracy did not predict seed piece weight accurately as determined by the product of predicted seed piece volume and the potato's specific gravity. Consequently cut and skin surface area calculations were of little value.

3.4.2 Metering Results

A summary of cut and whole seed metering trial results are presented in Table 3.1 (Summary of Appendix B1 and B2 respectively). Metering performance was measured in terms of metering errors or the percent of total metering events which were unsuccessful. Table 3.2 (summary of Appendix B3) and Table 3.3 (summary of Appendix B4) sets out the distribution of consecutive metering errors, expressed as a percentage of total metering errors, for cut and whole seed respectively.

3.4.2.1 Relation of Seed Shape to Metering Errors

The analysis of variance presented in the ANOVA in Table 3.4 indicated metering rates, and cut seed shape and size, were significant at p = 1 percent. Of the first-order interactions, metering rate x shape and metering rate x size interactions also proved to be significant at p = 1 percent but the seed shape x size

Table 3.1 Metering performance summary

Percent of metering events which were unsuccessful *

Seed attributes		Metering rate (plants/s)		
Size (g)	Shape	3.0	6.0	9.0
45	1-cut	26.6	27.0	31.6
	2-cut	29.7	22.4	13.4
	3-cut	25.9	11.4	10.1
60	1-cut	63.0	31.5	16.5
	2-cut	38.7	24.3	21.2
	3-cut	28.3	16.1	15.9
50-100	whole	55.4	30.8	14.0

* Average for 5 replications
(minimum of 100 metering events for each replication)

Table 3.2 Distribution of consecutive metering errors for cut seed

Percent of total metering events which were unsuccessful *										
	Consecutive metering errors									
	1	2	3	4	5	6	7	8	9	10
Metering rate										
3 plants/s	12.7	7.6	4.7	3.5	1.3	1.2	1.6	0.1	0.4	0.4
6 plants/s	12.4	5.2	2.0	0.6	0.4	0.1	0.0	0.0	0.0	0.0
9 plants/s	11.8	3.1	1.1	0.1	0.2	0.0	0.1	0.0	0.0	0.0
Seed shape										
1-cut	13.6	5.6	3.7	1.9	1.2	1.0	0.7	0.1	0.4	0.4
2-cut	13.5	5.6	2.8	1.5	0.3	0.3	0.2	0.0	0.0	0.0
3-cut	9.8	4.7	1.3	0.8	0.5	0.1	0.8	0.0	0.0	0.0
Seed size										
45 g	12.7	3.7	1.9	0.6	0.2	0.1	0.2	0.0	0.0	0.0
60 g	11.8	6.8	3.3	2.2	1.1	0.8	0.9	0.1	0.2	0.3

* Average for 5 replications
(minimum of 100 metering events for each replication)

Table 3.3 Distribution of consecutive metering errors for whole seed.

Percent of total metering events which were unsuccessful *										
	Consecutive metering errors									
	1	2	3	4	5	6	7	8	9	10
Metering rate										
3 plants/s	11.1	12.5	9.0	9.0	4.3	5.0	0.8	1.1	1.1	0.0
6 plants/s	14.9	7.1	5.4	2.7	0.6	0.0	0.0	0.0	0.0	0.0
9 plants/s	10.7	2.6	1.5	0.3	0.2	0.2	0.0	0.0	0.0	0.0

* Average for 5 replications
(minimum of 100 metering events for each replication)

interaction proved to be insignificant. The lack of significance of the seed shape and size interaction, when compared to the high levels of significance shown from other sources of experimental error, suggested that seed shape and size affect metering performance in an independent manner. The only second-order interaction (metering rate x shape x size) was significant at the p = 5 percent level. Metering rate for whole seed was established to be significant at the p = 1 percent level as summarized in the ANOVA in Table 3.5.

Metering errors tended to decrease as the number of cut surfaces increased, or as seed pieces became more blocky. This trend is illustrated in Figure 3.6 and may be due to a greater probability of a flat surface presenting itself simultaneously to both picks at an angle normal to the penetrating force. Seed pieces with rounded surfaces (eg. 1-cut pieces) laying near the picker wheel tend to project the seed's center of gravity away from the pick's path, and thus decreases the probability of a successful metering event. The possibility of only one pick penetrating potato flesh also is enhanced. Consequently some seeds became disengaged before reaching the planting tube.

An in-depth analysis of seed shape effects on metering performance revealed a distribution of consecutive metering errors favoring the performance of

Table 3.4 Analysis of variance for cut seed metering trials

Source of variation		df	SS	MS	F
Blocks	r-1 =	4	7,353	1,838	57.1 **
A = Shape	a-1 =	2	3,268	1,634	50.5 **
B = Metering rate	b-1 =	2	4,865	2,433	75.5 **
C = Size	c-1 =	1	905	905	28.1 **
AB	(a-1)(b-1) =	4	2,192	548	17.0 **
AC	(a-1)(c-1) =	2	70	35	1.1
BC	(b-1)(c-1) =	2	1,094	547	17.0 **
ABC	(a-1)(b-1)(c-1) =	4	342	86	2.7 *
Error	(r-1)(abc-1) =	68	2,399	32	
Total		89	22,488		

** significant at p = 0.01
* significant at p = 0.05

Table 3.5 Analysis of variance for whole seed metering trials

Source of variation		df	SS	MS	F
Among metering rates	t-1 =	2	4,313	2,157	216 **
Within metering rates	t(r-1) =	12	117	10	
Total		14	4,430		

** significant at p = 0.01

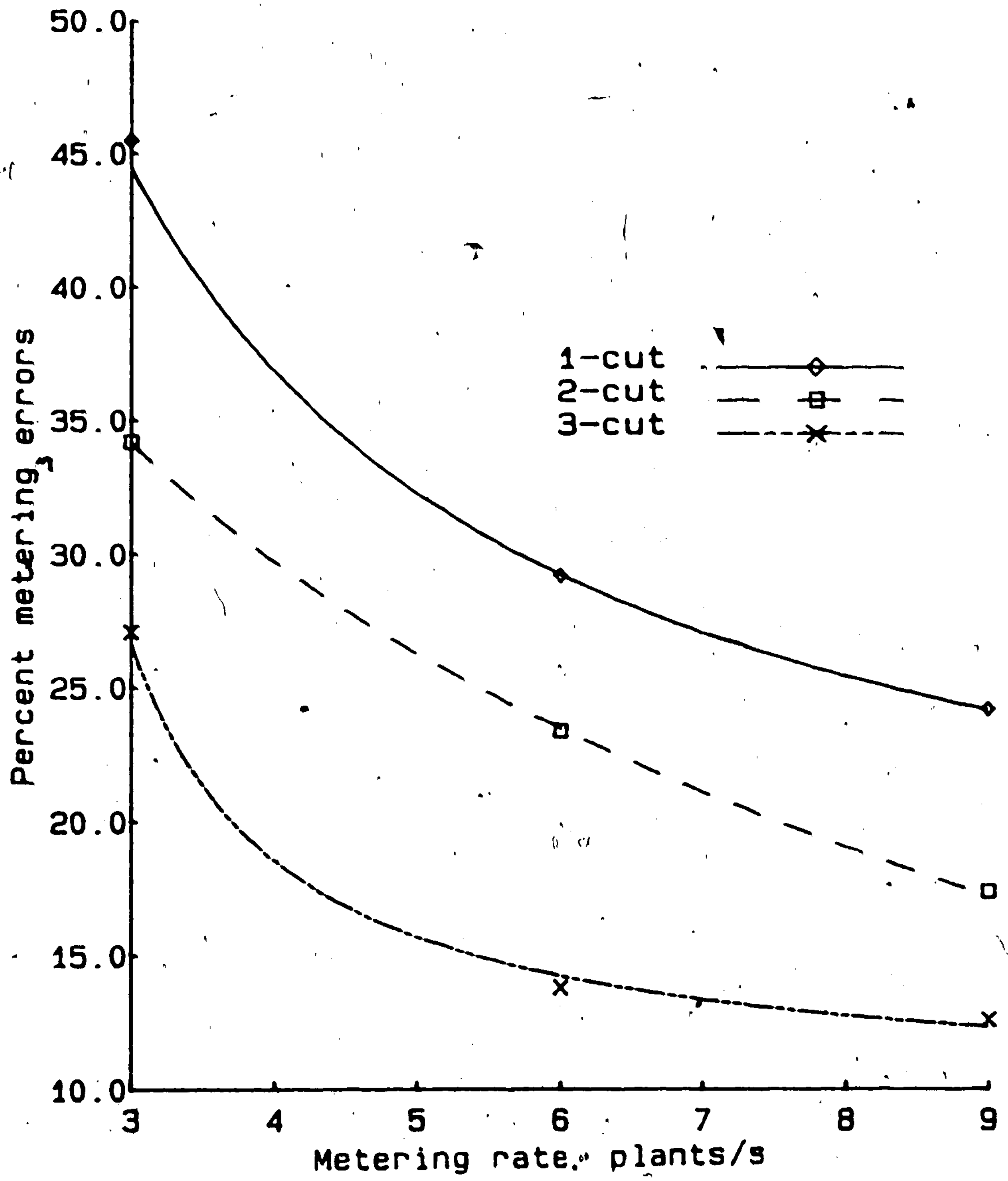


Figure 3.6 Seed shape effect on metering performance

3-cut pieces (Figure 3.7). The frequency of consecutive metering errors was consistently lower for 3-cut pieces when compared to 2-cut and 1-cut pieces.

3.4.2.2 Relation of Seed Size to Metering Errors

Results indicate the larger (60 g) seed performed poorly at 3 plants/s when compared to the 45 g seed. However, metering errors for each size were comparable above metering rates of 6 plants/s (Figure 3.8). The explanation for this trend is, simply, that larger and heavier seed tends to fall off the picks easier than smaller and lighter seed, especially when pick penetration is shallow. Poor performance of larger and heavier seed is partially due to an unbalanced distribution of seed weight on the picks which may lead to premature seed release.

Figure 3.9 presents the distribution of consecutive metering errors for both 45 g and 60 g seed. Aside from the one consecutive metering error category, 45 g pieces had fewer continuous misses.

3.4.2.3 Relation of Metering Rate to Metering Errors

Metering rate had the most distinct influence on metering performance. On average, cut seed metering errors were 35, 22, and 18 percent for planting rates of 3, 6, and 9 plants/s respectively. Figures 3.6, 3.8, and 3.9 illustrate the correlation between higher metering rates and fewer metering errors. Faster picker

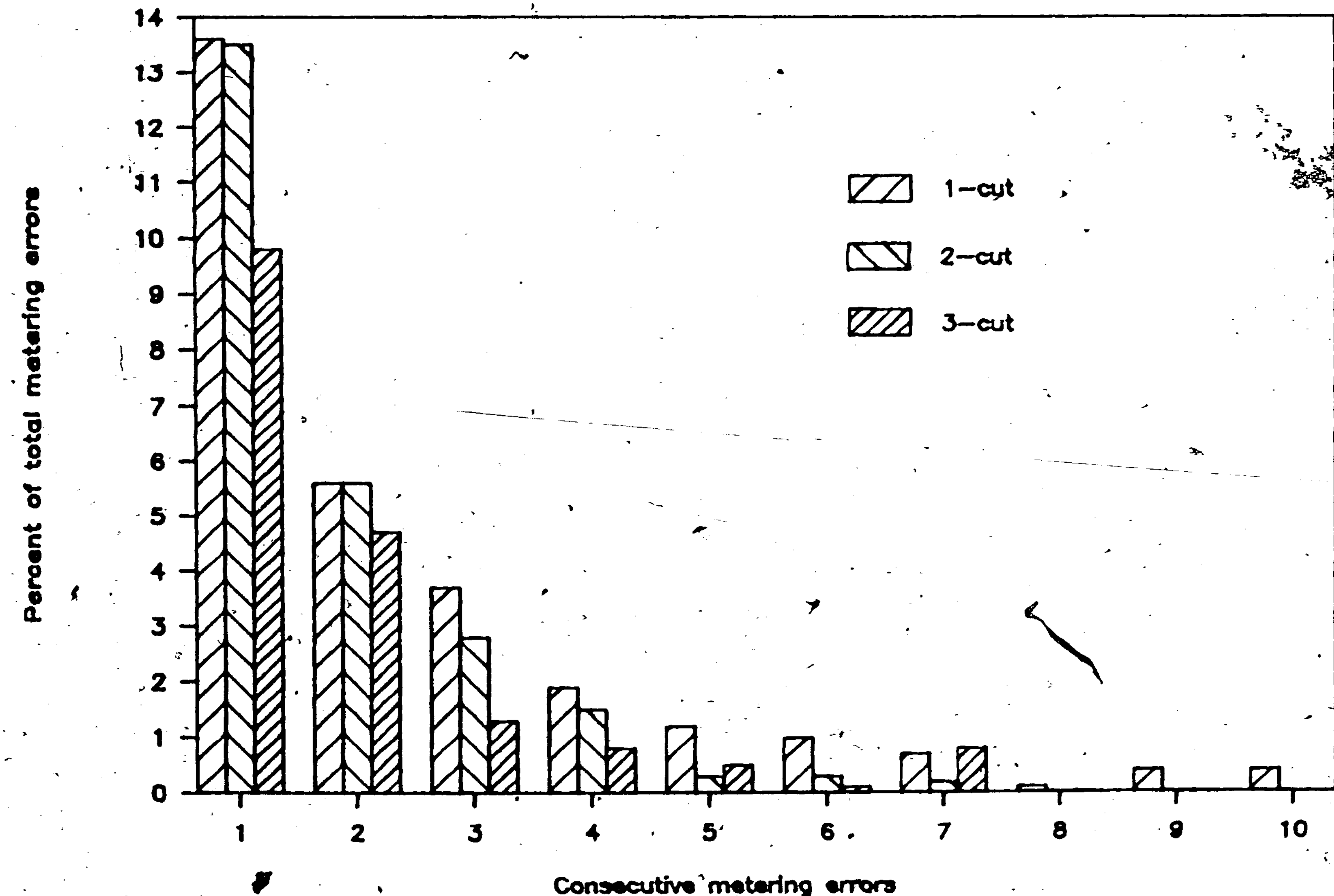


Figure 3.7 Consecutive metering error distribution for seed shape

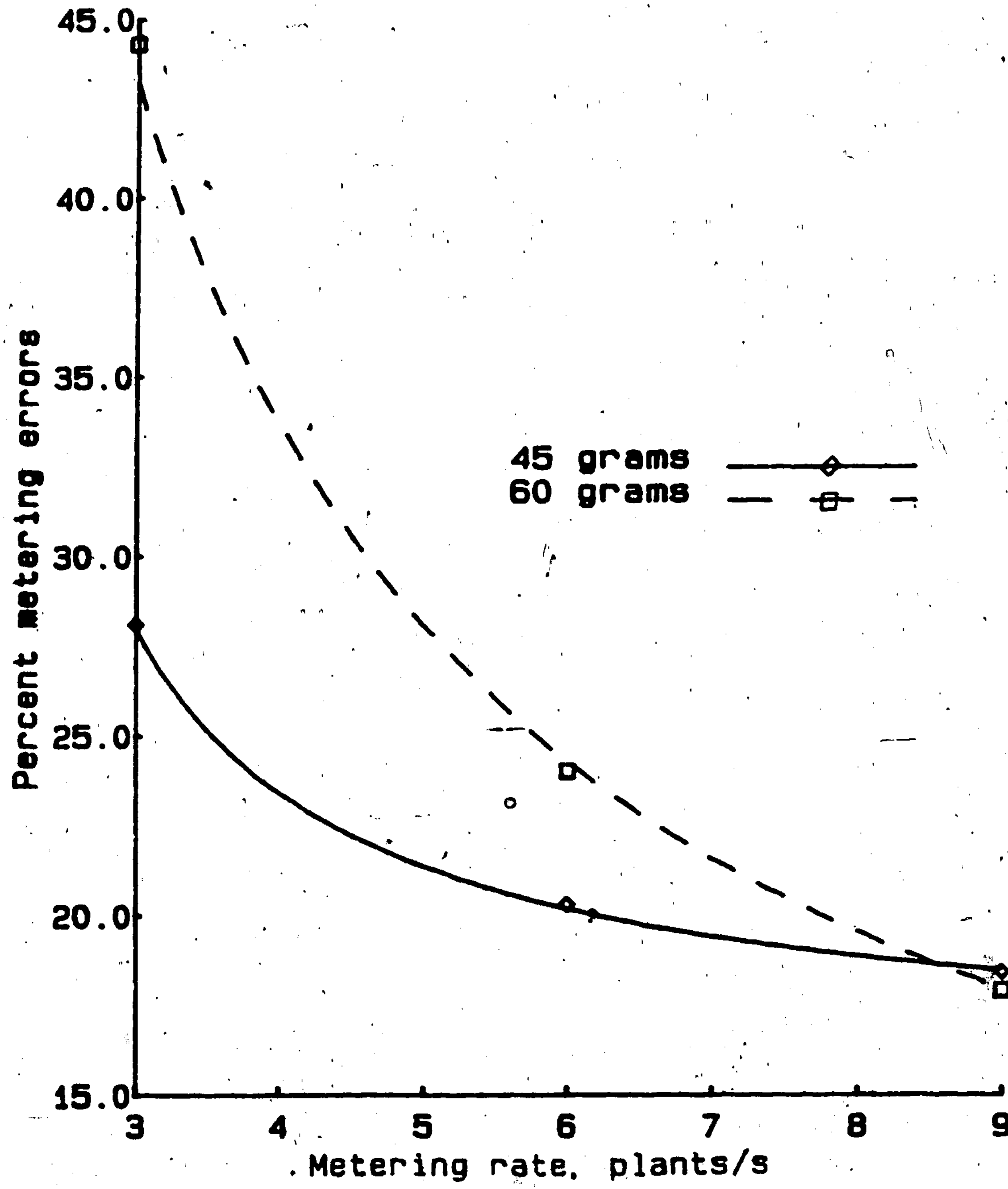


Figure 3.8 Seed size effect on metering performance

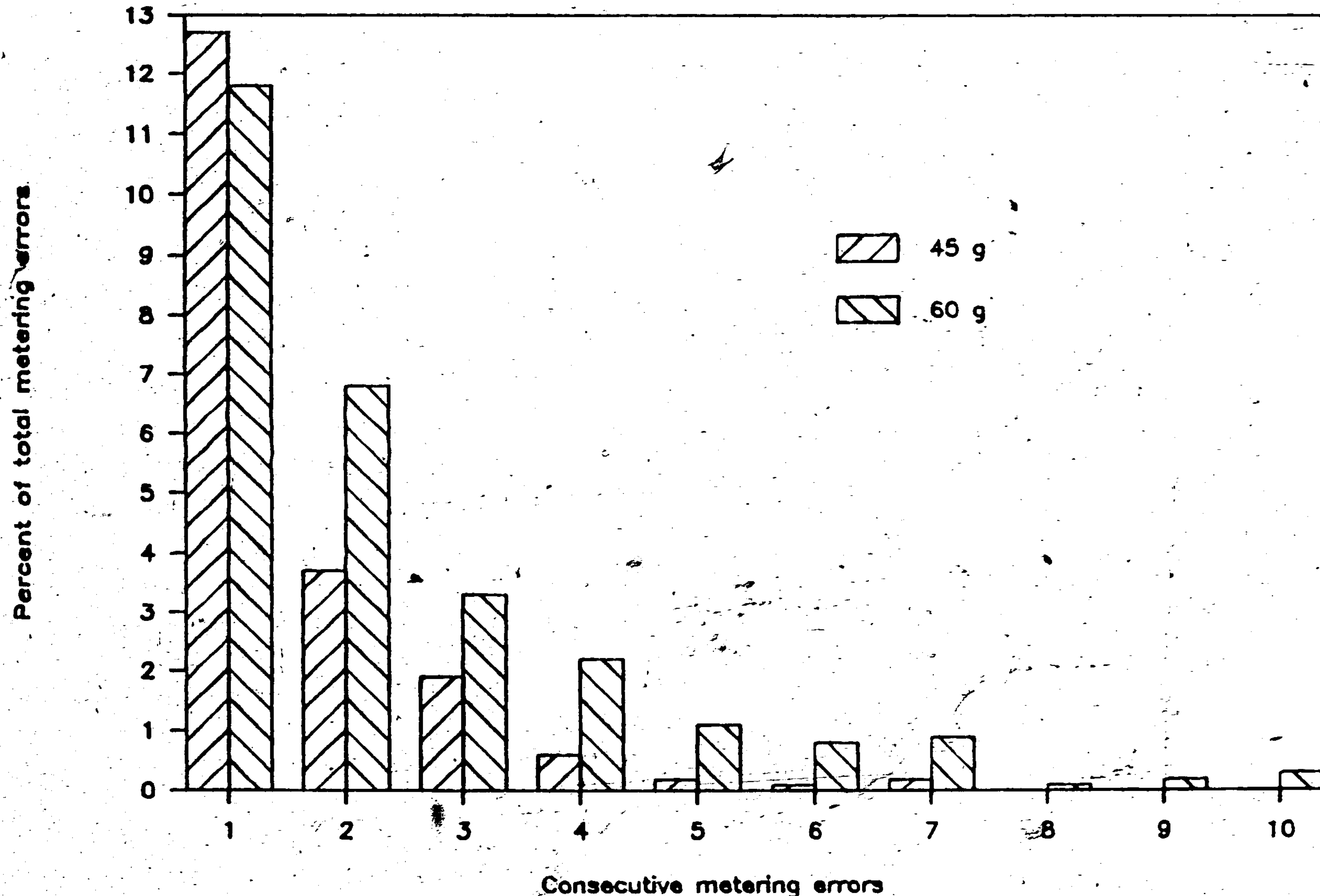


Figure 3.9 Consecutive metering error distribution for seed size

wheel velocity increased the penetration force exerted by the picks and resulted in a deeper and more secure engagement of the seed piece. The consecutive metering error distribution for all cut seed trials is summarized in Figure 3.10 and clearly shows a consistent improvement in metering performance as metering rate increased.

The analysis of variance for whole seed trials presented in Table 3.5 indicates that the metering rate is a significant factor for metering performance. Whole seed metering errors decreased as metering rate increased. However, metering rate effects are more pronounced for whole seed *versus* cut seed (Figure 3.11). The exceptionally high value of 55.4 percent metering errors at 3 plants/s was caused by insufficient penetration of the relatively heavy potatoes (50 to 100 g) which led to many premature releases. A similar situation was observed on high speed film by Sieczka et al (1986). This appears to support the significance of the metering rate x size interaction for cut seed.

The consecutive miss distribution for whole seed in Figure 3.12 provides a more detailed assessment of whole seed performance.

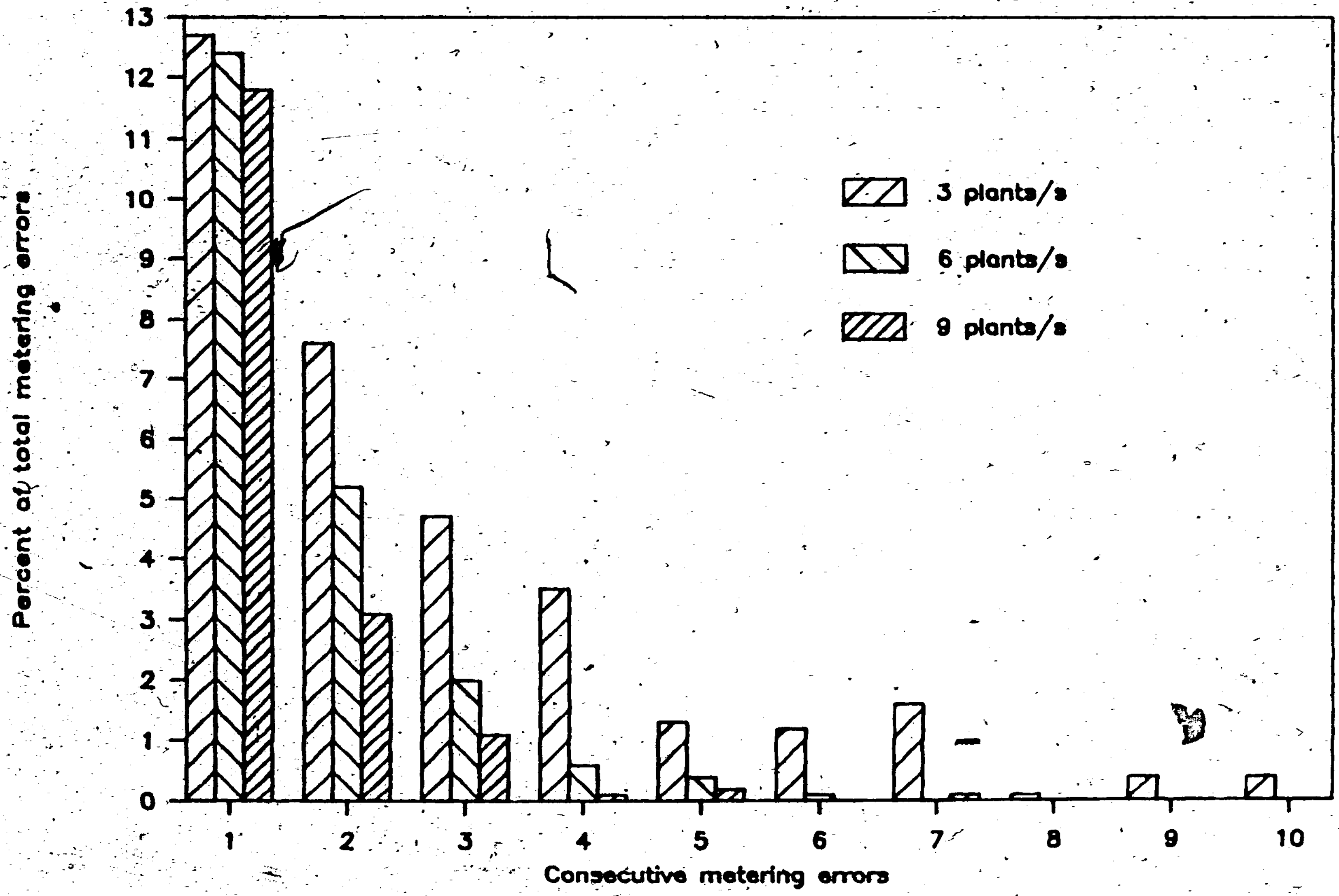


Figure 3.10 Metering rate effect on consecutive metering error distribution for cut seed

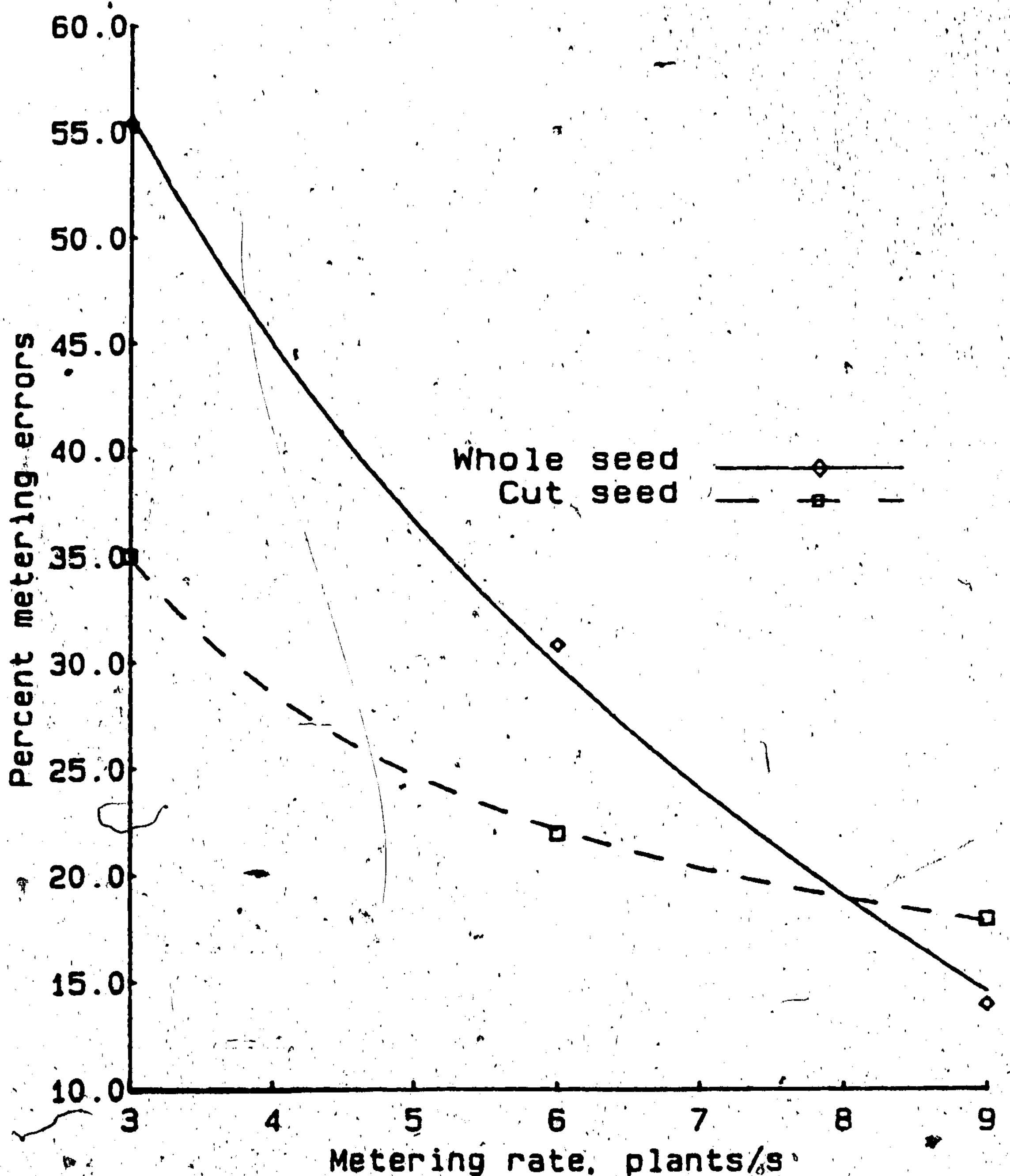


Figure 3.11 Metering performance of whole verses cut seed

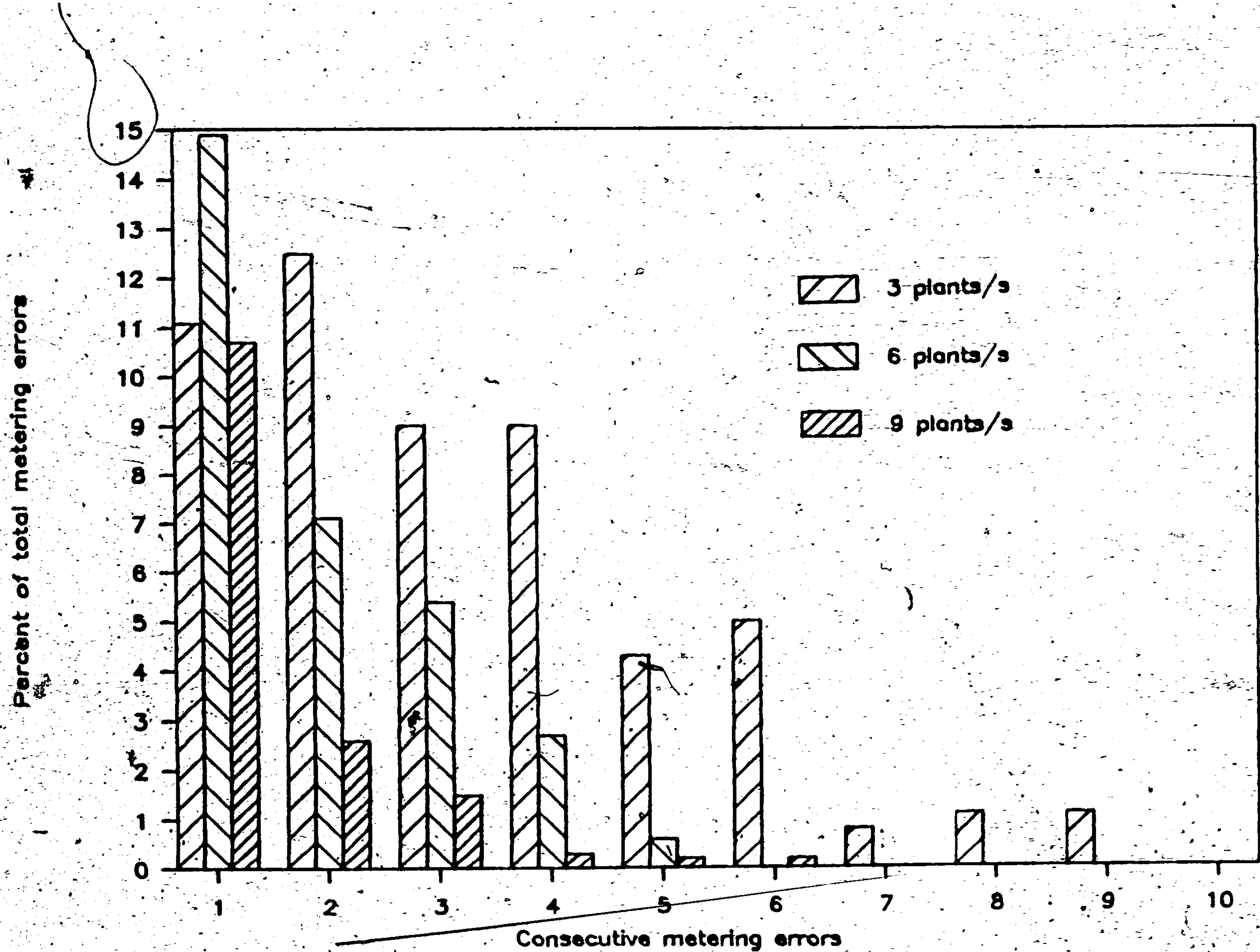


Figure 3.12 Metering rate effect on consecutive metering error distribution for whole seed

4. POTATO PLANTER MONITOR

4.1 Introduction

Although growers realize that potato seed attributes and planter operating conditions affect planter performance, a reliable means of accurately assessing performance in the field does not seem to exist. Today, operators are still seen riding on the planter to ensure adequate performance. Although this raises safety concerns, operator supervision provides a means of detecting mechanical problems as they occur and enables visual performance assessment. One-person planting operations have used elaborate mirror systems to monitor performance with some success. However, direct awareness of cup and pick-type planter performance could be possible through a monitoring system. The planter monitoring process, illustrated in Figure 4.1, encourages growers and planter operators to improve planter performance by avoiding undesirable interactions between seed potatoes, the planter and operating conditions.

4.1.1 Objective

The objective of this chapter is to discuss the design and development of a potato planter monitoring system capable of providing performance feedback to operators.

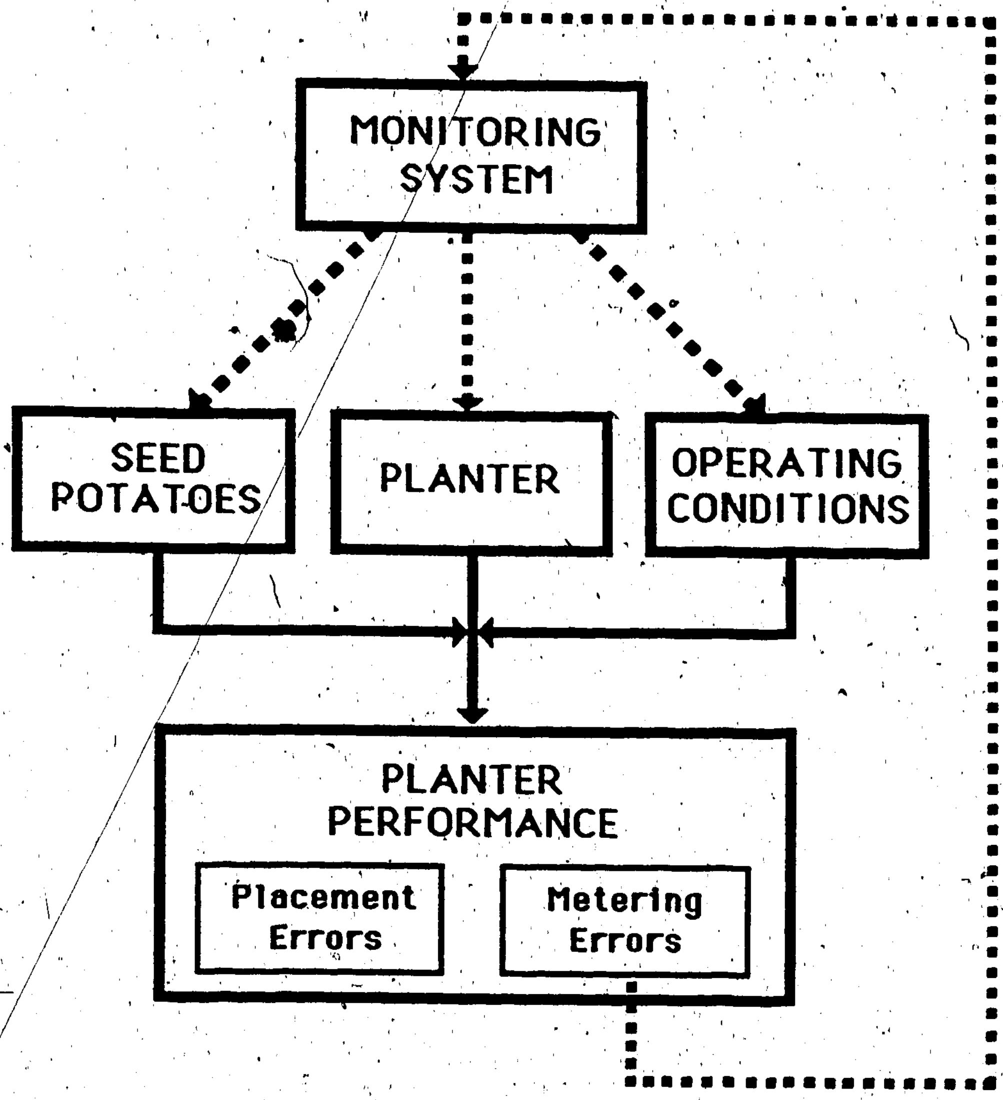


Figure 4.1 The potato planter monitoring process

4.1.2 Design Criteria

Improving potato planter performance has been a priority in the potato machinery industry for the last fifteen years. From the discussion on the effect of population density in section 2.2.1, the avoidance of consecutive metering errors caused, either by a disruption of seed flow, or an incompatibility within the planting operation, is more important than the accuracy of seed placement.

Gauthier (1985) assessed requirements of intelligent field management information systems in two main categories: functional and informational requirements. Functional requirements included: maintaining data consistency and validity, ability to handle a variety of information sources and transmission methods; the ability to adapt to the surrounding environment, and provision for displaying the information contained in memory. Information requirements were subdivided into attributive and historic categories. Field management information systems also need a means of altering system attributes in order to maintain system flexibility.

An accurate information base can be maintained only so long as correct information is received from the sensors. Indication of sensor malfunction alleviates the likelihood of erroneous information that may lead to performance degradation, equipment damage or safety hazards. Tylee (1986) presented a model-based approach to instrument failure detection.

Considering the requirements and limitations of the potato planting process, the following monitor design criteria were put forth:

1. Immediate visual indication of consecutive metering errors for each row.
2. Intermittent visual display of planter performance statistics for each row.
3. Visual indication of drive train and sensor malfunction.
4. Audio indication of defective metering elements.
5. Compatibility with cup and pick-type planters.
6. Efficient operation under field conditions.

The monitoring system developed from these criteria was tested under simulated conditions in the laboratory. Unfortunately a field prototype was not tested. However section 4.6 outlines some design details worth considering should further monitor development take place.

4.2 Hardware

The potato planter monitor's circuit consists of three distinct parts: the microprocessor board, the sensor system, and the display unit. For field applications, each planter row has a sensor system mounted in the appropriate position with shielded power and input/output wires leading to a sensor junction module on the planter. Details of sensor system operation, as discussed in section 3.3.2, should be understood in order to appreciate the following discussion.

Figure 4.2 illustrates how monitoring system modules function in relation to one another. The monitor module in the tractor cab contains the microprocessor board, display unit and input devices used to select the monitor's mode of operation. Sensor signals, from each row, are relayed through the junction module to the monitor module. The tractor's twelve volt electrical system provides an independent power supply to the monitor module and the junction module.

Four sources of performance feedback are available from the display unit (Figure 4.3). Each vertical array of LEDs corresponds to one of the planter's metering mechanisms. The four yellow metering LEDs operate in a up-down fashion to indicate the number of consecutive misses that have occurred in the last four metering events. The top and bottom status LEDs are red and indicate potato sensor and metering event sensor malfunction respectively. The bottom status LED also serves as a drive train malfunction indicator. A green row-select LED was positioned between the malfunction indicators to indicate the row corresponding to the statistics on the alphanumeric display. One of five performance statistics can be displayed on the single line, sixteen character liquid crystal display unit (LCD). The buzzer, mounted on the back of the display unit, serves to indicate a defective metering element.

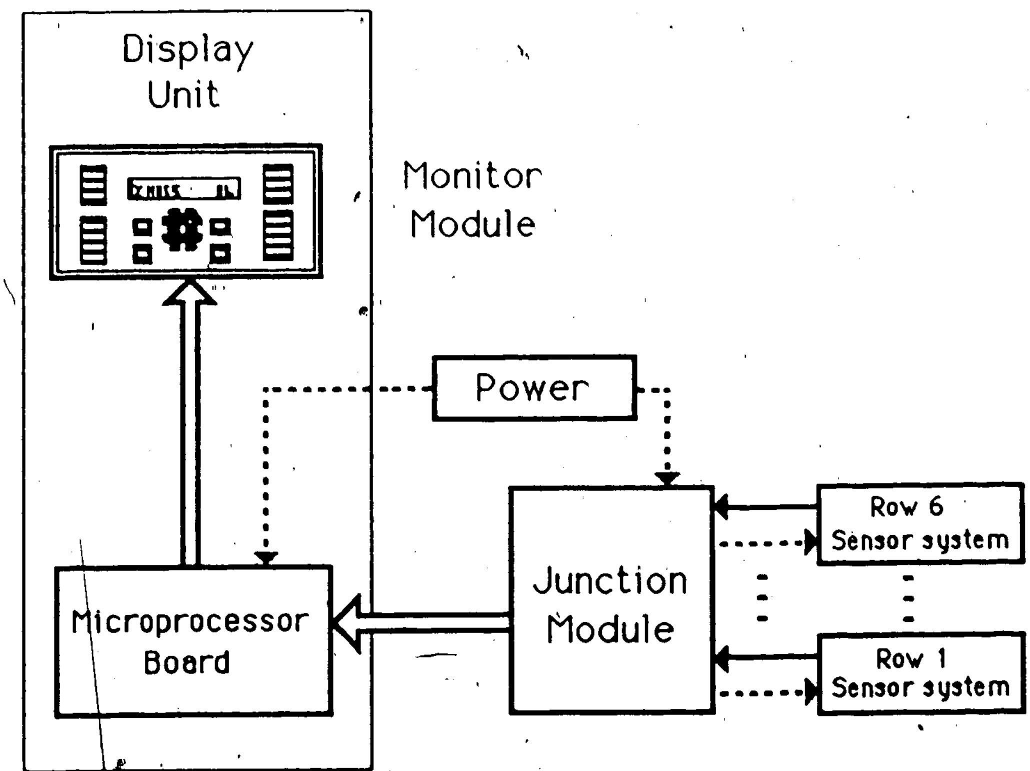


Figure 4.2 Block diagram for potato planter monitor modules

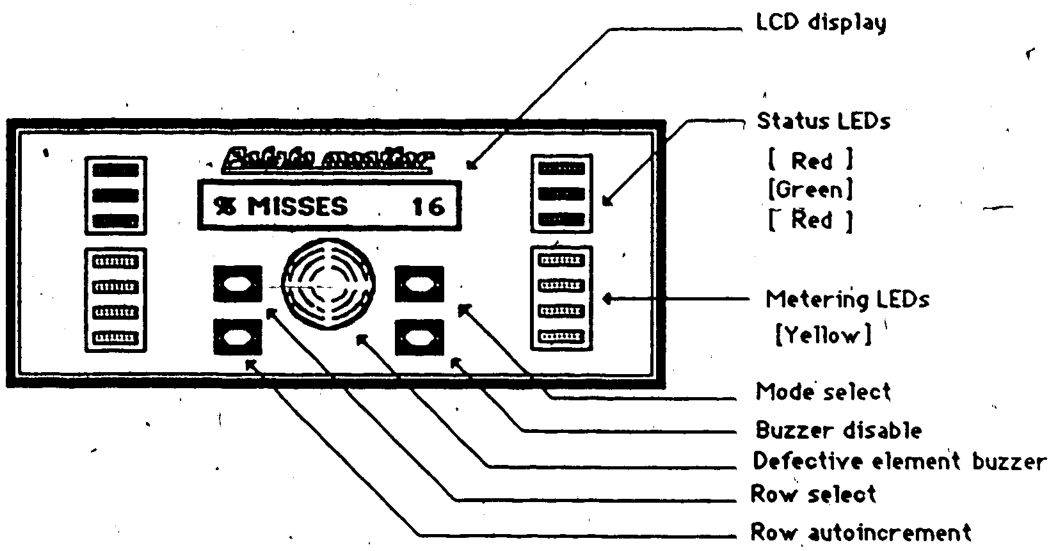


Figure 4.3 Monitor display unit

4.2.1 Circuit Description

A composite view of hardware function is illustrated in the block diagram presented in Figure 4.4. A complete list of the monitor's electronic components is found in Appendix C. Operating characteristics of the monitor's integrated circuits can be found in Motorola Semiconductor Products Inc. reference manuals.

4.2.1.1 Microprocessor Board

At the heart of the monitoring system is a M6809 microprocessor with 2K of read only memory (ROM) and 2K of random access memory (RAM). The M6809 is an eight bit microprocessor with a 16-bit address bus and an eight-bit data bus . Monitor circuit development took place on a perforated circuit board that was mounted on an aluminum frame. All components were set in sockets to facilitate component interchange. The wire wrap technique was used to make the required connections between socket pins.

Incoming 5.0 V (Vcc) and ground (Gnd) wires were attached to the Vcc or Gnd bars running the length of the underside of the microprocessor board. A 150 uF capacitor was positioned between the incoming end of the Vcc and Gnd bars to reduce power supply fluctuations. Decoupling capacitors (10 uF) were positioned between the Vcc and Gnd bars at 25 mm intervals. This provided a steady 5 v potential across the processor board.

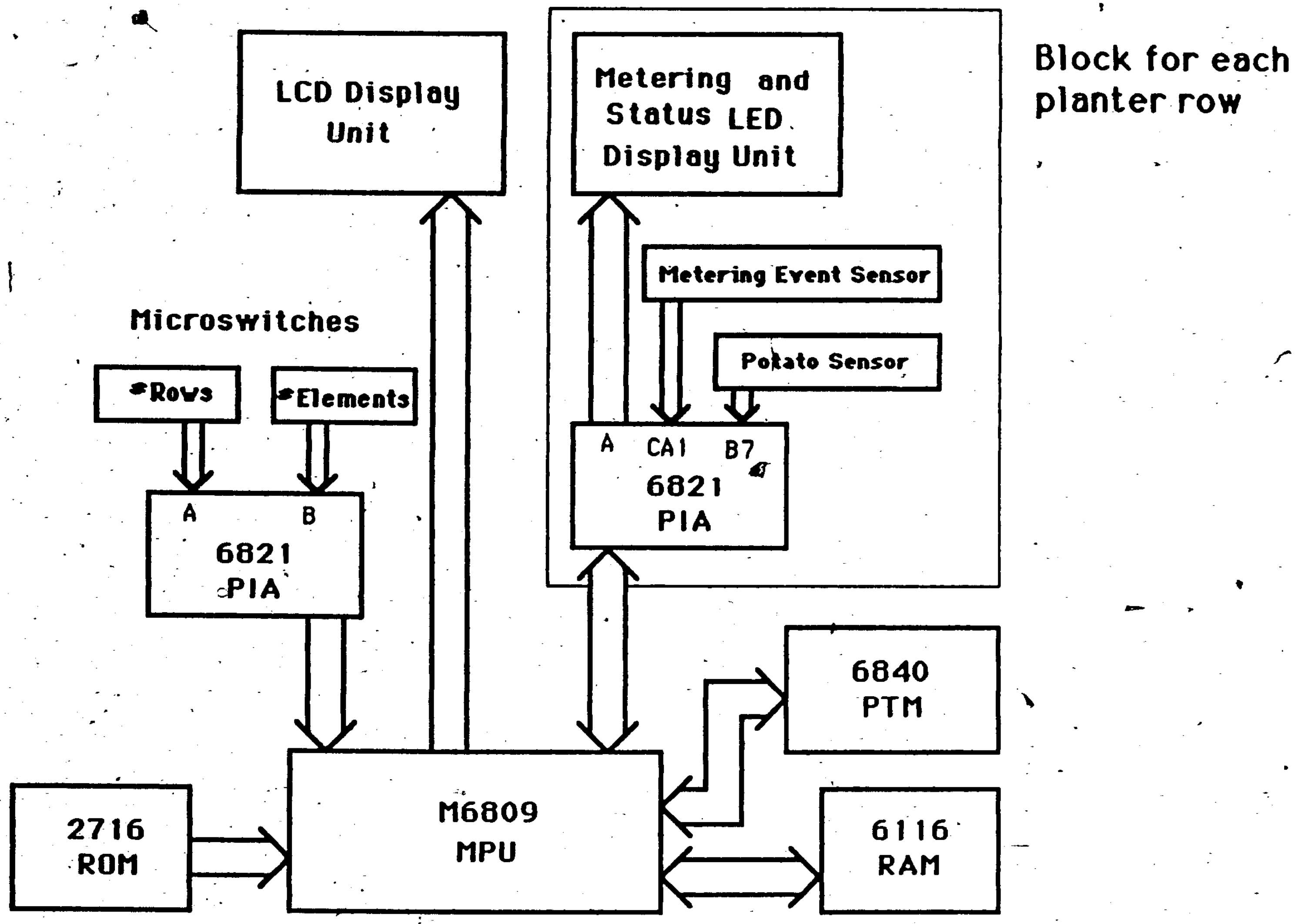


Figure 4.4 Potato planter monitor block diagram

A single 3.58 MHz crystal connected to ground via two 27 pF capacitors produced the external clock signal. The crystal was connected to the EXTAL and XTAL pins on the M6809 microprocessor in order to activate the the M6809's internal oscillator at four times the crystal frequency (14.31 MHz). Circuit details are given in Appendix D1.

Several pins of the M6809 were unused. Consequently their voltage potential was set to Vcc through 4.7 kΩ pull-up resistors to ensure proper microprocessor function. The nonactive control pins were the Fast Interrupt Request (FIRQ*), Halt (HALT*), Direct Memory Access/Break (DMA/BREQ*), and Memory Ready (MRDY). Refer to Appendix D1 for microprocessor circuit details.

A reset circuit (Appendix D1) was implemented to eliminate multiple pulses due to contact bounce. A normally open momentary push button switch was connected via two cascaded inverters (7414 Hex Schmitt-Trigger inverter) to the reset pin on the M6809. A pull up resistor of 10 kΩ was connected to the inverter input thus yielding a normally high voltage. When the reset button was depressed, the voltage potential on the reset pin was drawn to ground and the microprocessor's reset instructions were executed.

Buffers were installed on the data, address and control lines to prevent loading conditions. Data lines were buffered with an octal bus transciever (74LS245), and address and control lines were buffered with octal buffers/line drivers/line receivers (74LS244). The buffered control lines on the M6809 were the E and Q clock signals, bus status (BS), bus available (BA), and read write (R/W*) lines. The E* pin on the data line buffer was grounded to permit continuous data line access. The DIR pin on the data line buffer was connected to the buffered R/W* ~~line~~ to control the direction of data transfer. The E1* and E2* pins on the address and control line buffers were grounded to ensure continuous access to these lines. Appendix D1 contains details for circuit buffers.

Buffered address lines A12 to A15 were decoded by a 74LS154 four to sixteen line decoder demultiplexer. The decoder operated on the E clock cycle through a NAND gate (7400 two-input positive NAND gate). Decoder output provided sixteen select lines (SEL 0 - SEL F) which effectively divided the 64k of addressable space into sixteen 4k blocks. Refer to Appendix D2 for the address decoding circuit diagram. All addresses in the following discussion are in hexidecimal notation.

The 2716 erasable programmable read only memory (EPROM) was connected to operate in the addressable range of F800 to FFFF. To address this memory block, further decoding was necessary and was accomplished by comparing the SEL F line and the address line A11 with a NAND gate. The output from the NAND was connected to the output enable pin (G*) on the EPROM. Thus the EPROM was selected when the address on the address bus fell between F800 and FFFF. An additional EPROM address space (F000-F7FF) was provided for future program expansion. Address decoding for this EPROM was accomplished by comparing the SEL F* and A11* lines with a NAND gate. The resulting signal was fed to the G* pin of the second EPROM. Hence, the two EPROMs were contained in a continuous address space. Refer to Appendix D3 for the EPROM circuit diagram.

A 6116, 2048 word by eight bit, high speed, static CMOS RAM, provided 2k of memory. The 6116 chip has a low power requirement, fast access time, is TTL compatible, and is compact in design. The RAM's address range spanned memory locations D000-D7FF. Address lines A0-A6 were decoded to select one of the rows in the RAM's internal matrix while address lines A7-A10 were used to select the matrix columns. A by a high to low transition on SEL D line provided the 6116 RAM's chip select signal. Data transfer to or from RAM memory, via the buffered data bus, was controlled by the read/write line. Refer to Appendix D4 for the RAM circuit diagram.

Two 6850 asynchronous communications interface adapters (ACIAs) were connected to the monitoring system for the purpose of serial communication with a microcomputer. The host ACIA was located in the memory space of E008 to E009 while the terminal ACIA occupied addresses E00A to E00B. Address decoding was based on the SEL E signal and address lines A0 to A3. The data bus was connected to both of the ACIAs as was the R/W* line and the interrupt request (IRQ) line. Unused pins Vss, DCD* and CTS* were grounded. External access to the ACIAs was provided through a D-9 connector. Appendix D5 illustrates the ACIA circuits. Although serial communication is not supported by current system software, the necessary hardware is in place and could be useful for downloading the distribution of consecutive misses for each row to a microcomputer. This would facilitate a detailed assessement of planter performance in terms of established planting density relationships.

Peripheral interface adapters (PIAs) were used to provide a means for parallel communication between external devices and the microprocessor system. A sensor system and a corresponding vertical array of seven light emitting diodes (LEDs) were associated with each row PIA. The monitoring system accomodates planters with two to six rows and therefore row PIAs are labeled PIA1 to PIA6. An additional PIA was needed to read the microswitch values that are used, by the operator, to set the number of planter rows and the number of metering elements for each row. Row PIAs were assigned addresses 1000, 2000, ...,6000 and the microswitch PIA occupied the address 7000. The corresponding select lines, SEL 1 to SEL 7, were connected to the respective PIA's CS2* pin. Address decoding was completed by connecting the address lines A0 and A1 to RS0 and RS1 respectively. The unused chip select pins, CS0 and CS1 were connected directly to Vcc. Data bus connection facilitated the transfer of information from the sensors and to the display LEDs. Refer to Appendix D6 for the row PIA circuit diagram, and Appendix D7 for the microswitch PIA circuit diagram.

The MC6840 Programmable Timer Module (PTM) provides the microprocessor system with three timers. Since the PTM has data input and output requirements, the eight data bus lines were connected to the PTM. The PTM occupied memory locations E000-E007. This PTM was selected by the SEL E line which was connected to the PTM's CS0* pin. Address lines A0, A1, A2, and the inverted A3 line were connected to lines RS0, RS1, RS2 and CS1 respectively, to complete addressing requirements. Control lines R/W*, E, RES* and IRQ* were connected to their corresponding PTM pins. Two of the three on-board timers (timers two and three) were cascaded to give a five-second timeout signal. Timer one assumed an internal clock function. The periodic five-second timeout initiated a metering statistic update and refreshed the LCD display. Appendix D8 contains details of the PIM circuit.

4.2.1.2 Input Devices

Two eight bit microswitches were used, one to indicate the number of planter rows, the other to set the number of metering elements per row. Port A of the microswitch PIA corresponded to the number of rows and port B was used to indicate the number of metering elements per row. Pins on the 'on' side of the microswitch were connected to Vcc. Pins on the 'off' side of the microswitch were connected through a 10 kΩ resistor, to ground before being tied to either A or B port pins on the microswitch PIA. Refer to Appendix D7 for circuit details.

The dual-sensor, event-triggered system discussed under section 3.3.2 was used to determine metering status. The output signal from the Hall effect switch (3019T, Sprague), or metering event sensor, was passed through two inverters to obtain a TTL-compatible logic signal (Appendix D10). This signal was in turn fed to the CA1 pin of the PIA corresponding to the interrupting sensor. High to low transitions on the CA1 pin signalled a metering event and interrupted the microprocessor to indicate the need for a metering update.

A photoscanner (MCS-651 series, Warner Electric, Marengo, IL.) was used as the potato sensor (Appendix D9) and determined the metering status. The photoscanner used a modulated infrared light beam that was immune to external sources of light and had an operational range of 50 cm. Both the photoscanner transmitter and receiver had a 5 V power supply requirement. The output from pin 1 of the receiver amplifier was pulled up with a 4.7 kΩ resistor and fed through a NAND gate acting as an inverter. The resulting signal was passed to pin 7 of port A on the row PIA corresponding to the potato sensor. Thus, a broken beam produced 5.0 V (logic 1) and an intact beam resulted in 0.0 V (logic 0).

Five operator input devices were included in the operating system. Three momentary closed push button switches were used for the reset, mode change, and row change functions. The mode change and row change circuits are illustrated in Appendix D11 and D12 respectively. Two toggle switches were used, one for the row autoincrement function and the other for the buzzer disable function.

4.2.1.3 Output Devices

Three types of output device were used in the monitor module: an alphanumeric display unit, vertical arrays of seven LEDs to indicate metering and status information, and a buzzer. These devices are illustrated on the monitor display unit in Figure 4.3.

A one line by sixteen character, top view, five by seven dot matrix alphanumeric liquid crystal display

(LCD) module (Printed Circuits International PCIM 200) was used to display messages and performance statistics. A performance statistic corresponding to one of five modes of operation was displayed constantly when the planter was in operation. For example, a typical display would be '% MISSES 16', where '%MISSES' is the descriptor and '16' represents the performance statistic. The LCD display module employed low power CMOS circuitry and was connected directly to the M6809 data bus. Sixty-four commonly-used ASCII characters formed the character set and could be passed directly from the data bus through the module's sixteen character buffer and onto the display line. The display was automatically refreshed, temperature compensated and had fully adjustable contrast. Control instructions allowed the display to be operated in various modes. The module required thirteen pin connections, eight of which were data lines. Other lines were Vcc, ground, and the CS* pin which was connected to the SEL 0 pin of the address decoder, placing the device at the address 0000. The Memory Write pin (MWR*) was connected to the R/W* line of the M6809. The remaining pin, memory read (MWR*), was connected to Vcc in order to deactivate the memory read function. Refer to Appendix D13 for the display circuit diagram.

The metering and status LEDs were connected to the B side of row PIAs through a high-voltage open-collector output buffer/line driver (7407N). In order to illuminate a LED, the driver had to be supplied with a low voltage from PIA data port pins. Output lines 0 through 3 on the PIA were connected to the four yellow metering LEDs to indicate the number of current consecutive metering errors. Output lines 4 and 6 were connected to the red LEDs which were used to indicate a malfunctioning metering event sensor or potato sensor. The middle status LED was green and was termed the row select LED. Performance statistics on the LCD corresponded to the row with the illuminated row select LED. The current flowing through the LEDs was limited by 47Ω resistors. This provided adequate illumination while ensuring LED longevity. LED anodes were connected to the Vcc and the cathodes were connected to the driver which provided the ground needed to turn the LEDs on. All LEDs were rectangular in shape and were visible in an outdoor environment.

The defective element indicator was a 5-volt buzzer (Radio Shack 273-068). The buzzer produced a sound loud enough for the operator of a tractor to hear. The buzzer was connected through output line 7 on the B side of the row PIAs and was driven by an open collector line driver identical to the ones used for the LED circuits. Thus the buzzer was activated when the PIA output was low.

4.2.1.4 Power Supply

Although a 5.0 V switching regulator was considered for field operating conditions, laboratory testing was done with a Hewlett Packard 6236B power supply unit set to 5.0 V.

4.3 Software

Program software provided the 6809 microprocessor with instructions for the monitoring algorithm in an effective and well-defined manner.

The potato planter monitor program was written in Motorola 6809 Assembler Language. All programs associated with this project were assembled using the UNSP:M6809ASM assembler implemented on the MTS system at the University of Alberta. The resulting object code was downloaded to EPROMS using a Unipak System 19 Data I/O unit. Program and hardware debugging were done with the assistance of a Hewlett Packard model 1615A logic analyzer and the potato planter simulation unit. The assembled monitor program, as listed in Appendix E, occupies 1.8 K of ROM and is designed to function with two to six sets of sensors.

4.3.1 Memory Structure

Memory structure can be thought of as the ordered arrangement of program and memory addresses. The six identifiable divisions in the potato monitor's memory structure are: device addresses (Appendix F1), program addresses in ROM (Appendix F2), system vectors in ROM (Appendix F3), ROM data addresses (Appendix F4), program variable addresses in RAM (Appendix F5) and RAM data blocks for each row (Appendix F6). Program-variable address assignments and descriptions are on lines 13 to 89 of the program listing in Appendix E. Alphabetic listing of variable names, together with the line numbers they were referenced on, are listed in the cross reference section of Appendix E (assembler page numbers 17-19).

Due to identical program and memory requirements for each row being monitored, a structured, top-down programming approach was employed and relative addressing was used extensively. Base addresses for row PIAs were arranged at address intervals of 1000. Similarly row data blocks in RAM were arranged in address intervals of 0100. This allowed one block of program code to process the input and output requirements for two to six rows and made the iterative performance statistic calculations more efficient.

System service routine addresses for the interrupt request function (IRQ), non maskable interrupt (NMI), and reset (RESET) were assigned to ROM addresses FFF0-FFFF. If the pins corresponding to these microprocessor functions recognize a transition in logic voltage, the processor is diverted to the appropriate internal instructions before program flow is directed to the function's address.

4.3.2 Description

The program listing in Appendix E is commented extensively and flow charts are utilized in the following discussion as an aid to understanding program logic. For general questions related to 6809 Assembly language programming, the reader is referred to Leventhal (1981).

Upon a reset condition, the monitoring system executes an initialization sequence and then simply waits for interrupt signals (Figure 4.5). When interrupts occur, one of four options are pursued: a metering update, a statistics and display update, a mode change to alter the type of statistic on display, or a row change to alter the row currently displayed on the LCD. A fifth mode for displaying the distribution of consecutive metering errors was only partially implemented and thus remains inoperable. The IRQ service routine is used to identify system needs and directs program flow. The general overview of the IRQ service routine presented in Figure 4.6 illustrates the interrupt-driven nature of the monitoring program.

4.3.2.1 Initialization

The flow chart for the initialization routine is set out in Figure 4.7. Initialization of the LCD display involved setting parameters within the display itself. This facilitated passage of ASCII characters from microprocessor registers to the display buffer through a single memory location. Ten display initialization flags (listed in hexidecimal notation)

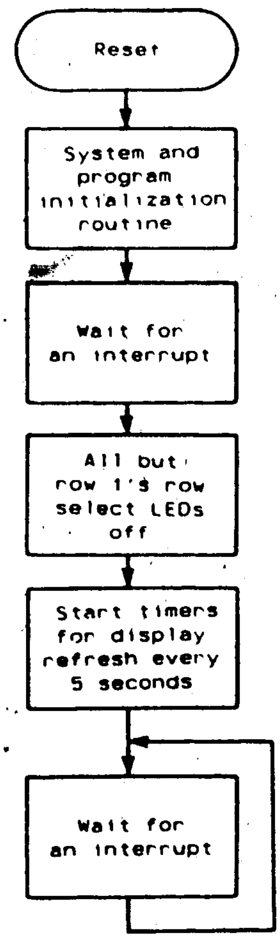


Figure 4.5 Potato planter monitor program flow chart

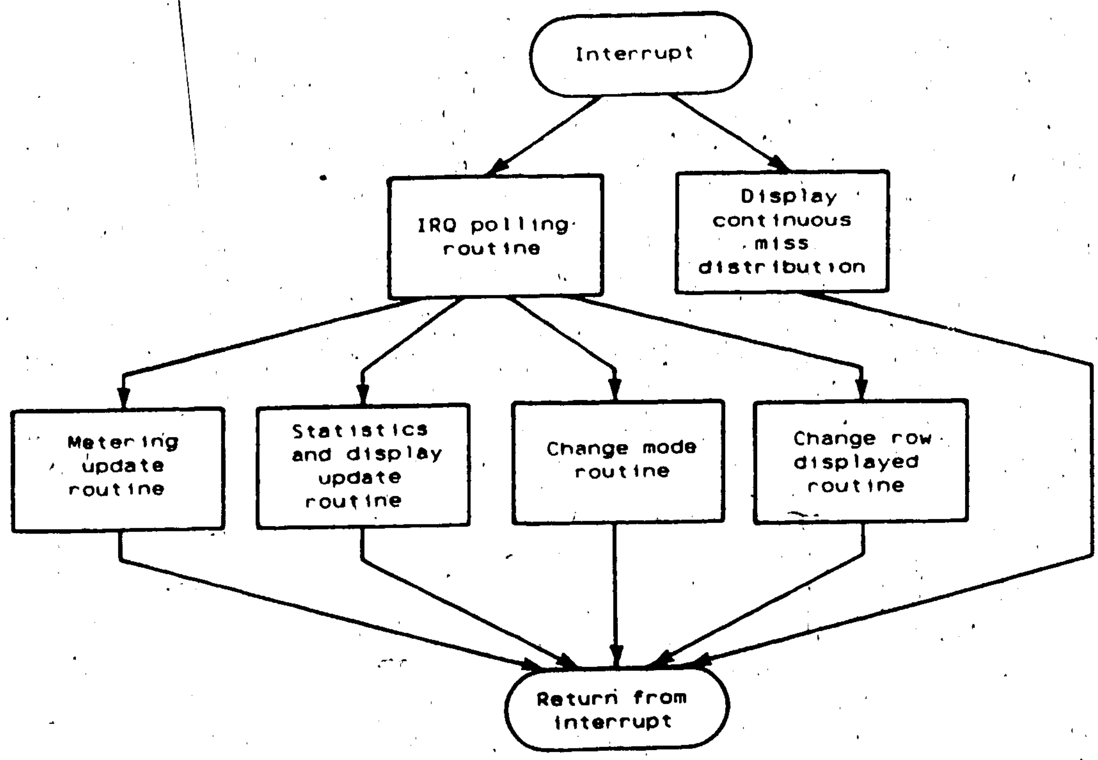


Figure 4.6 IRQ service routine flow chart

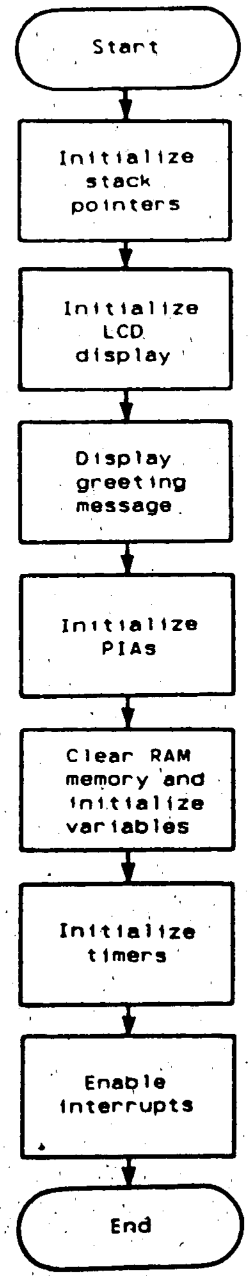


Figure 4.7 Initialization routine flow chart

were sent to the display in the following order.

1. 68 reset blank display
2. 6B set visible cursor
3. 61 set blinking cursor
4. 6D set cursor line
5. 62 reset blinking display
6. 65 auto increment cursor
7. 67 set up for increment
8. 6E reset rapid load
9. 00 blank characters
10. 8A clear display

The subroutine short delay, SDELAY, was used to give the display ample time to set up. After the flags were sent to the display, the display was cleared by the subroutine CLRLCD.

To display a message, a series of ASCII characters were fed to the LCD display with a short delay after each character to allow for latch time. The greeting message, "$POTATO MONITOR$", was displayed on the LCD immediately after a reset condition.

A PIA reset was necessary to initialize the PIAs in their direction of data transfer and to set initial operation conditions. Row PIAs were initialized with port A as inputs and port B as outputs with the CA1 control line enabled. Therefore, a transition on line CA1 would cause an interrupt in the system when a metering event ocurred. Side B was initially set to FF in order to shut all the metering LEDs off. The microswitch PIA was initialized with both sides as inputs, port A corresponding to the number of rows, and port B the number of metering elements per row.

A memory initialization routine cleared all RAM locations prior to planter operation. The RAM locations, starting with D000 and ending with D7FF were sequentially set to 00. Program variables then were initialized.

Microswitch settings were read and their values were stored accordingly. An initial memory offset for the number of consecutive misses per element was calculated by adding 10 to the number of elements per row.

The primary task of the PTM reset was to initialize the timers to produce an interrupt every five seconds for purposes of the statistics update and display refresh. Timer latches 2 and 3 were loaded with decimal values 44642 and 50 respectively. Timer 2 was set for 16-bit operation, continuous mode, output enabled, interrupt mask set and internal clock. Timer 3 was set for external clock, 16-bit operation, continuous mode with both the interrupt and output enabled. All timers were preset until a metering event occurred.

4.3.2.2 Main Program

The main program was engaged on the first metering event after start up. PTM timers were started and the display mask 11011111 (binary notation) was sent to port B on PIA1 to illuminate row one's row-select LED.

The primary purpose of the main program was to have instructions for the processor to execute if none of the interrupt service routines were engaged. As such the interrupt-driven main program contained a CWAI instruction which enabled interrupts and stacked all registers in anticipation of the next interrupt. Once an interrupt occurred and was serviced, program control returned to the main program.

4.3.2.3 IRQ Service Routines

The IRQ interrupt service routines performed a number of functions including: user-generated row and mode change requests, metering performance updates, statistics update, and sensor malfunction tests. Upon entering the IRQ service routine, interrupts are disabled by setting bits 6 and 4 of the condition code register. Figure 4.8 provides a flow chart of the IRQ polling routine. Each device connected to the IRQ line was polled in sequence to identify the source of the interrupt. Bit 7 (B7) of the interrupting PIA's status register was set. Upon identifying the source of the interrupt, the program flow was directed to the appropriate service routine. Row PIAs were checked

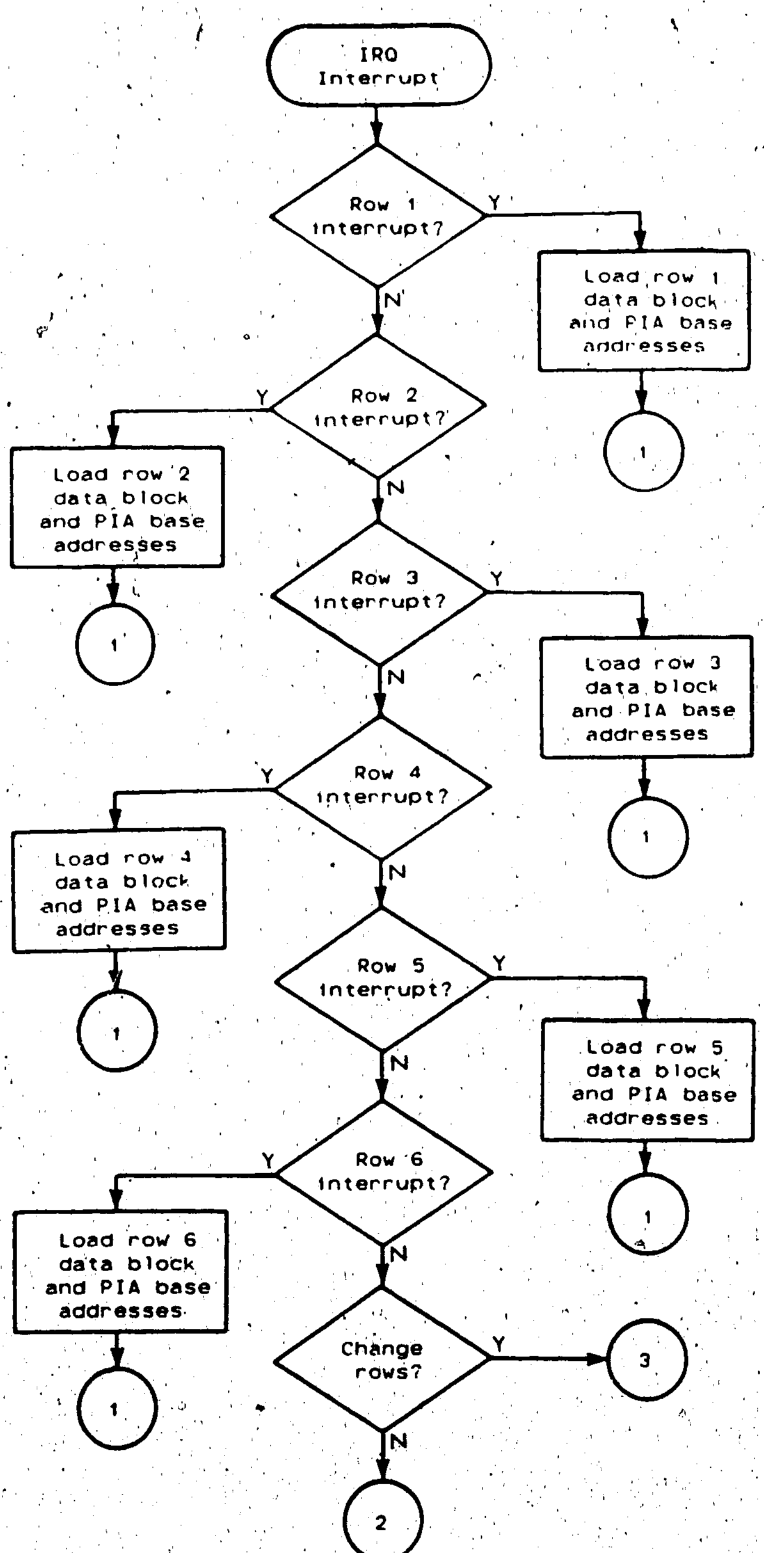


Figure 4.8 IRQ polling routine flow chart

first to determine if a metering event had occurred. If a metering event was not indicated, the microswitch PIA was polled to see if a row change had been requested. Barring successful identification of an interrupting device, the program defaulted to the statistics update and display refresh routines. A return from interrupt (RTI) instruction was placed at the end of every service routine to direct program flow back to the main program.

When a metering event was detected, the base address of the data block containing the row's metering statistics was loaded into the X register and the base address of the interrupting PIA is loaded into the Y register. This allows relative addressing to be used in the metering update routine.

4.3.2.4 Metering Update

Metering update logic is illustrated in Figure 4.9. When a metering event is indicated a check is made to determine whether a previous metering event has ocurred since the last statistics update. If not, a potato sensor malfunction test is performed. In this manner all potato sensors are checked for proper function once every five seconds. Further comment on defective sensor checks can be found in section 4.3.2.10.

Program variables affected by the metering update routine are defined on lines 78 to 89 of the program

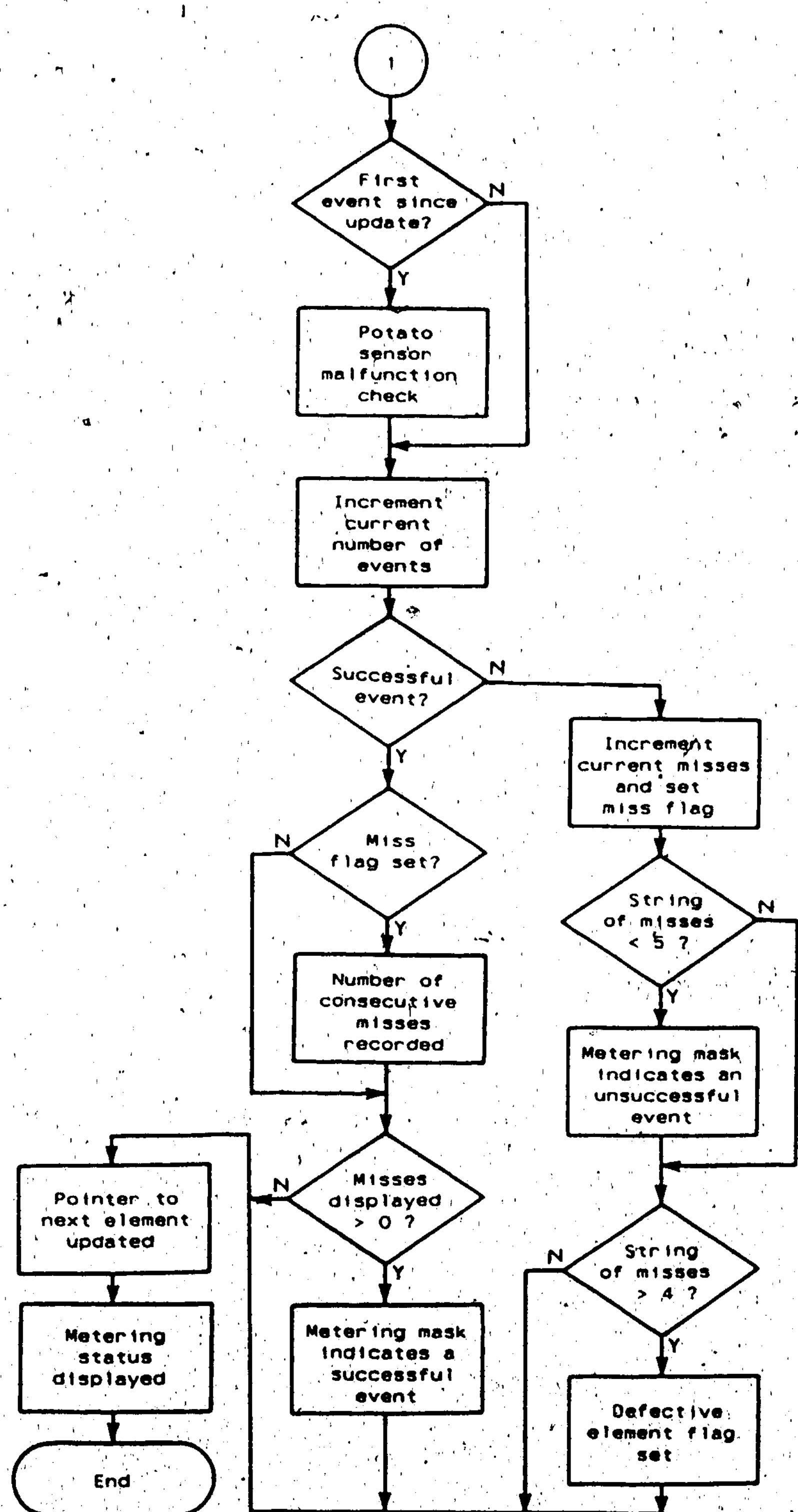


Figure 4.9 Metering update flow chart

listing (Appendix E). The memory offsets from data block base addresses also are listed. A metering update addresses only the data block associated with the interrupting PIA. The current events counter (CNEV) is incremented before a check for a successful metering event is performed (bit 7 of port A = 1). If a metering error has occurred the current metering error counter (CNMISS) is incremented and a check is done on the number of consecutive misses (MISLED). If less than four of the yellow metering LEDs are illuminated, the top unlit metering LED is turned on and the number of misses displayed (MISLED) is incremented. A lookup table was used to determine the LED mask which represents the number of consecutive metering errors.

If a particular metering element consistently failed, a buzzer was sounded. This necessitated keeping track of how each element in the metering chain performs. Variable NEXTEL contains the offset from the data block's base address to the memory location containing the count of consecutive misses associated with the interrupting metering element. Should the successive metering errors be greater than four, the buzzer is turned on, otherwise the the number of consecutive misses for that element is incremented.

If bit 7 on port A of the interrupting PIA is zero a successful metering event is indicated. The number of consecutive misses displayed on the yellow metering

LEDs are checked and if greater than zero, the top-most illuminated LED is turned off.

A successful metering event indicates that the interrupting metering element is functioning properly and, therefore, the consecutive miss count for that element is zeroed. The offset to the memory location of the next element to be monitored in the interrupting row is then decremented. If a complete cycle of the metering chain is indicated, the offset (NEXTEL) is reset to point to the memory location corresponding to the next expected metering element.

The monitoring system could only display metering performance statistics on the LCD display one row at a time. This required the row select mask (LEDROW) to be and-ed with register A to preserve the row select indicator (green status LED). At this point the status word in register A contains current metering and system status information for the interrupting row. Metering and status LEDs then were updated by sending the contents of register A to the interrupting PIA's B data port.

4.3.2.5 Statistics Update

Upon an interrupt from clock 3 of the PTM (every 5 s), the statistical update took place as illustrated in Figure 4.10. Data blocks for each row were updated in an iterative manner by the statistics calculation subroutine CALC (Figure 4.11). Five statistics are

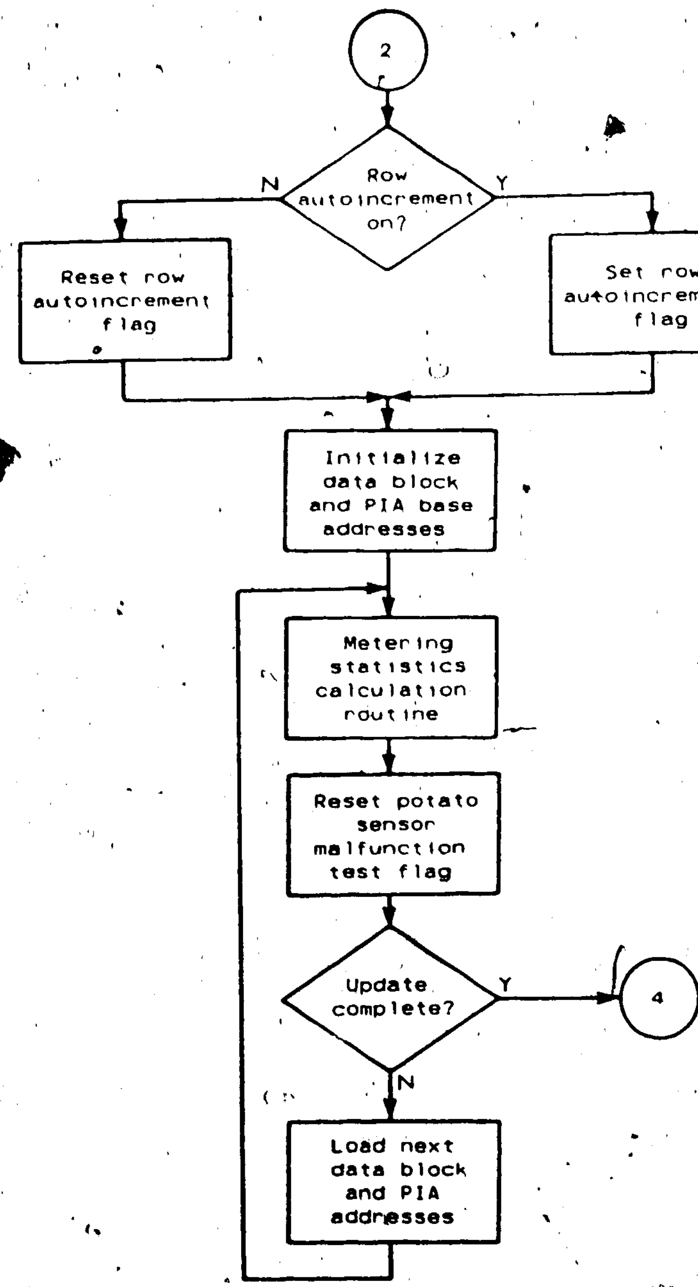


Figure 4.10 Statistics update flow chart

derived in the calculation routine: planting rate, current percent misses, total number of events, total number of unsuccessful metering events, and total number of successful metering events. The statistics update routine performs the additional function of checking for a malfunctioning metering event sensor. After performance statistics have been updated and sensor checks performed, the LCD display is refreshed with updated values and PTM timer 3 is reloaded to count down the time to the next update.

Planting rate is expressed in plants/min and is calculated by multiplying the current number of events by 12, the number of updates in a minute. The 2 byte result is stored in PLRATE.

The current percentage of metering errors is calculated by dividing the product of the current number of events (CNEV) and 100 by the current number of misses (CNMISS).

The total number of events (TEVENT) was updated by adding the current number of events (CNEV) to the total number of events. The address of TEVENT was loaded into the X register and CNEV was loaded into the A register in preparation for the addition subroutine call. If the planter was operating and no metering events occurred in the last five seconds, variable CNEV would be zero and, thus, a malfunctioning metering sensor was assumed. Metering sensor malfunction was indicated by

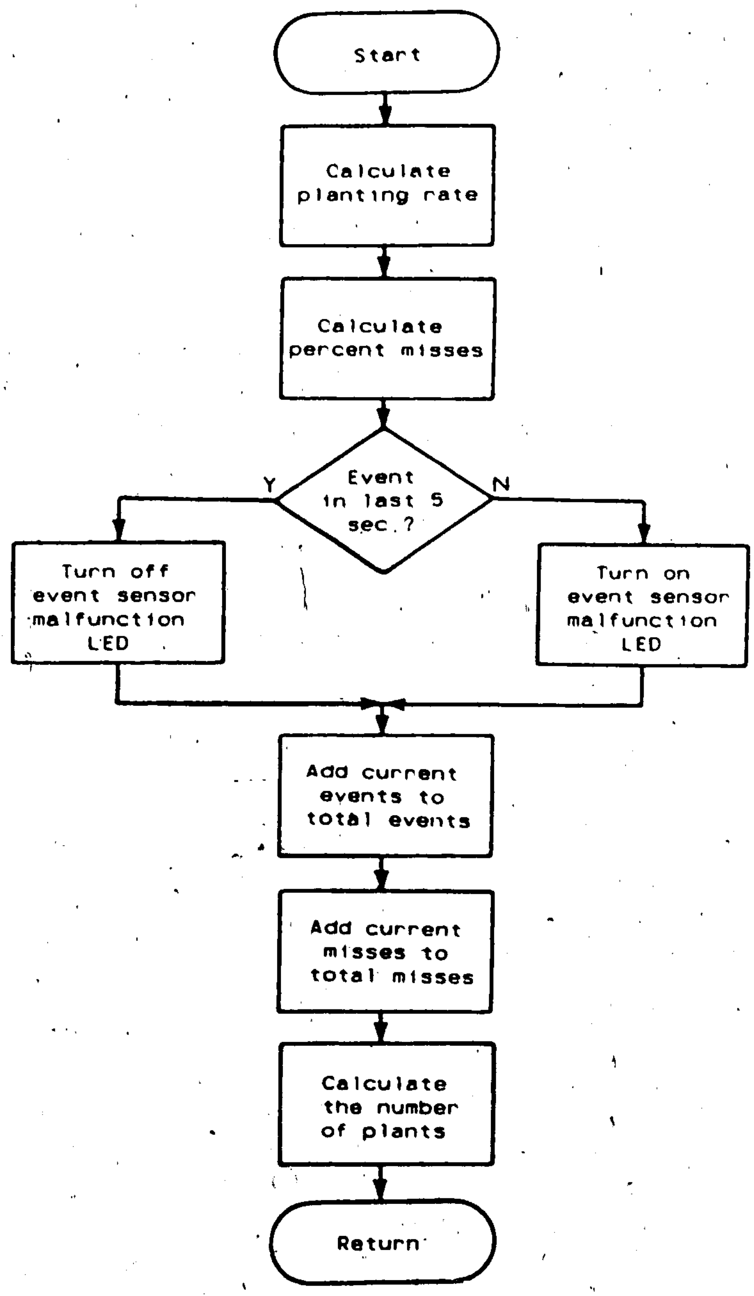


Figure 4.11 Statistics calculation flow chart

illuminating the bottom red status LED while successful malfunction tests ensure malfunction indicators were turned off. Section 4.3.2.10 contains further sensor malfunction discussion. After returning from the addition routine, the current number of misses is zeroed in preparation for the next calculation routine call.

The addition of current number of misses (CNMIS) to the total number of misses (TMIS) proceeds in a similar fashion with current number of misses being zeroed after returning from the addition routine.

A running total of the number of potatoes planted is calculated by subtracting the total number of misses from the total number of events.

4.3.2.6 Mode Change

The NMI service routine was entered only after the push button switch for a mode change caused the NMI* pin of the processor to go low. This indicated a user request to change the performance statistic on the monitor's LCD display. Routine logic is presented in the mode change flow chart in Figure 4.12. The mode counter was updated before the statistic for the next mode was displayed. Thus a wrap-around to the first mode occurred when successive mode change requests exceeded the number of modes. Mode number assignments and labels were: 0 - "% MISSES", 1 - "NO. EVENTS", 2 - "NO. MISSES", 3 - "NO. PLANTS", 4 "POTATO/MIN". Once

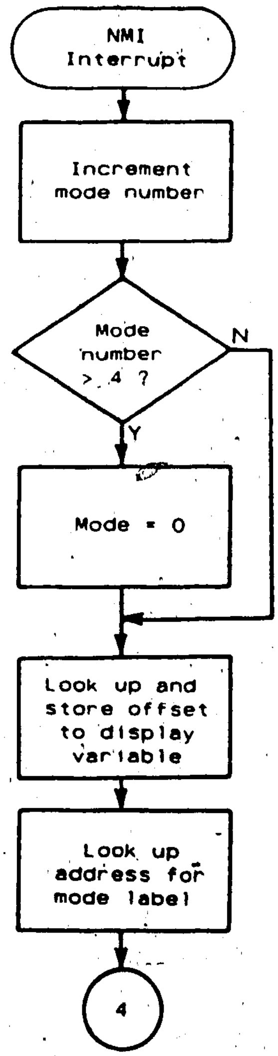


Figure 4.12 Mode change flow chart

the new mode was selected, the processor would execute the subroutine DISPLY to display the correct performance information on the LCD.

4.3.2.7 Row Change

The row change routine updates program variables and system status upon a user request to display the selected performance statistic from another row. A wrap-around strategy similar to the one discussed in section 4.3.2.6 was used. The flow chart in Figure 4.13 sets out routine tasks. The current row's row-select LED is turned off and the row-select LED of the new row is illuminated. PIA and data block base addresses are updated before returning from the subroutine call.

4.3.2.8 Display Refresh

The purpose of routine DISPLY was to display the correct descriptor, for example, "POTATO/MIN", and the corresponding performance statistic (Figure 4.14). This required the proper string of ASCII characters to be assembled in successive memory locations before being dumped to the LCD. ASCII codes for mode descriptors were arranged in the first ten memory locations after the variable DUMP. The subroutines HEXVAL and CONVAL were then called to obtain the correct ASCII codes representing the value of the performance statistic. The next six DUMP memory locations were filled with the resulting ASCII characters. After the LCD was cleared

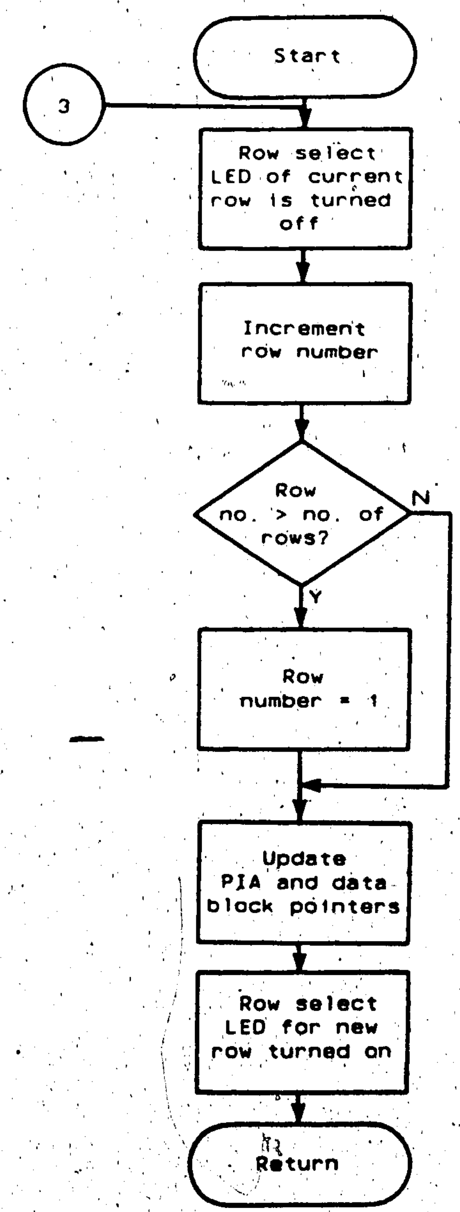


Figure 4.13 Row change flow chart

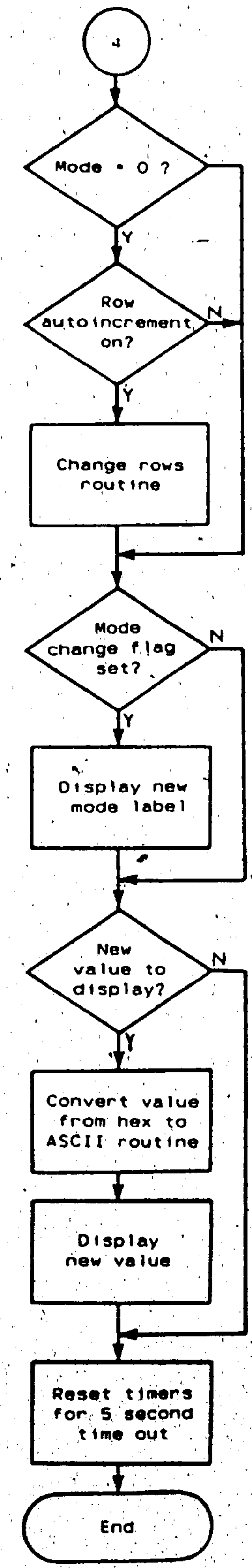


Figure 4.14 Display refresh flow chart

by the CLRLCD routine, the ASCII characters were sent to the display at 0.78 ms intervals.

The purpose of the CLRLCD subroutine was to send flags 8A and 00 to the LCD in order to clear the display and enable the transfer of ASCII characters for display. A short delay was used to ensure character codes were transfered properly.

The short delay subroutine (SDELAY) simply decremented a counter causing a 0.78 ms delay before returning to the calling program.

4.3.2.9 Code Conversion

HEXVAL was the subroutine that chose the correct performance statistic indicated by the MODE counter. Program flow details are shown in Figure 4.15. The value chosen was stored in a two byte variable called VALHEX.

The subroutine CONVAL converted the hexadecimal representation of the performance statistic to be displayed into an ASCII character string. The selected two byte hexadecimal performance statistic was translated to five decimal counters by means of successive comparisons of the value in VALHEX to multiples of the base ten. The counter values then were converted to ASCII character codes and leading zeros were replaced with blanks by routine LDZERO. ASCII character codes then were appended to the last occupied memory location of variable DUMP. The decimal counters

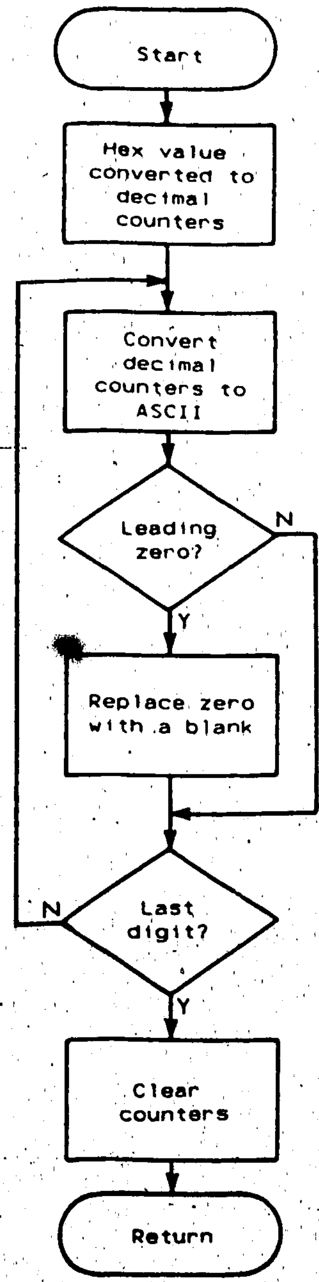


Figure 4.15 Code conversion flow chart

then were cleared for the next conversion.

4.3.2.10 Malfunctioning Sensor Check

Both the potato sensor (photoscanner) and the metering event sensor (Hall Effect switch) have malfunction checks associated with them. A metering event sensor malfunction is assumed if a metering event has not taken place since the last statistics update. Although this mode of operation will indicate a problem when the planter stops operating, the operator obviously will be able to discriminate between a halt and a problem signal.

In order to detect a malfunctioning potato sensor, a check was made to see if the desiginated photoscanner had an output signal of +5 V (beam intact). The desiginated photoscanner refers to a photoscanner from a non-interrupting row that theoretically is unobstructed. Base addresses for the PIAs and the data blocks corresponding to the desiginated photoscanners were assigned, in the inilization routine (section 4.3.2.1), to each data block in variables beginning with LKDAT and LKPIA, respectively. Subroutine FAIL performs the sensor malfunction test by checking for a '0' (fail) in bit 7 (photoscanner output) of port A of the designated PIA. If a potato sensor malfunction is detected the top status LED (red) is turned on, otherwise the LED is turned off. Refer to section 4.3.2.4 for the potato sensor malfunction algorithm.

4.4 Potato Planter Simulator

The two-row potato planter simulation unit shown in Figure 4.16 was constructed for program debugging, system performance assessment, and demonstration purposes. Two horizontal axles were aligned vertically and their pillow block bearing mounts were fastened to an angle iron frame. On each axle were two sprockets, one for each row. An endless chain with six equally spaced metal cups was installed between the vertically aligned upper and lower sprockets. Sensors were mounted on an adjustable arm that extended past the path of the metering chain. Ceramic permanent magnets, 13 mm in diameter and 7 mm thick, were bonded to the lower edge of each cup with south poles facing outward. Sensors were positioned such that metering status could be determined in the manner discussed in section 3.3.3. Figure 4.17 presents the position of monitor sensors. Styrofoam cups were used in place of real potatoes and could be arranged to simulate a pattern of misses. The 0.18 kW, variable-speed electric motor provided power to the simulation unit.

4.5 Performance Analysis

A detailed performance assessment of the potato planter monitoring system was not undertaken, however, general observations were noted and areas for improvement are discussed.

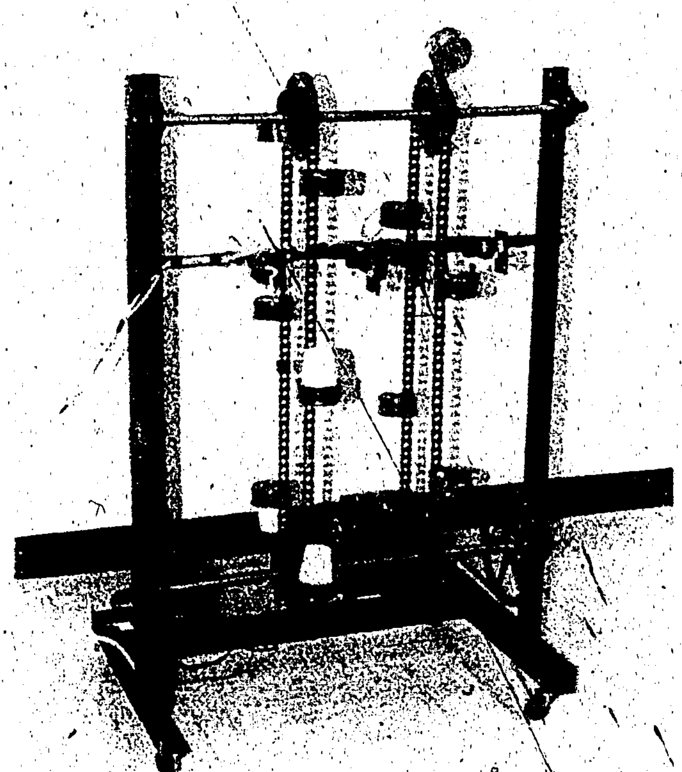


Figure 4.16 Potato planter simulation unit

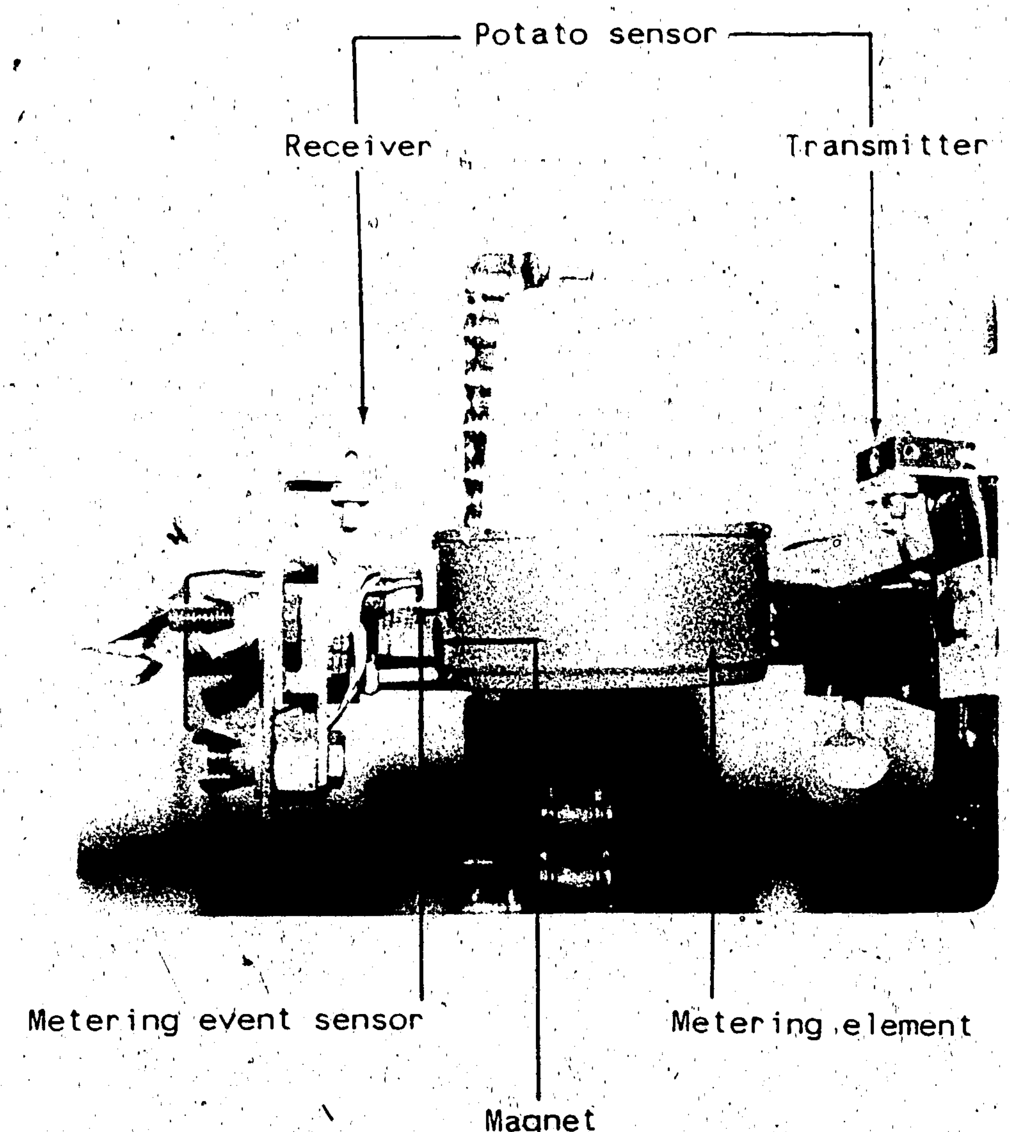


Figure 4.17 Sensor arrangement on the planter simulator

4.5.1 Microprocessor Board and Software

The basic microprocessor system and software performed to a satisfactory level. Simulated planting rates of 700 plants/min produced very predictable feedback. Metering rates past 800 plants/min began to reflect system loading conditions, and resulted in a small proportion of misses going undetected. The cause of system instability above 800 plants/min was attributed to both chain slap on the simulator unit and actual system loading conditions. However, causes of metering rate limitations were not determined directly. Accurate monitoring of planter performance under simulated conditions can be maintained up to equivalent ground speeds of 9 km/h for two rows, 6 km/h for four rows, and 3 km/h for six rows assuming a 30 cm plant spacing. Improvements to input/output algorithms are discussed in section 4.6 and, if implemented, would improve the monitoring system's operating efficiency.

All performance statistics calculations were carried out as expected. The metering rate calculation takes a five second display cycle to stabilize after each row change request. Metering rate accuracy could be improved if the metering events from each row were summed every five seconds. The resulting metering rate would represent the planter's metering rate rather than the metering rate for a single row.

Input and output functions and associated hardware performed well over an estimated one hundred thousand test and demonstration metering events. Mode-change and row-select functions operated smoothly and the autoincrement and buzzer switches functioned properly.

4.5.2 Input Device Evaluation

All system input devices performed their designated function. The metering event sensor on row 1 of the simulation unit was configured with a ceramic magnet backing as discussed in section 3.3.2 whereas the row 2 metering event sensor had a 13 mm diameter by 25 mm long aluminum nickel alloy magnet backing. Row 1 tolerated a sensor-to-magnet spacing of roughly 5 mm while row 2 had double the spacing tolerance.

The potato sensor performed exceptionally well and operated to its rated 50 cm range. Under actual field conditions, lens obstruction from dust or seed chips is possible. A "chalk brush" test covered the lens with a substantial layer of chalk dust yet the sensor unit still performed to design expectations.

Metering and potato sensor configuration in relation to one another is an important aspect to the overall design perspective. The sensor mounts on the potato planter simulator could be adjusted in the x, y and z planes. Magnet attachment to metering elements posed another challenge worthy of mention. Considering the repeated impacts of potato seed in the seed reservoir and possible bond fracture due to the harsh Canadian winters, bolting magnets to the metering elements seems more advantageous than a bonding solution.

Microswitches met the need for a means to set planter configurations. Although a more sophisticated input device would look nicer, placement of microswitches inside the monitor unit is worthy of consideration since parameter settings are rarely altered.

4.5.3 Output Device Evaluation

The output devices discussed under sections 4.2.1.3 performed well and gave a clear, straightforward representation of the planter simulator operation. The metering and status LEDs could be located in the operator's peripheral vision and, by pure color discrimination, the performance of the planter would be known without looking directly at the monitor. The information on the LCD display would be secondary during field operations but would provide useful information at a glance. The mode-select function would enable the operator to choose among performance statistics according to the type of information desired. Having a row autoincrement option allowed the percentage of misses to be displayed for each row in an alternating fashion. This function was thought to be of value since it presents performance information for the total planting system without diverting the operator's attention.

Both metering event sensor and potato sensor malfunctions were detected without fail. Indicators for metering sensor malfunction served a dual purpose since the signal producing magnets on metering elements were a component of the last moving part in the drive chain. Thus, all drive train malfunctions will be indicated through the metering event sensor malfunction LED.

The one drawback of the LCD display was that of the long (0.78 ms) set-up time needed for each character. A slight refinement to system software could prevent the unnecessary repetition of identical display segments. The current delay caused by character transfer contributed to system loading at high metering rates.

The current monitor unit was suited for a two-to six-row row planter. A dash mount would require a top-view LCD whereas a ceiling mount obviously would be suited to a bottom-view LCD screen.

The buzzer, unquestionably, would alert operators to the problem of a defective element in the metering chain. At times the buzzer was annoying but could be silenced with the buzzer disable toggle switch. The case of two potatoes becoming lodged in a cup or the occurrence of bent picks are aspects which the defective element test is designed to detect.

4.6 Design Discussions

Although the potato planter monitoring system met the first five design criteria listed in section 4.1.2, the sixth design criteria, ~~efficient~~ operation under field conditions, was not directly met since the monitoring system was not field tested. Improvements to the existing monitoring system would enable the potato planter monitor to be used as a means for assessing potato planter performance on existing cup and pick-type planters. The following discussion outlines the author's suggestions for system improvements.

Perhaps the biggest drawback to the system is the limited capacity for field data acquisition. A row spacing of 90 cm and a plant spacing of 30 cm gives each potato plant a growing area of 0.27 m^2. Therefore, a quarter-section of potatoes requires nearly 2.4 million seed pieces. In order to tabulate the metering status for all metering events, program variables having totals greater than can be represented by two bytes (65,536) should be expanded to three bytes. Computational routines need to be adapted accordingly. A monitoring system based on a three byte system will accommodate up to 16.8 million metering events, or data for approximately 450 ha whereas the present two byte system will handle only 1.75 ha of metering data.

Improvement of the display refresh routine to avoid the costly 13 ms delay every 5 s would improve the system's operating efficiency. Although this delay does not appear to be overly significant, the system performance can be affected. This applies especially to the defective element tests, which rely on the consistent logging of metering status.

The suggestion is made that additional modes be implemented, such as ground speed and time rate of area covered. This would greatly enhance the monitor's capabilities.

A number of hardware improvements are needed if the monitoring system is to proceed to the production phase. The design and development of printed circuit boards would enhance system flexibility, ease hardware assembly requirements, and allow for component interchange. The following circuit modules are suggested: a board for the basic microprocessor system, add-on input/output boards for each row, a display board, and a sensor junction module board. A keypad for operator input would be more aesthetically pleasing than the push buttons currently used and would have the added benifit of providing the input hardware for additional user options.

A five-volt switching regulator is suggested for the monitor's power circuit.

Installation of a non-volatile RAM with a battery back-up power circuit would enable the metering performance data to be retained if the monitor was removed from the tractor. This is an important addition since growers may choose to download their performance data to a micro-computer for further analysis.

The most important factor for successful implementation of the monitoring system is the accuracy of sensor placement. Development of a sensor mounting system which allows stable sensor positioning relative to one another in the x, y, and z planes is necessary if the dual-sensor, event-triggered system is to be effective. Sensor system mounts must provide a flexible means of attachment to the planter's frame. Reliable data acquisition also depends on the stability of the metering mechanism. Pick-type planters do not present this problem, however, an idler may be required near the sensor system mounts on cup-type planters if chain or belt vibration is to be avoided.

5. SUMMARY AND CONCLUSIONS

The need for a means of assessing potato planter performance is based on the quantitative and qualitative improvements to potato yields that can be achieved with a uniform planting pattern. The seed - metering mechanism interaction is specific to the type of metering mechanism, seed piece attributes, and the operating conditions during planting. Control over seed piece attributes, such as size and shape, depends on the size distribution of whole seed tubers and the manner in which they are cut.

Seed attributes affect main stem density and the uniformity of planting patterns in an independent manner. The shape and size of seed pieces play a key role in determining the uniformity of planting pattern, the number of stems per seed piece and the number of stems per unit area. Therefore, seed attributes strongly influence the yield and size distribution of harvested tubers.

The critical nature of the planting process calls for potato planter performance experiments to produce meaningful results. Separating the metering and placement aspects of planter performance will help researchers and growers to understand better how planting parameters influence yields. Planter performance experiments should contain a full description of seed material used and, with studies on placement performance, the standard deviation of seed placement should be reported. The CV statistic is a useful measure of placement performance as long as the mean seed spacing is close to the intended seed spacing. Comparisons made otherwise are misleading from a performance perspective.

If planter performance studies reported the distribution of consecutive metering errors, the effect of planting pattern on yield could be assessed by taking into account the variable yield compensation effect exerted by plants adjacent to a number of missing plants.

After careful consideration of the experimental procedure and the statistical analysis, the following conclusions were drawn.

1. Assessment of potato planter metering and placement performance can be carried out in an independent manner.

2. Compatibility between pick-type metering mechanisms and seed material improves as metering rate increases from 3 plants/s to 9 plants/s and as the number of cut surfaces on the seed pieces increases from one to three. Therefore a pick-type planter's metering performance responds favorably to high metering rates and blocky seed pieces.

3. Seed pieces weighing 45 g produce fewer metering errors than 60 g seed pieces at metering rates up to 6 plants/s in pick-type planters.

4. Seed piece shape and size affect the occurrence of metering errors in an independent manner, however, a strong interaction exists between seed shape and metering rate, and seed piece size and metering rate.

5. Cut 45 g and 60 g seed pieces have a more consistent metering performance compared to 50-100 g whole seed tubers when using a pick-type planter, especially at metering rates below 6 plants/s.

The following conclusions are put forth for the design and development of the potato planter monitoring system.

1. The dual-sensor event-triggered system provides an effective means of detecting metering errors for cup and pick-type potato planters.

2. Sensor positioning is critical for accurate determination of metering errors. Secure sensor mounts and the ability to adjust sensors in all three planes are critical aspects of monitoring planter performance in a reliable manner.

3. The potato planter monitoring system is capable of providing valuable performance feed back to operators. Indicator mechanisms that relay the number of consecutive misses for each row, drive train malfunction, sensor malfunction and performance statistics such as metering rate and percent of metering errors, all contribute toward the efficiency of the planting operation by improving the quality of information available to the operator.

4. Data logging capabilities of the potato planter monitoring system can establish the pattern of consecutive metering errors and thereby provide growers with the performance information needed to accurately assess the actual population density effects on yield.

6. RECOMMENDATIONS FOR FURTHER STUDY

Separate field experiments for potato planter metering and placement performance is encouraged. A four-row or six-row planter with a monitoring system would serve as an excellent experimental unit for field metering performance experiments. A suggested method of conducting potato placement experiments is through a series of high-speed 16 mm film clips. Digitial characterization of the placement sequence would assist in determining the effect of placement parameters.

Further experimentation on the effect of seed piece shape and size will help define how seed pieces and metering mechanisms interact in terms of metering performance. Experimental procedures could be improved if a photoscanner was positioned below the point of seed release. This would allow the number of seed pieces to be counted as they fell and would enable researchers to determine the actual seed rate and the number of doubles.

Planter performance investigations and yield response studies using small whole tubers (40-70 g) would provide valuable information for assessing the costs, benifits and alterations to planting operations and potato machinery that are required for potato production with small whole seed tubers.

Expressing metering performance as a function of seed piece surface area ratios may prove to be advantageous. A skin surface area to total surface area ratio, or a skin surface area to cut surface area ratio, can be used to define both seed shape and seed size effects on a metering performance continuum. Another facet of seed attributes that may be worthy of investigation is the relationship between surface area ratios and the total and marketable yields. Establishing seed piece yields and planter performance in terms of seed attributes would serve as a good starting point for a potato planting model. By implementing planting parameters of greatest utility to the grower, under-utilization of agricultural inputs can be avoided and yields will be enhanced accordingly.

7. REFERENCES

Alberta Agriculture. 1982. The economics of potato and vegetable production in Alberta - 1980. Economic Services Division, Production Economics Branch. 55 p.

Agriculture Canada. 1985. Canadian seed potatoes. Cat. No. A22-104/1983e. Ottawa, ON. 20 p.

Agricultural Development and Advisory Service. 1975. The effects of different types of potato planters on crop yield and profitability. England. Short Term Leaflet 182. 18 p.

Allen, E.J. 1978. Plant density. p 278-326. In: P.M. Harris (ed). The potato crop. Chapman and Hall. New York, NY.

Allen, E. J. and D.C. Wurr. 1973. A comparison of two methods of recording stem densities in the potato crop. Potato Research 16:10-20.

Andrew, W.T. 1968. Plant stands in potato fields. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:4-7.

Andrew, W.T. 1971. Some factors affecting plant stands in potato fields. Proceedings of the 1971 Washington State Potato Conference and Trade Fair:53-55

Andrew, W.T. and T.A. Preston. 1969. Factors affecting plant stands in potato fields: 1969 studies. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:11-15.

Andrew, W.T., I. Soliman and T.A. Preston. 1970. The influence of simulated gaps on yield of potatoes. Proceedings 10th Annual Washington State Potato Conference Trade Fair:37-41.

Andrew, W.T., P.D. McCalla, E.W. Toop and T.R. Krahn. 1976. Potato production in Alberta. Alberta Agriculture. 9 p.

Andrew, W.T. and K.W. Domier. 1978. A progress report on the possible integration of seed pieces, cutters and planters. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:54-58.

Andrew, W.T., G.H. Silva, E.J. Hauck and K.W. Domier. 1983. More attention to your seed cutter means more money in your pocket. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato

Commission:70-83.

Andrew, W.T. and G.S. Silva. 1983. Influence of seed tuber portions on potato. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:49-53.

Bleasdale, J.K. 1965. Relationship between set characteristics in maincrop potatoes. Journal of Agricultural Science 64:361-366.

Bleasdale, J.K. and R. Thompson. 1966. The effects of plant density and pattern of plant arrangement on the yield of parsnips. Journal of Horticultural Science 41:371-378.

Blodgett, F.M. 1941. A method for the determination of losses due to diseased or missing plants. American Potato Journal 18:32-35.

Boyd, D.A. and W.J. Lessells. 1954. The effect of seed rate on yield of potatoes. Journal of Agricultural Sciences 44:465-476.

Breece, H.E. 1975. Fundamentals of machine operation Planting. John Deere Publications. Moline, IL.

Brown, E. 1973. Preliminary survey on the identification of potato varieties by tuber characteristics. Journal of the National Institute of Agricultural Botany 13(1):67-86.

Bufton, L.P., P. Richardson and M.J. Dogherty. 1974. Seed displacement after impact on a soil surface. Journal of Agricultural Engineering Research 19:327-338.

Burema, H.J., E.N. Meijer and M.G. Telle. 1975. Development of a self-recording sticky belt. Institute of Agricultural Engineering, Wageningen, Netherlands. Research Report 80-3:1-13.

Cameron, S.D. 1984. PEI's mighty spud. p 26-35. In: Canadian Geographic 104(5). Ottawa, ON.

Carlow, C.A. 1983. An instructible rejection system for quality grading of potatoes and other produce. Journal of Agricultural Engineering Research 28:373-383.

Carruthers, J. 1975. Further development of a high speed planter. Departmental note No. SIN/192. 21 p. The British Society for Research in Agricultural Engineering. Penicuik, Midlothian.

Carruthers, J., I.W. Dunn and D.P. Blight. 1984. A microprocessor controlled potato planter. EAPR 1986 Proceedings - Abstracts of Conference Papers:168-169.

Collins, W.B. 1977. Analysis of growth in Kennebec with emphasis on the relationship between stem number and yield. American Potato Journal 54:33-40.

Davies, G.J. 1954. Report of the National Institute of Arricultural Engineering. No. 38. 28 p.

Davies, H.V. 1984. Mother tuber reserves as factors limiting potato sprout growth. Potato Research 27:209-218.

Davis, W.M. 1980. ASAE standards development and their contribution to product safety. p 52-57. In: Engineering a safer food machine, a collection of agricultural safety papers and speeches. Am. Soc. Agric. Eng. St. Joseph, MI.

Dawes, D.S., R.B. Dwelle, G.E. Kleinkoph and R.K. Steinhorst. 1983. Comparative growth analysis of Russet Burbank potatoes at two Idaho locations. American Potato Journal 60:717-733.

Eddowes, M. 1986. Tuber quality control in potatoes for chip production from vine kill to storage. p 334-337. In: B.F. Cargill (ed). Engineering for potatoes. ASAE. St.

Joseph, MI.

Entz, M.H. and L.J. LaCroix. 1984. The effect of in-row spacing and seedtype on the yield and quality of a potato cultivar. American Potato Journal 61:93-105.

Fishman, S. and H. Talpaz. 1984. A phenomenological model of dry matter partitioning among plant organs for simulation of potato growth. Agricultural Systems 14:159-169.

Fishman, S., H. Talpaz, R. Winograd, M. Dinar, Y. Arazi, Y. Roseman and S. Varshayski. 1985. A model for simulation of potato growth on the plant community level. Agricultural Systems 18:115-128.

French, G.W. 1958. Seed cutting and handling. In:1958 Potato handbook - machinery and equipment issue. The Potato Association of America. New Brunswick, NJ.

Gauthier, L. 1985. Design for a field management system. ASAE Paper No. 85-5523. Am. Soc. Agric. Eng. St. Joseph, MI.

Glotzbach, J.M. 1973. A survey of European production of potatoes. The Agricultural Engineer 28(1):30-33.

Goryachkin, V.P. 1974. Potato sorting. In: Collective works Vol.3200-212,[transl. E. Vilim Jerusalem]. USDA. Washington D.C.

Halderson, J.L. 1981. A laboratory evaluation of planter selection accuracy for singular seeds. ASAE Paper No. PNR 81-306. Am. Soc. Agric. Eng. St. Joseph, MI.

Harriott, B.L. 1970. A packaged environment system for precision planting. Transactions of the ASAE 13(5):550-553

Hauck, E.J., W.T. Andrew and K.W. Domier. 1982. Improving the efficiency of potato planters and cutters. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:1-7.

Hirst, J.M., G.A. Hide, O.J. Stedman and R.L. Griffith. 1973. Yield compensation in gappy potato crops and methods to measure effects of fungi pathogenic on seed tubers. Annals of Applied Biology 73:143-150.

Hofman, V., M. Berge and C. Moilanen. 1986. Row crop planter seed spacing accuracy. ASAE Paper No. NCR-86-502. Am. Soc. Agric. Eng. St. Joseph, MI.

Holliday, R. 1960. Plant population and crop yield:Part I. Field Crop Abstracts 13:159-167.

Holmes, J.C., R.W. Lang and A.K. Sing. 1970. The effects of five growth regulators on apical dominance in potato seed tubers and on subsequent tuber production. Potato Research 13:342-352.

Holt, J.E. and D. Schoorl. 1985. Technological change in agriculture - the systems movement and power. Agricultural Systems 18:69-79.

Hunt, D.R. 1986. Engineering models for agricultural production. The AVI Publishing Co. Inc. Westport, CN.

Hyde, G.M., R.E. Thornton and R. Kunkel. 1979. Potato planter mechanism performance. Proceedings of the 1971 Washington State Potato Conference and Trade Fair:55-59.

Hyde, G.M. and R.E. Thornton. 1980. Potato planter mechanism performance II. Proceedings of the 1980 Washington State Potato Conference and Trade Fair:59-63.

Hyde, G.M., R.E. Thornton and G.K. Cuillier. 1983. Automatic load control system for potato conveyors. Transactions of the ASAE 25:14-18.

Iritani, W.M, R. Thornton, L. Weller and G. O'Leary. 1972. Relationships of seed size, spacing, stem numbers to yield of Russet Burbank potatoes. American Potato Journal 49:463-469.

Iritani, W.M., L.D. Weller and N.R. Knowles. 1983. Relationship between stem number, tuber set and yield of Russet Burbank potatoes. American Potato Journal 60:423-431.

Iritani, W.M. and R.E. Thornton. 1984. Potatoes: influencing seed tuber behavior. Cooperative Extension Service of Washington State University. PNW Extension Publication 248. 15 p.

James, W.C., C.H. Lawrence and C.S. Shih. 1973. Yield losses due to missing plants in potato crops. American Potato Journal 50(10):345-352.

James, W.C., R.H. Bradley, C.S. Shih and S.I. Wong. 1975. Misses in potato crops in New Brunswick in 1973; their extent, distribution and cause. American Potato Journal 52:83-87.

Jarvis, R.H. 1972. Comparison of 30 in. and 36 in. rows for maincrop potatoes. Part II, Soil factors, workrates and mechanical damage. Experimental Husbandry 21:85-92.

Jarvis, R.H. 1978. The Potato Crop. Chapman and Hall Limited, London. p 365-371.

Jarvis, R.H. and G.M. Palmer. 1973. Effects of type of planter on the growth and yield of maincrop potatoes. Experimental Husbandry 24:29-36.

Jarvis, R.H., D.S. Rogers-Lewis and W.E. Bray. 1976. Effects of irregular set spacing on maincrop potatoes. Experimental Husbandry 30: 28-41.

Jarvis, R.E. and F.E. Shotton. 1971. Population studies with King Edward potatoes. Experimental Husbandry 20:12-29.

Jarvis, R.H. and F.E. Shotton. 1972. Comparison of 30 in. and 36 in. rows for maincrop potatoes. Part I. Effects on yield. Experimental Husbandry 21:78-84.

Johnson, L.F. and G.E. Vogt. 1973. 1972 potato planter study. Proceedings of The Idaho Potato Commission:54-65.

Johnston, E.F. 1970. Relating potato tuber size to seed piece weight. Research in the Life Sciences 18(3-4):30-33.

Klassen, J. 1977. Planter performance study. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:14-27.

Klassen, J. 1980. Field man's report. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission: 69-85.

Klenin, N.I., I.F. Popov and V.A. Sakun. 1985. Agricultural machines. Amerincl Publishing Co. Ltd. New Dehli.

Knowles, N.R., W.M. Iritani and L.D. Weller. 1985. Plant growth response from aged potato seed-tubers as affected by meristem selection and NNA. American Potato Journal 60:289-300.

Kolchin, N.N. and E.A. Semekhunov. 1975. Promising principles of grading potatoes and vegetables. Trak Sel'Khozmash: 1975(10):19-21.

Krall, J.M., H.A. Esechie, R.J. Raney, S. Clark, G. TenEyck, M. Lundquist, N.E. Humburg, L.S. Axthelm, A.D. Dayton and R.L. Vanderlip. 1977. Influence of within-row variability in plant spacing on corn grain yield. Agronomy Journal 69:797- 799.

Krijthe, N. 1955. Observations on the formation and growth of tubers of the potato plant. Netherlands Journal of

Agricultural Science. 3:291-304.

Larsson, K. 1986. Personal communication. Swedish Institute of Agricultural Engineering. Uppsala.

Leach, S.S., J. Thibodeau and R. Thibodeau. 1972. Mechanical potato cutters can produce high quality seed pieces. Research in the Life Sciences 19(16):1-8.

Leventhal, L. 1981. 6809 Assembly Language Programming. Osborne/McGraw-Hill. Berkeley, CA.

Lidgett, W.D. 1983. Proposed metric tuber sizes. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:12-14.

Likhyani, S.K., K.W. Domier and W.T. Andrew. 1980. Performance characteristics of cup and pick type potato planters. CSAE Paper No. 80-305. Ottawa, ON.

Likhyani, S.K., K.W. Domier and W.T. Andrew. 1981. Seed piece-planter relationship. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:78-93.

Lynch, D.R. and R.G. Rowberry. 1977a. Population density studies with Russet Burbank I. Yield/stem density models. American Potato Journal 54: 43-56.

Lynch, D.R. and R.G. Rowberry. 1977b. Population density studies with Russet Burbank II. The effect of fertilization and plant density on growth and yield. American Potato Journal 54:57-71.

Maughan, G.L. 1973. Performance assessment of sugar beet machinery. The Agricultural Engineer 28(1):26-27.

Maunder, W.F. 1983. Planting and mechanical handling of seed. The Agricultural Engineer 38(2):38-41.

McRae, D.C. 1980. Potato grading and inspection. The Agricultural Engineer 35(2):52-53.

McRae, D.C. 1985. A review of developments in potato handling and grading. Journal of Agricultural Engineering Research 31:115-138.

Milthorpe, F.L. and J. Moorby. 1979. An introduction to crop physiology. Cambridge University Press. Cambridge, England.

Misener, G.C. 1979. Relative performance of cup and pick type potato planters. Canadian Agricultural Engineering 21:131-134.

Misener, G.C. 1982. Potato planters - uniformity of spacing. Transactions of the ASAE 25(6):1504-1511.

Molnar, S.A. 1978. Comparison of small whole tubers with cut seed pieces. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission: 48-53.

Murphy, D.J. 1980. Human behavior and agricultural safety: understanding the conflicts. p 88-93. In: ASAE Engineering a safer food machine, a collection of agricultural safety papers and speeches. ASAE publications. St. Joseph, MI.

North, J.J. and J.M. Proctor. 1973. Row widths for King Edward potatoes. Experimental Husbandry 22:99-103.

Pascal, J.A. and I.H. Provan. 1969. Potato spacing Trials - 1969. Departmental note No. 56. 9 p. The British Society for Research in Agricultural Engineering. Penicuik, Midlothian.

Pascal, J.A. and A. Langley. 1971. The Howard 2-row potato planter. Departmental note No. SSN/94. 29 p. The British Society for Research in Agricultural Engineering. Penicuik, Midlothian.

Pascal, J.A. and T.P. Robertson. 1975. Potato planter Departmental note No. SSN/182. 6 p.trials 1974. The British Society for Research in Agricultural Engineering. Penicuik, Midlothian.

Pascal, J.A., T.P. Robertson, and A. Langley. 1977. Yield effects of regular and irregularly spaced potato tubers. Experimental Husbandry 32:25-33.

Pitts, M.J. and G.M. Hyde, 1985. Algorithms for determining tuber shape and cutting potato seed pieces. ASAE Paper No. PNR 85-403. Am. Soc. Agric. Eng. St. Joseph, MI.

Poesse, G.J, U.D. Perdok and E. Strooker. 1973. Aspects of soil preparation and planting for the potato crop. The Agricultural Engineer 28(1):34-36.

Prairie Agricultural Machinery Institute. 1978a. Evaluation Report No. E1077:McConnell model 555 potato planter. 4 p.

Prairie Agricultural Machinery Institute. 1978b. Evaluation Report No. E1178A:Lockwood model L06200-00423 potato planter. 4 p.

Prairie Agricultural Machinery Institute. 1978c. Evaluation Report No. E1178B:Dahlman model PT potato planter. 4 p.

Prairie Agricultural Machinery Institute. 1979. Evaluation Report No. E0579:Acme ST potato planter. 4 p.

Prairie Agricultural Machinery Institute. 1980. Evaluation Report No. E0480:Lockwood L06200-00403 Accumatic potato planter. 4 p.

Preston, T.A. 1971. Simulated gap studies - second year - 1971. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:16-23.

Reestman, A.J. and C.T. De Wit. 1959. Yield and size distribution of potatoes as influenced by seed rate. Netherlands Journal of Agricultural Sciences. 7(4):257-268.

Rempel A. 1978. Whole seed vs. cut seed panel discussion. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission:46-47.

Robertson, T.A. and J.A. Pascal. 1974. Potato spacing trials - 1973. Departmental note No. ssn/158. 4 p. The British Society for Research in Agricultural Engineering. Penicuik, Midlothian.

Rowberry, R.G., and A.J. Howells. 1979. Potato production, marketing and use in North America. Potato Research 22:163-175.

Rowell, A., E. Ewing and R. Plaisted. 1986. Comparative field performance of potatoes from seedlings and tubers. American Potato Journal. 63:219-227.

Sands, P.J. and Regal. 1983. A model of the development and bulking of potatoes V. A simple model for predicting graded yields. Field Crops Research 6:25-40.

Schotzko, R.T., G.M. Hyde and R.E. Thornton. 1982. The dollars and cents of the 1982 potato seed size and spacing survey. Proceedings of the 1983 Washington Potato Conference and Trade Fair:23-29.

Schotzko, R.T., W.M. Iritani and R.E. Thornton. 1984. The economics of Russet Burbank seed size and spacing. American Potato Journal 61:57-66.

Sharpe, P.R. and J.B. Dent. 1968. The determination and economic analysis of relationships between plant population and yield of maincrop potatoes. Journal of Agricultural Sciences 70:123-129.

Shotton, E.F. 1973. Aspects of soil preparation for the potato crop. The Agricultural Engineer 28(1):37-43.

Shotton, F.E. 1976. An evaluation of different types of potato planters. Experimental Husbandry 30:1-17.

Sieczka, J.B., E.E. Ewing and E.D. Markward. 1986. Potato planter performance and effects of non-uniform spacing. American Potato Journal 63:25-37.

Silva, G.H. and W.T. Andrew. 1984. A possible formula to evaluate cut seed portions in relation to potential yields of potato. Proceedings of the Annual Meetings of the Alberta Potato Growers Association and Alberta Potato Commission: 54-63.

Silva, G.H. and W.T. Andrew. 1985. Hill to hill variations in tuber yield of potatoes in Alberta. American Potato Journal 62:119-127.

Słomnycki, I. and I. Rylski. 1964. Effect of cutting and gibberellin treatment on autumn grown seed potatoes for spring planting. European Potato Journal 7:184-192.

Smith, R.D., R.M. Peart and J.R. Barrett. 1985. Agricultural production management with decision support systems. ASAE Paper No. 85-3076. St. Joseph, MI.

Steel, G.D. and J.H. Torrie. 1980. Principles and procedures of statistics a biometrical approach. McGraw-Hill Book Company. New York, NY.

Svensson, B. 1973. Development of potato stands in relation to their density. Swedish Journal of Agricultural Research. 3:3-12.

Svensson, B. 1977. Changes in seed tubers after planting. Potato Research 20:215-218.

Thornton, R.E. and J.B. Sieczka. 1980. Commercial potato production in North America. American Potato Journal Supplement to Volume 57. 36 p.

Thornton, R.E., T. Schotzko and G.M. Hyde. 1983. Some other factors in obtaining good plant stands. Proceedings of the 1983 Washington Potato Conference and Trade Fair: 93-102.

Timm H., J.C. Bishop, V.H. Schweers, W.R. Corrin, R.E. Voss, J.W. Perdue, L.J. Clemente and D.B. Grimes. 1973. Soil conditioning and seed potato handling are keys to survival of summer planted potatoes. California Agriculture, December:10-12.

Townsend, J.S. 1972. A field trial of cup type and picker type potato planters. Proceedings of the Nineteenth Annual Convention of the Vegetable Growers Association of Manitoba: 31-34.

Tylee, J.L. 1986. Model-based approach to instrument failure detection. Intech. March:59-62.

Webster, T. 1970. Developments in the description of potato varieties. Part II. Inflorescences and tubers. Journal of the National Institute of Agricultural Botany 12:17-45.

White, R.P. and J.B. Sanderson. 1983. Effect of planting date, nitrogen rate, and plant spacing on potatoes grown for processing in Prince Edward Island. American Potato Journal 60:115-126.

Wiersema, S.G. and R. Cabello. 1986. Comparative performance of different-sized seed tubers derived from true potato seed. American Potato Journal 63:241-249.

Wilkins, D.E. 1979. A microprocessor controlled planter. ASAE paper No. 79-1515. St. Joseph, MI.

Wilson, D.R. 1970. The effect of seedpiece spacing on yield and size distribution of Russet Burbank potatoes in Maine. Research in the Life Sciences 18(1):1-4.

Wilson, R.J. 1983. A history of instrumentation on agricultural equipment. Agricultural electronics - 1983 and beyond. ASAE publication 8-84. Am. Soc. Agric. Eng. St. Joseph, MI.

Wurr, D.C. 1974. Some effects of seed size and spacing on the yield and grading of two maincrop potato varieties. Journal of Agricultural Science 82:37-45.

Wurr, D.C. and D.C. Morris. 1979. Relationships between the number of stems produced by a potato seed tuber and its weight. Journal of Agricultural Science 93: 403-409.

Zaag, D.E. van der. 1976. Potato production and utilization in the world. Potato Research 19:37-72.

Zaag, D.E. van der. 1984. Reliability and significance of a simple method of estimating the potential yield of the potato crop. Potato Research 27:51-73.

Zaag, D.E. van der and D. Horton. 1983. Potato production and utilization in world perspective with special reference to the tropics and sub-tropics. Potato Research 26:323-362.

Zhao, K., G.M. Hyde, M.J. Pitts, R.E. Thornton and J.A. Robertson. 1986. Seed piece optimization and seed piece separation. ASAE Paper No. PNR 86-103. Am. Soc. Agric. Eng. St. Joseph, MI.

8. APPENDIX A. METERING DATA ANALYSIS PROGRAM

```
10  'Program name:   HITMISS.BAS
20  'Purpose:        To analyse potato planter metering data
50  'Programmed for: IBM PC
60  'Language:       BASICA
70  'Programmer:     Edward J. Hauck
80  '------------------------------------------------------------------------
90  '
100 ' ** MAIN PROGRAM **
102 '
104 GOSUB 200                  '   Program initialization
105 '                          ' CUT SEED METERING DATA '
106 FOR M=1 TO 3               '   Metering rates 1-3 (3, 6 and 9 plants/s)
108    FOR H=1 TO 3            '   Seed shapes 1-3 (1-cut, 2-cut and 3-cut)
110       FOR Z=1 TO 2         '   Seed size 1-2 (45 g and 60 g)
112          FOR R=1 TO 5      '   Replications 1-5
113             FILE$ = "M"+RIGHT$(STR$(M),1)+"H"+RIGHT$(STR$(H),1)+"Z"+_
                       RIGHT$(STR$(Z),1)+".R"+RIGHT$(STR$(R),1)
114             GOSUB 300      '   Data file analysis (% metering errors and
115 '                          '      and distribution of consecutive misses)
117          NEXT R
122       NEXT Z
128    NEXT H
134 NEXT M
136 '
137 '                          ' WHOLE SEED METERING DATA '
138 FOR M=1 TO 3               '   Metering rates 1-3 (3, 6 and 9 plants/s)
140    FOR R=1 TO 5            '   Replications 1-5
14        FILE$ = "M"+RIGHT$(STR$(M),1)+"HO"+".R"+RIGHT$(STR$(R),1)
142       GOSUB 300            '   Data file analysis (% metering errors and
143                            '      distribution of consecutive misses)
145    NEXT R
150 NEXT M
152 GOSUB 800                  '   Output for percent metering errors
154 GOSUB 900                  '   Output for consecutive metering errors
156 LOCATE 12,25:PRINT "FINISHED  ";:PRINT CHR$(7)
158 END
160 '------------------------------------------------------------------------
162 '
200 ' ** Program initialization **
205 '
210 CLS
215 DIM OP$(110,5),CMISS(110,70)
220 M = 1:H = 1:Z = 1:R = 1:NO = 1
225 FILE$ = "":L.FILE$ = ""
230 TPU1$ = " File          Misses Hits Events %Misses"
235 PU1$  = "\           \  ##     ##   ###    ###.#"
240 PU2$  = "\           \"
245 TPU3A$ = "  Frequency distribution of consecutive metering errors"
250 TPU3B$ = "                  1  2  3  4  5  6  7  8  9  10"
255 TPU3C$ = "                 11 12 13 14 15 16 17 18 19  20"
260 PU3$   = "                 ## ## ## ## ## ## ## ## ##  ##"
265 RETURN
270 '------------------------------------------------------------------------
275 '
300 ' ** Data file analysis (% metering errors and and distribution of
305 '    consecutive misses) **
310 '
335 LOCATE 12,30:PRINT "Crunching: ";FILE$;
340 LOCATE 14,20:PRINT "Last file: ";L.FILE$;"  ";"% MISSES: ";MISS
345 I% = 1:MISS = 0:HIT = 0
```

```
350  OPEN "I",#1,"B:"+FILE$
355  INPUT#1,EVENT$:INPUT#1,EVENT$:INPUT#1,EVENT$
360  INPUT#1,EVENT$
365  IF EOF(1) THEN GOTO 410
370  IF VAL(EVENT$) = 1 THEN HIT = HIT + 1:GOSUB 1000 ELSE IF VAL(EVENT$) = 0_
        THEN MISS = MISS + 1:CONFLG = 1:CON.MISS = CON.MISS+1 ELSE GOTO 360
375  IF I% = 100 THEN GOTO 390
380  I%=I%+1
385  GOTO 360
390  INPUT#1,EVENT$
395  IF EOF(1) THEN GOTO 415
400  IF EVENT$ = "1" OR EVENT$ = "0" THEN I%=I%+1
405  GOTO 390
410  GOSUB 1000
415  CLOSE 1
420  OP$(NO,1) = FILE$:OP$(NO,2) = STR$(HIT):OP$(NO,3) = STR$(MISS):_
       OP$(NO,4) = STR$(I%):OP$(NO,5) = STR$(MISS*100/I%)
425  NO = NO + 1
435  L.FILE$ = FILE$
440  RETURN
445  '-----------------------------------------------------------------------
450  '
800  ' **  Output for percent metering errors
805  '
810  OPEN "O",#1,"RESULTS"
815  PRINT TUP1$
820  FOR  N=1 TO NO-1
825     LPRINT USING PU1$;OP$(N,1);VAL(OP$(N,2));VAL(OP$(N,3));VAL(OP$(N,4));_
          VAL(OP$(N,5))
830     PRINT USING PU1$;OP$(N,1);VAL(OP$(N,2));VAL(OP$(N,3));VAL(OP$(N,4));
          VAL(OP$(N,5));VAL(OP$(N,5))
835     PRINT#1,OP$(N,1);" ";OP$(N,2);" ";OP$(N,3);" ";OP$(N,4)
840  NEXT N
845  CLOSE 1
850  RETURN
855  '-----------------------------------------------------------------------
860  '
900  ' ** Output for consecutive metering errors **
905  '
910  OPEN "O",#1,"MISTRING"
915  PRINT TPU3A$:PRINT TPU3B$:PRINT TPU3C$
920  FOR  N=1 TO NO-1
925    PRINT#1,OP$(N,1)
930    PRINT#1,USING PU3$;CMISS(N,1);CMISS(N,2);CMISS(N,3);CMISS(N,4);_
         CMISS(N,5);CMISS(N,6);CMISS(N,7);CMISS(N,8);CMISS(N,9);CMISS(N,10)
935    PRINT#1,USING PU3$;CMISS(N,11);CMISS(N,12);CMISS(N,13);CMISS(N,14);_
         CMISS(N,15);CMISS(N,16);CMISS(N,17);CMISS(N,18);CMISS(N,19);CMISS(N,20)
940  NEXT N
945  CLOSE 1
950  RETURN
955  '-----------------------------------------------------------------------
960  '
1000 ' ** Check for string of consecutive misses **
1005 '
1010 IF CONFLG=1 THEN CMISS(NO,CON.MISS) = CMISS(NO,CON.MISS)+1
1015 CONFLG=0:CON.MISS=0
1020 RETURN
1025 '-----------------------------------------------------------------------
```

9. APPENDIX B. METERING DATA

B1. Cut Seed Metering Data

The following data summary presents the cut seed metering trial results. Each data point represents one of five replications for each set of experimental variables.

Percent of metering events which were unsuccessful *

Seed piece attributes		Metering rate (plants/s)		
Shape	Size (g)	3.0	6.0	9.0
1-cut	45	50.2	50.8	47.1
		50.9	50.5	51.2
		18.2	8.4	46.4
		13.7	10.0	8.5
		10.7	15.4	5.0
	60	64.2	28.8	13.8
		70.2	36.0	13.4
		61.6	26.8	26.0
		60.2	34.3	13.3
		58.6	31.7	15.9
2-cut	45	32.9	17.9	16.8
		44.6	19.8	16.3
		41.6	22.1	8.1
		13.6	17.2	6.1
		15.7	34.9	20.1
	60	42.6	26.2	19.7
		29.7	27.4	13.0
		35.0	21.1	25.3
		44.5	23.5	19.3
		41.9	23.3	28.9
3-cut	45	18.4	9.9	10.5
		15.2	9.9	8.8
		44.8	18.2	13.1
		36.0	7.4	11.7
		15.1	11.8	6.5
	60	19.7	16.0	15.1
		25.3	6.0	16.3
		27.3	21.7	28.7
		47.2	22.3	11.6
		22.0	14.4	7.6

* Minimum of 100 metering events

B2. Whole Seed Metering Data

The data listed below summarizes whole seed metering results. Each data point represents one of the five experiment replications.

Percent of metering errors which were unsuccessful *

Metering rate (plants/s)		
3.0	6.0	9.0
55.8	31.3	16.4
56.1	35.8	19.0
57.3	28.4	14.4
54.7	27.2	9.2
53.0	31.1	11.0

* Minimum of 100 metering events

B3. The following data set represents the distribution of consecutive metering errors expressed as a percent of total metering errors for cut seed metering trials.

	Percent of total metering errors									
	Consecutive metering errors									
Trial	1	2	3	4	5	6	7	8	9	10
M1H1Z1R1	13.5	16.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R2	22.5	6.8	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R3	12.8	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R4	9.2	3.1	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z1R5	7.6	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H1Z2R1	4.8	10.9	14.3	5.4	0.0	0.0	9.5	0.0	6.1	6.8
M1H1Z2R2	6.1	5.6	6.7	17.8	2.8	13.8	7.8	4.4	0.0	0.0
M1H1Z2R3	11.2	14.2	12.2	6.1	5.1	6.1	3.6	0.0	0.0	0.0
M1H1Z2R4	8.4	10.5	6.3	12.6	7.9	3.2	0.0	0.0	4.7	0.0
M1H1Z2R5	13.6	12.1	12.6	3.7	9.3	2.8	0.0	0.0	0.0	4.7
M1H2Z1R1	20.9	5.8	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z1R2	15.8	9.9	8.9	9.9	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z1R3	10.7	6.6	12.4	3.3	4.1	0.0	0.0	0.0	0.0	0.0
M1H2Z1R4	8.7	3.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z1R5	13.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z2R1	22.2	6.2	4.6	6.2	0.0	0.0	3.6	0.0	0.0	0.0
M1H2Z2R2	20.3	6.1	1.3	1.7	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z2R3	14.1	7.5	4.2	3.8	0.0	0.0	0.0	0.0	0.0	0.0
M1H2Z2R4	11.5	9.2	5.5	11.1	0.0	5.5	0.0	0.0	0.0	0.0
M1H2Z2R5	18.5	8.6	10.3	3.4	0.0	2.6	0.0	0.0	0.0	0.0
M1H3Z1R1	12.3	2.7	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z1R2	15.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z1R3	12.5	11.0	0.0	6.0	2.5	3.0	3.5	0.0	0.0	0.0
M1H3Z1R4	12.1	10.1	3.0	4.0	0.0	0.0	7.1	0.0	0.0	0.0
M1H3Z1R5	12.7	1.7	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z2R1	10.3	5.9	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z2R2	7.4	14.9	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1H3Z2R3	10.3	6.9	3.4	0.0	0.0	0.0	8.0	0.0	0.0	0.0
M1H3Z2R4	12.1	12.9	2.4	6.5	8.1	0.0	5.6	0.0	0.0	0.0
M1H3Z2R5	11.1	8.5	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R1	22.3	6.2	3.1	1.0	1.3	0.0	0.0	0.0	0.0	0.0
M2H1Z1R2	29.2	3.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R3	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R4	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z1R5	9.7	3.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H1Z2R1	12.2	9.1	1.5	2.0	2.5	0.0	0.0	0.0	0.0	0.0
M2H1Z2R2	16.3	8.1	2.7	5.4	4.5	0.0	0.0	0.0	0.0	0.0
M2H1Z2R3	15.7	7.1	4.6	0.0	0.0	0.0	0.0	0.0	0.[illegible]	0.0
M2H1Z2R4	11.2	9.7	10.2	0.0	0.0	2.9	0.0	0.0	0.0	0.0
M2H1Z2R5	14.5	8.7	7.2	1.9	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R1	11.1	4.3	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R2	14.8	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R3	15.5	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R4	13.5	2.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z1R5	16.8	10.8	4.9	2.2	0.0	0.0	0.0	0.0	0.0	0.0

M1 = 3 plants/s H1 = 1-cut Z1 = 45 g R1..5 = replication
M2 = 6 plants/s H2 = 2-cut Z2 = 60 g
M3 = 9 plants/s H3 = 3-cut

Trial	Percent of total metering errors									
	Consecutive metering errors									
	1	2	3	4	5	6	7	8	9	10
M2H2Z2R1	16.6	8.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R2	14.0	12.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R3	10.8	6.1	2.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R4	13.7	6.8	1.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0
M2H2Z2R5	16.4	5.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
M2H3Z1R1	8.8	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R2	7.9	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R3	12.7	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R4	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z1R5	7.1	1.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R1	11.7	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R2	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R3	10.2	7.3	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R4	12.1	5.6	2.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0
M2H3Z2R5	11.6	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R1	21.8	1.4	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R2	28.2	0.0	4.8	0.0	1.1	0.0	0.0	0.0	0.0	0.0
M3H1Z1R3	29.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R4	7.7	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z1R5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R1	10.7	1.8	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R2	10.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R3	17.0	4.5	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R4	5.4	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H1Z2R5	11.2	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R1	11.5	3.1	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R2	13.1	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R3	6.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R4	5.5	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z1R5	13.0	5.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R1	15.5	1.7	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R2	9.2	1.9	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R3	15.6	5.4	2.7	0.0	2.2	0.0	0.0	0.0	0.0	0.0
M3H2Z2R4	13.8	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H2Z2R5	19.6	5.5	1.2	0.0	0.0	0.0	2.7	0.0	0.0	0.0
M3H3Z1R1	7.3	1.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R2	6.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R3	7.9	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z1R4	9.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	0.0
M3H3Z1R5	4.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	0.0
M3H3Z2R1	9.7	3.6	1.8	0.0	0.0	0.0	0.0	0.0	[illegible]	0.0
M3H3Z2R2	11.7	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z2R3	10.9	7.8	2.3	3.1	3.9	0.0	0.0	0.0	0.0	0.0
M3H3Z2R4	7.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H3Z2R5	6.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

M1 = 3 plants/s H1 = 1-cut Z1 = 45 g R1..5 = replication
M2 = 6 plants/s H2 = 2-cut Z2 = 60 g
M3 = 9 plants/s H3 = 3-cut

B4. Whole seed-metering trial data listed below represents the distribution of consecutive metering errors expressed as a percent of total metering errors.

Trial	Percent of total metering errors									
	Consecutive metering errors									
	1	2	3	4	5	6	7	8	9	10
M1H0R1	11.8	17.0	13.7	5.2	3.3	3.9	0.0	0.0	0.0	0.0
M1H0R2	8.2	10.6	8.8	14.1	0.0	10.6	0.0	0.0	5.3	0.0
M1H0R3	12.4	12.9	12.4	4.7	5.9	7.1	0.0	0.0	0.0	0.0
M1H0R4	10.9	10.9	8.2	5.4	6.8	0.0	0.0	5.4	0.0	0.0
M1H0R5	12.6	11.0	1.7	15.4	5.5	3.3	3.8	0.0	0.0	0.0
M2H0R1	16.4	6.9	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2H0R2	14.6	10.1	8.4	2.3	0.0	0.0	0.0	0.0	0.0	0.0
M2H0R3	14.9	8.3	3.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0
M2H0R4	15.5	3.7	3.7	0.0	3.1	0.0	0.0	0.0	0.0	0.0
M2H0R5	12.6	6.6	3.3	8.8	0.0	0.0	0.0	0.0	0.0	0.0
M3H0R1	14.3	1.5	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H0R2	13.2	2.4	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H0R3	8.1	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H0R4	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M3H0R5	8.8	2.8	1.6	1.4	0.9	1.1	0.0	0.0	0.0	0.0

M1 = 3 plants/s   H0 = whole seed   R1..5 = replication
M2 = 6 plants/s
M3 = 9 plants/s

10. APPENDIX C. MONITOR COMPONENTS

Potato Planter Monitor Components

Name	Description	Code Number	Purpose
Components for the microprocessor board			
M6809	8-BIT Micro-processor	U1 1	MPU - executes M6809 instruction set
74ls245N	Octal bus transceivers	U2 1	Buffers for data lines
74LS244	Octal buffer line drivers /receivers	U3-U5 3	Buffers for address and control lines
74154N	4-line to 16-line de-multiplexer	U7 1	Facilitates division of addressable memory into 16 - 4K memory blocks
2716JL	2048 word x 8 bit erasable prom	U8,U9 2	Provides one 2K reprogrammable ROM
6116P	2048 word x 8 bit high speed static CMOS RAM	U11 1	Random access memory for program variables, and system stacks (2K)
MC6850	ACIA	U13,U14 2	Facilitates serial communications
MC6821P	PIA	U19 1	Facilitates physical-logical interface with peripheral devices
MC6840	PTM	U15 1	Provides 3 programable timers, used for 5 s statistical and display updates
7400N	Quad 2 input NAND gates	U10 1	NAND logic function decoding
74LS02	Quad 2 input NOR gates	U12 1	Allows for 2 of 4 decoding
7404N	Hex inverter	U29 1	Inverts logic signals
7408N	Quad 2 input AND gates	U30 1	Row change request circuit

cont...

Monitor Components (cont...)

Name	Description	Code Number	Purpose
7414N	Hex Schmitt-trigger inverters	U6 1	
<u>Crystal</u>			
MP0368	3.57 MHz crystal	C1 1	Provides input signal for M6809 clock signal (E and Q)
<u>Capacitors</u>			
150 uF	Incoming end of Vcc and Gnd bars	1	Smooths power supply
27 pF	In crystal circuit	C1 2	Sine wave O/P
10.0 uF	Between Vcc and GND bars	9	Decoupling
1.0 uF	In reset circuit	R1 1	Switch debouncing
2.4 nF	Row change	R4 1	Switch debouncing
<u>Resistors</u>			
1 kΩ	1/4 W	R2-R4 17	Pull-up resistors in microswitch and photoscanner circuit, row select debouncing
2.7 kΩ	1/4 W	R4 1	Row select switch debouncing
4.7 kΩ	1/4 W	R1,R5 6	Pullup resistors for IRQ, FIRQ, HALT, NMI, BMA/BREQ, MRDY, on MPU and row select circuit
10 kΩ	1/4 W	R1,R5 R4 17	Debouncing circuit, crystal circuit, and PTM to Gnd circuit

cont...

Monitor Components (cont...)

Name	Description	Code / Number	Purpose
Input devices			
Micro-switches	8 bit micro switch	S2, S3 2	Allows input of number of rows and number of elements/row for the planter
Pulse switches	Normally open	S1, S4 S5 3	Reset and display mode change, row change
Toggle switches	on-off	S6, S7 2	Used to enable row autoincrement function and defective element indicator (buzzer)
Output devices			
PCIM200	PCI alphanumeric LCD dot matrix module	T9 1	Facilitates the display of ~~per~~formance information
Buzzer	Small Radio Shack buzzer	T10 1	Indicates defective metering element
Connectors			
D9	9 pin male	D9 1	Serial communication port
40 pin	Right angle ~~male,~~ board mount	U22, U23 2	Microprocessor board to monitor connection
40 pin	Ribbon clamp female	U22, U23 2	Microprocessor board to monitor connection
16 pin	Male IC ribbon connector	J4	Sensor connection to microprocessor board
IC Sockets			
	40 pins	U1, U16 U19 3	MPU, PIA socket

cont...

Monitor Components (cont...)

Name	Description	Code Number	Purpose
	28 pins	U15 1	PTM socket
	24 pins	U7 U8 U9 U11 U13,U14 6	Demultiplexer socket EPROM socket EPROM socket RAM socket ACIA (x 2) sockets
	20 pins	U2-U5 4	Buffer sockets
	16 pins	R1-R5 5	ICs and resistor bank sockets
	14 pins	R1,U6 U10,U12 U17 5	ICs and resistor banks sockets
Misc.			
Board	Perforated IC board	2	For microprocessor system and display
Board stand	Al board holder with legs top and bottom	1	Allow for circuit assembly and provides
Wire wrap wire	Plastic coated	Fair bit	Connections between socket pins
Ribbon wire	40 pin	30 cm	Connects main board to display board
	16 pin	130 cm	Connects sensors to main board
Power cord	With banana plugs	2	Vcc and Gnd connection

cont...

Monitor Components (cont...)

Name	Description	Code Number	Purpose
Components for each row monitored			
MC6821P	PIA	U16 1	Facilitates physical-logical interface with peripheral devices
Inverters (7404N)	2 Input inverter gates	U29 6	Used to generate logic level O/P from 'Hall Effect' sensor
Drivers (7407N)	Hex buffer/drivers with open collector high voltage O/P gates	U20,U21 8	Drives LEDs and buzzer
NAND gates (7400N)	2 Input NAND gates	U17 2	Used to generate logic level O/P from photoscanner
Input devices			
MCS-651 (Wanner Electric)	Modulated IR through beam photoscanner	N1 1	Potato sensor
UGS3019T	Sprague 'Hall Effect' switch	N2 1	Detects occurence of metering event
Output devices			
LEDs	Retangular yellow	L1 4	Indicate consecutive metering misses
	red	L1 2	Indicate sensor malfunction
	green	L1 3	Row display indicator
Resistors			
47Ω	1/4 W	R6 8	Current limiting resistors for LED

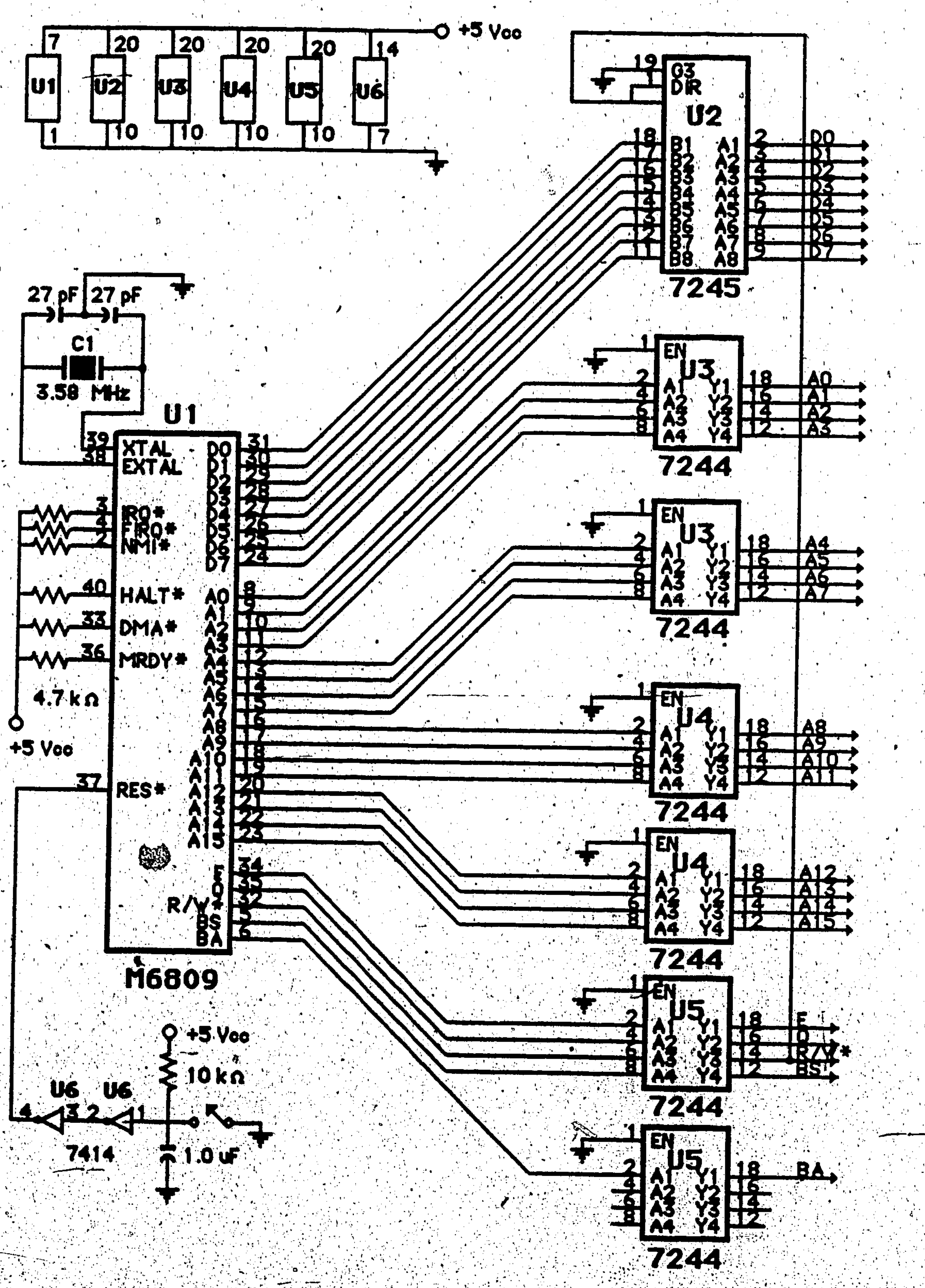
cont...

Monitor Components (cont...)

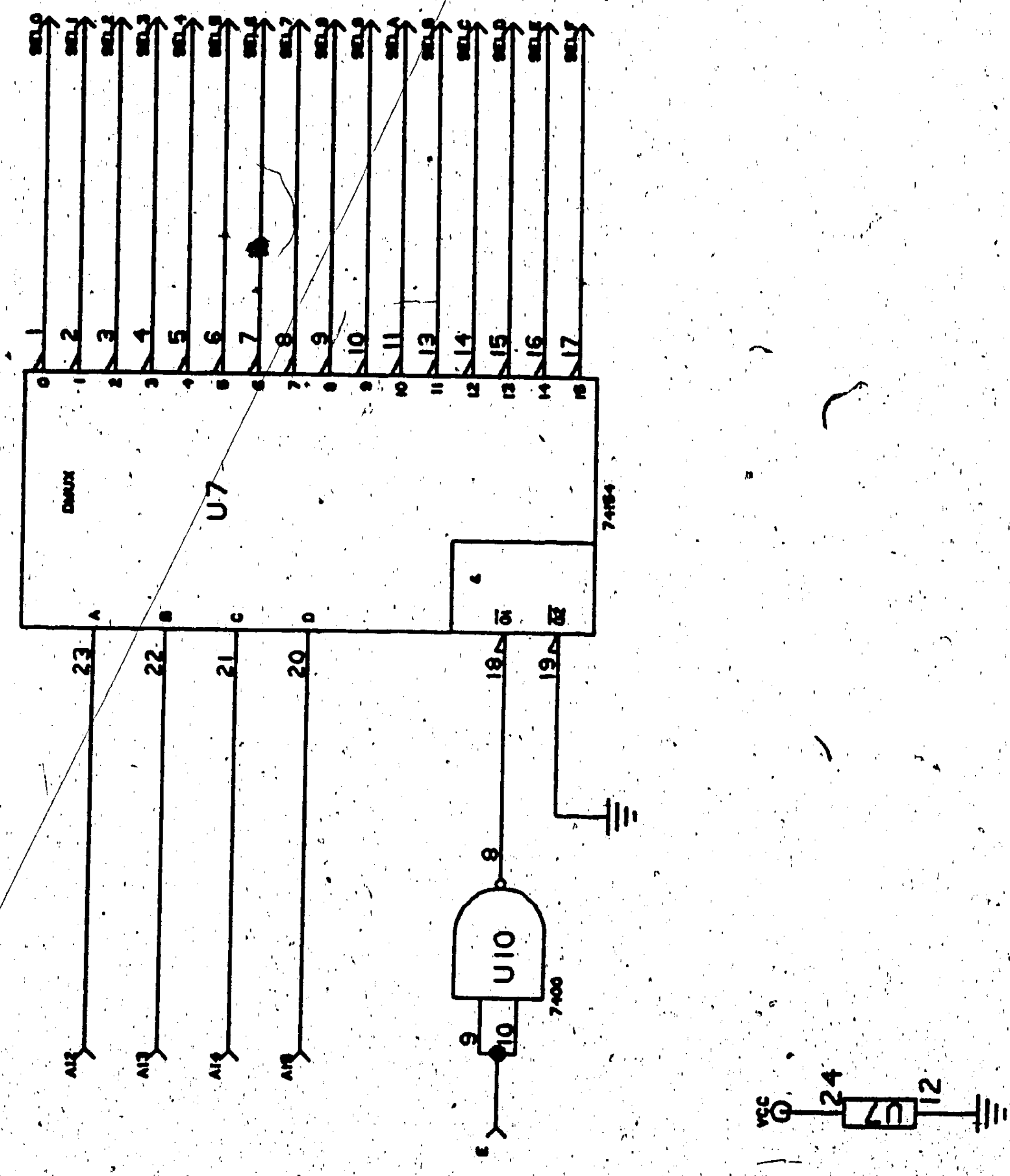
Name	Description	Code Number	Purpose
4.7 kΩ	1/4 W	R5 1	Pullup for IR photo-scanner circuit.
Misc.			
Wire wrap wire	Plastic coated	Fair bit	Connections between socket pins
IC Sockets	40 pins	U16 1	PIA socket

11. APPENDIX D. MONITOR CIRCUIT DIAGRAMS

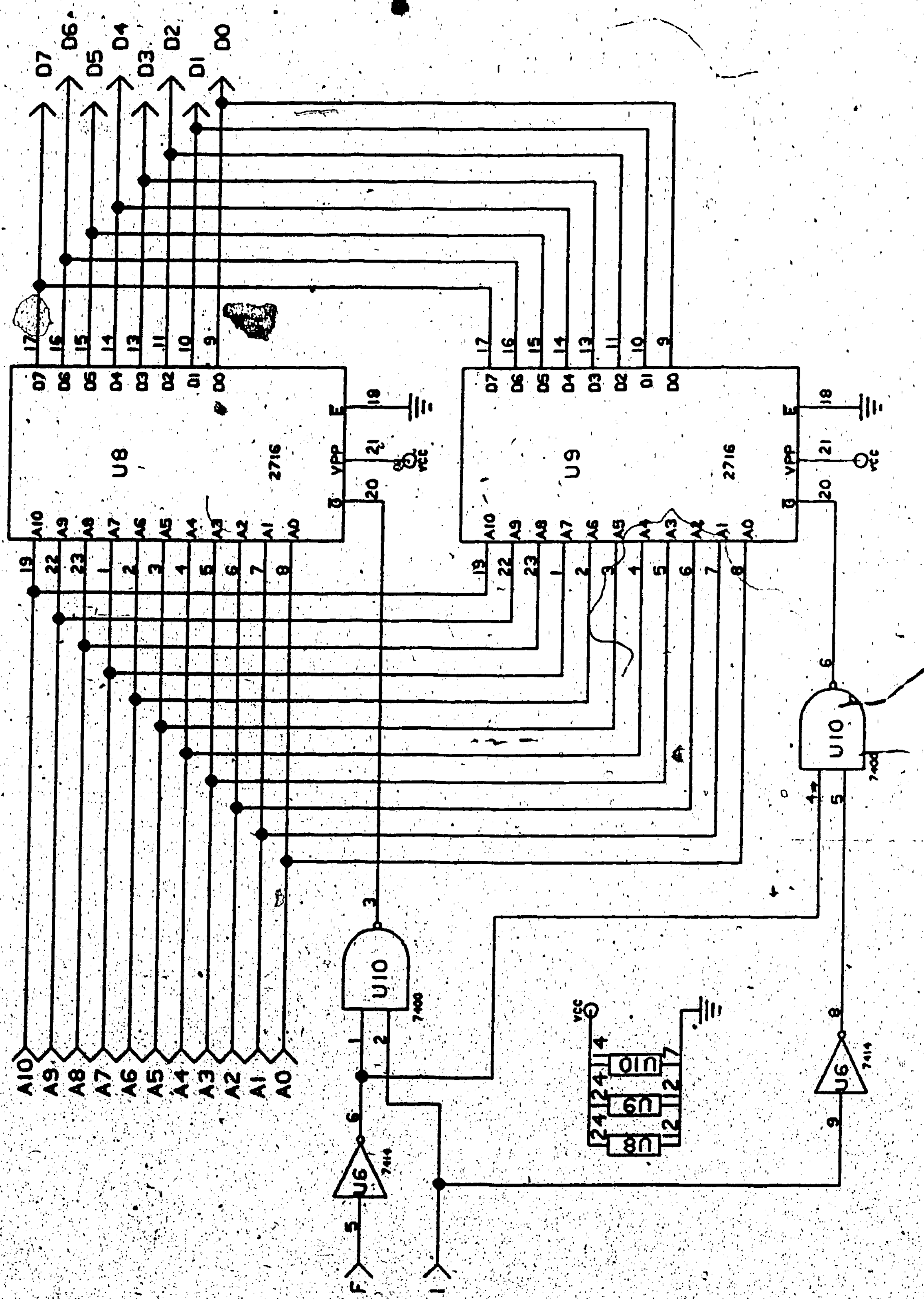
D1. Microprocessor, Clock, and Reset Circuit



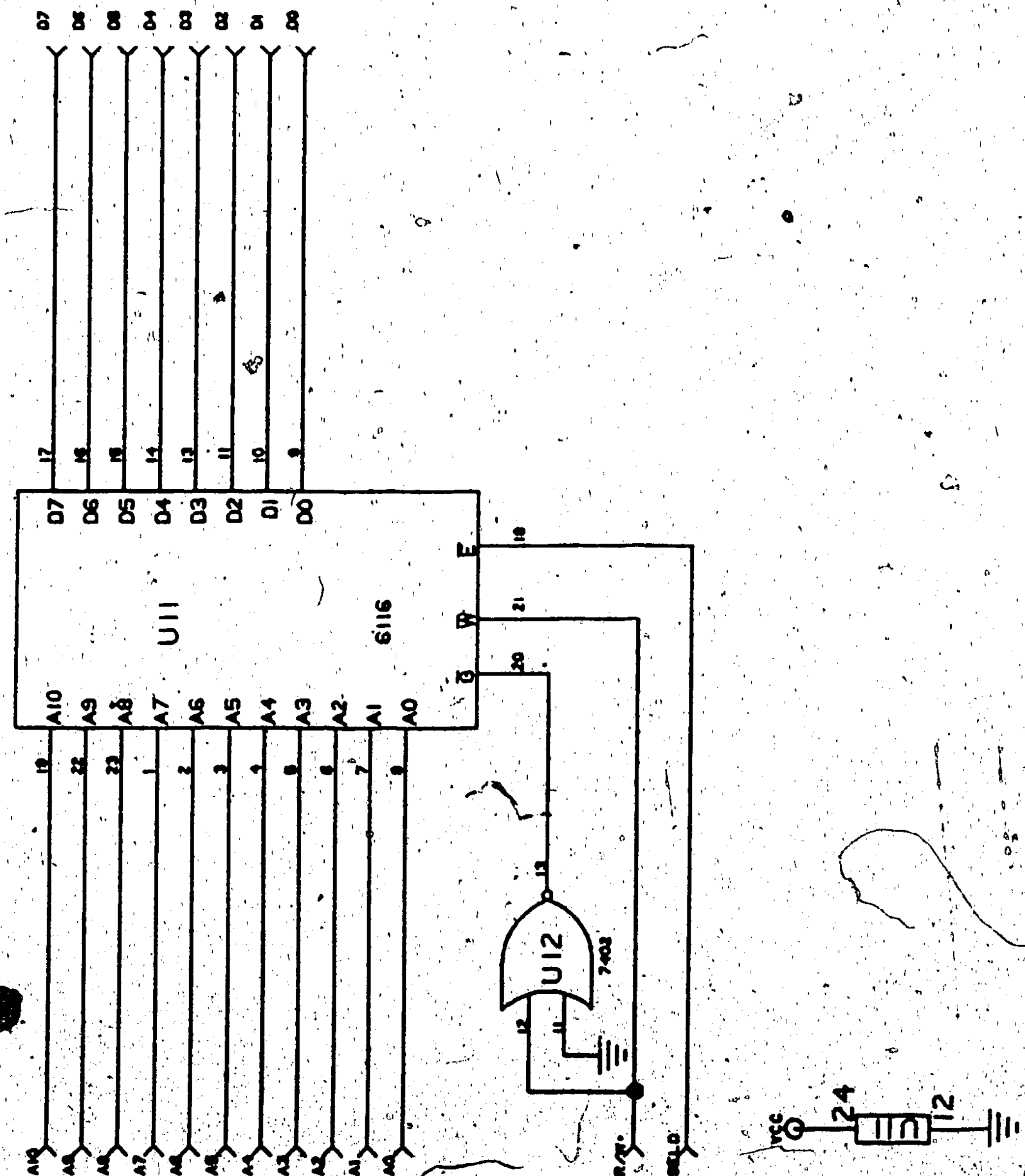
D2. Address Decoding Circuit



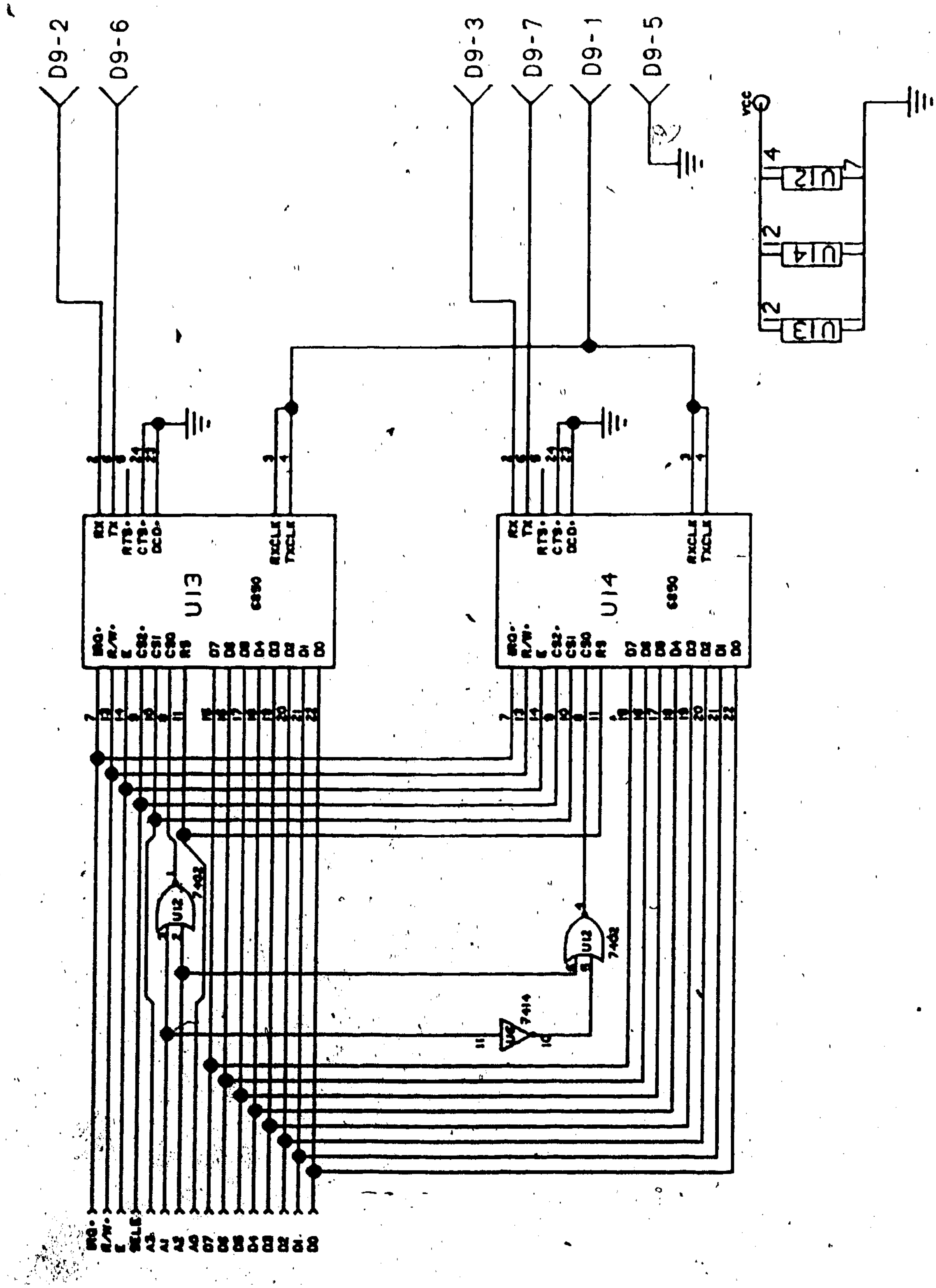
D3. EPROM Circuit



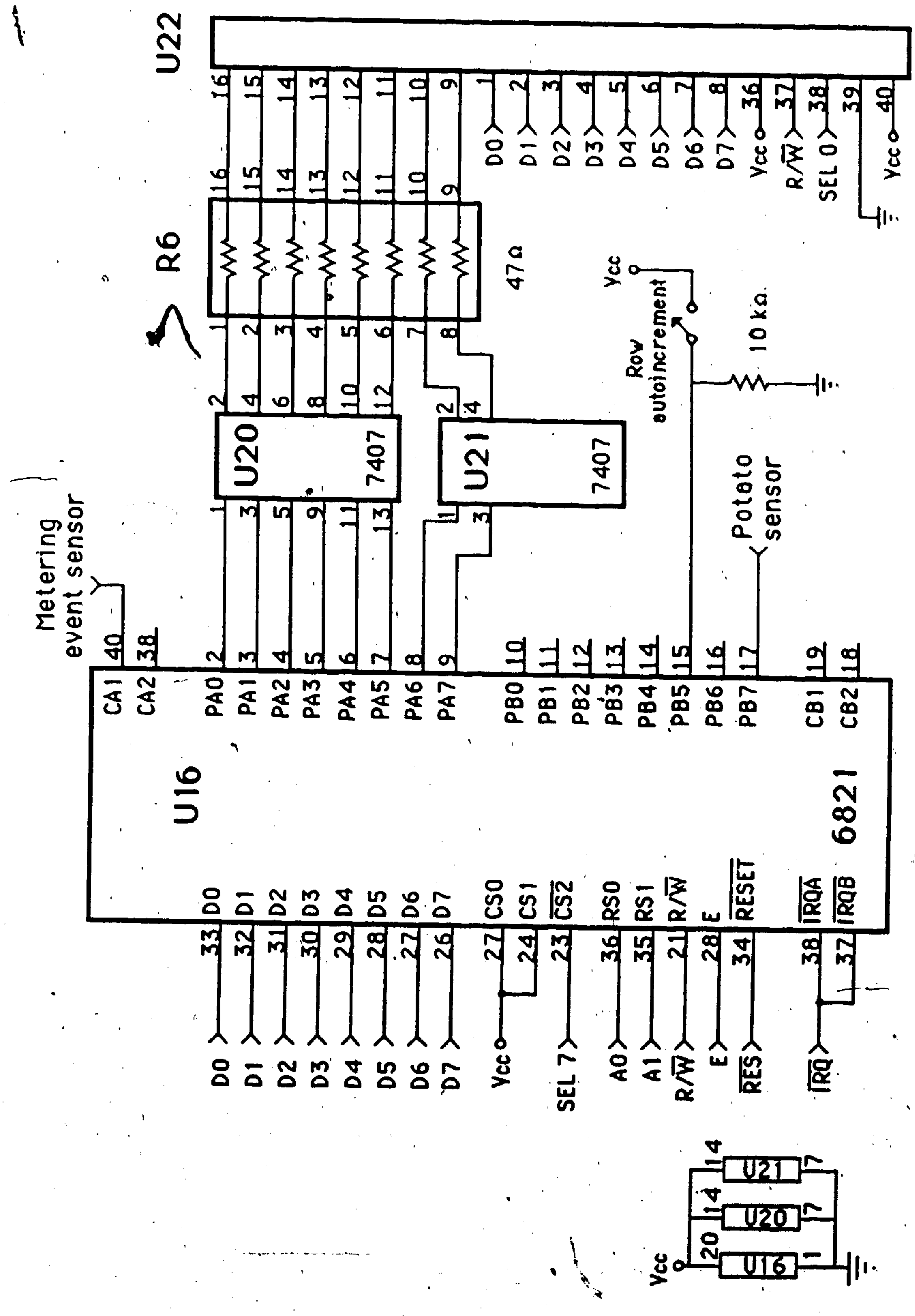
D4. RAM Circuit



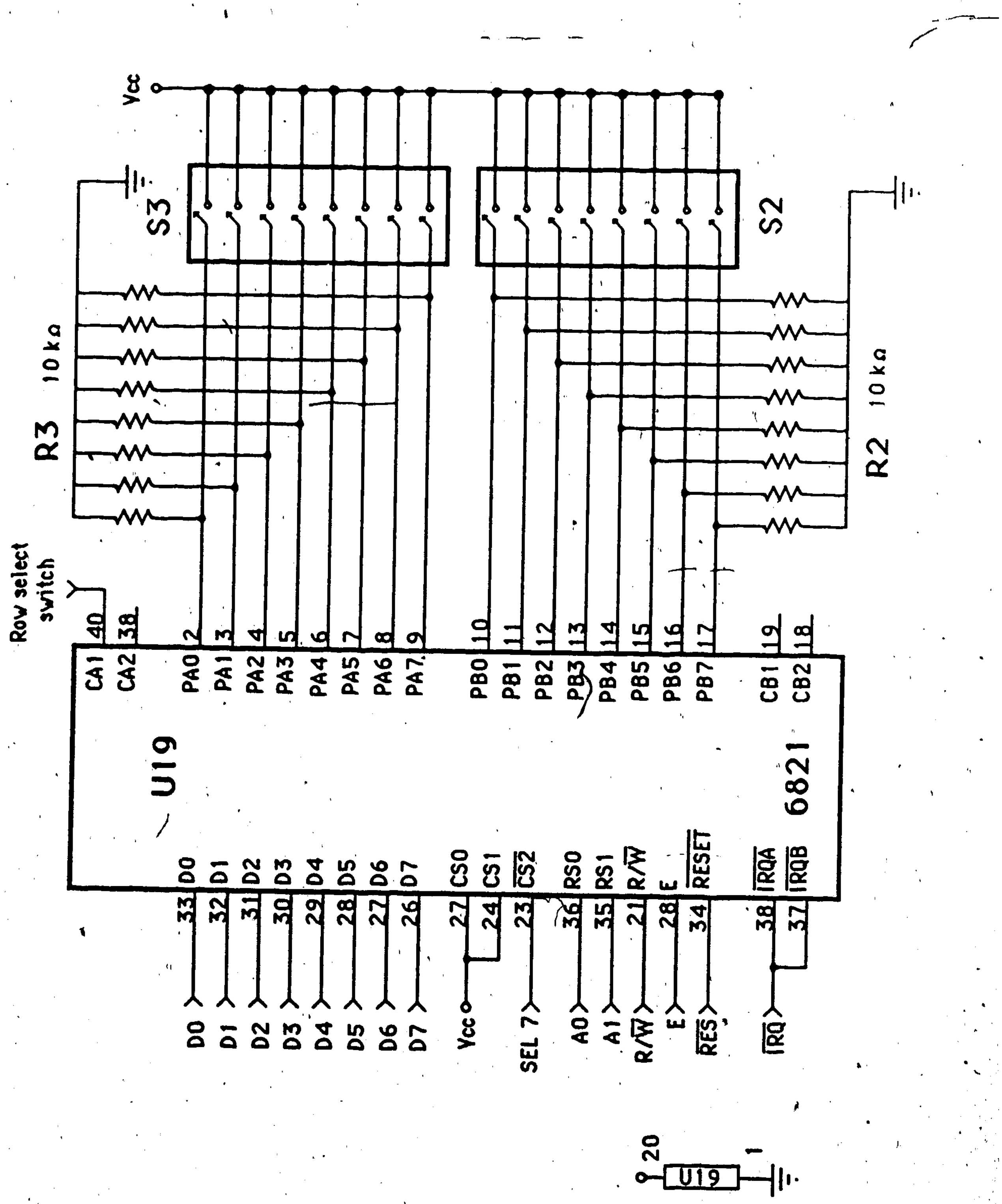
D5. ACIA Circuit



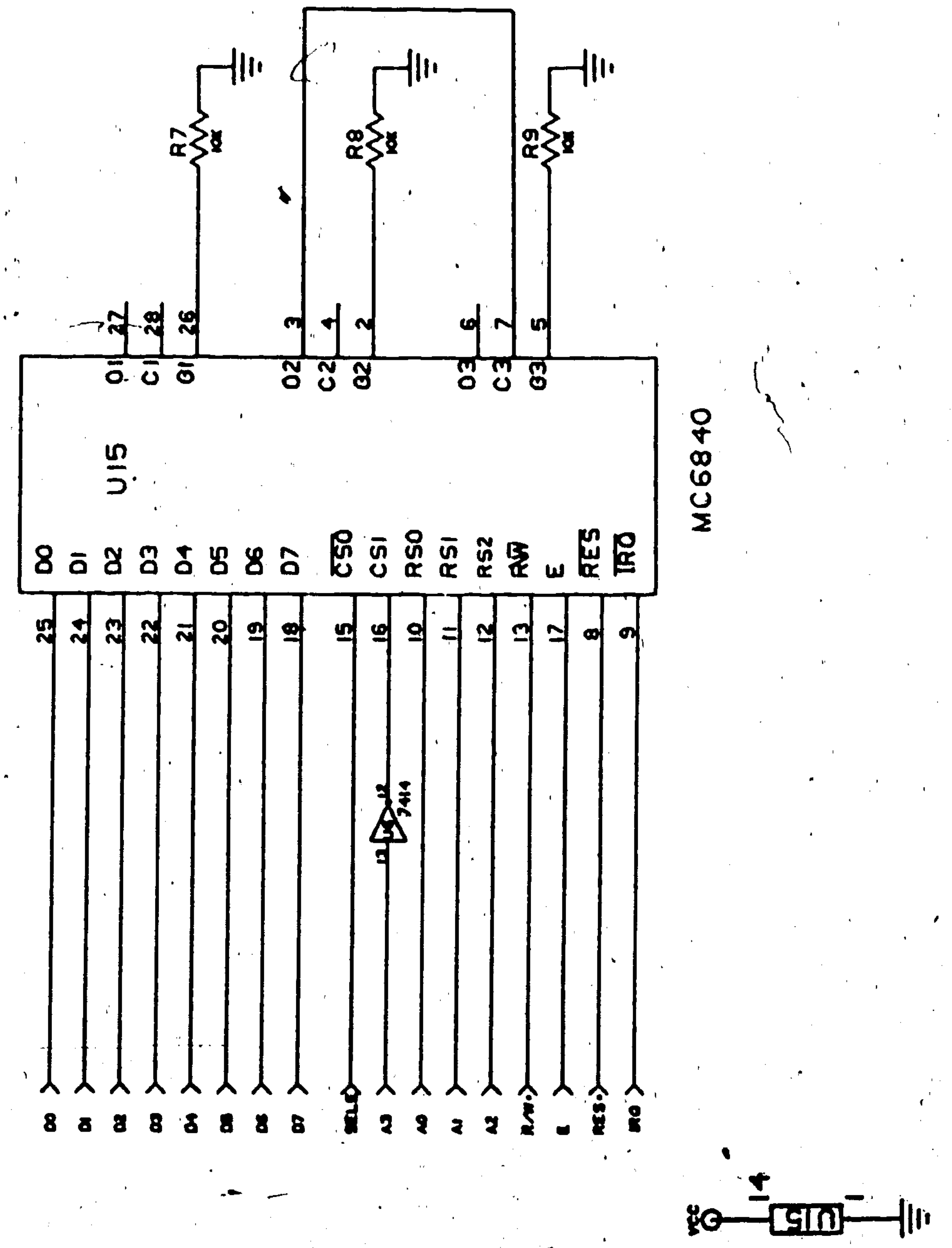
D6. Row PIA Circuit



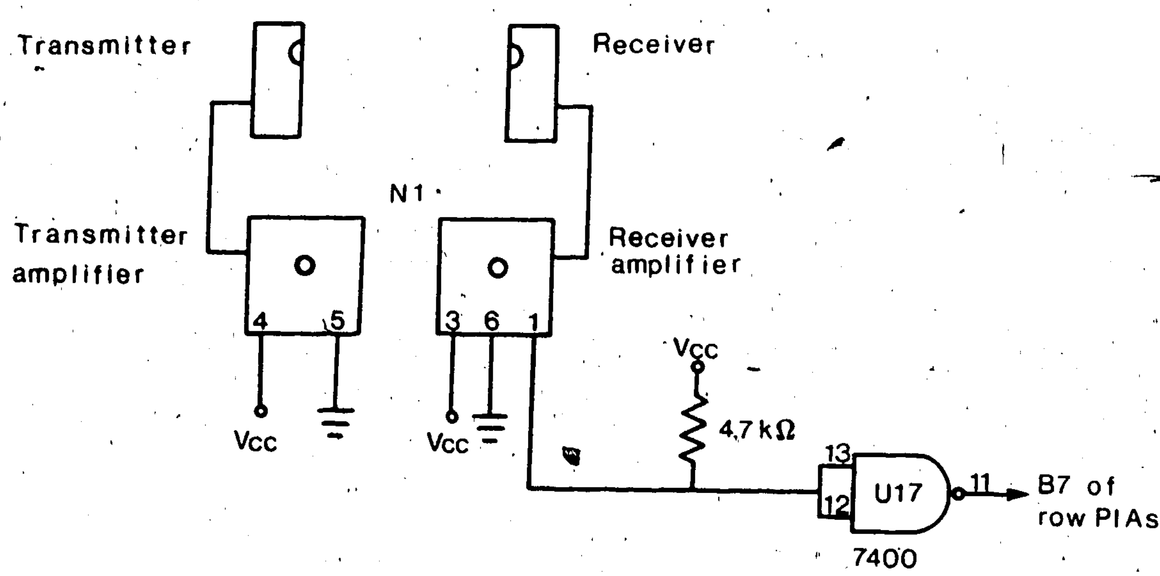
D7. Microswitch PIA Circuit



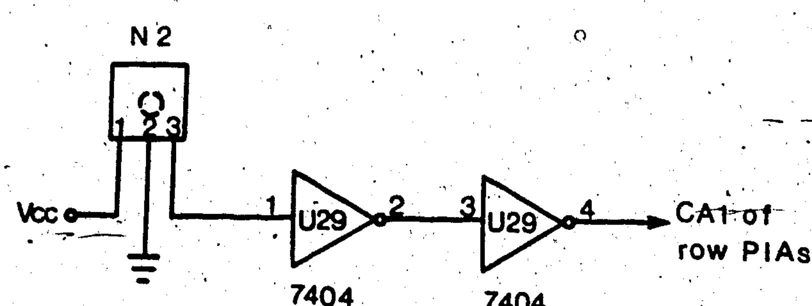
D8. PTM Circuit



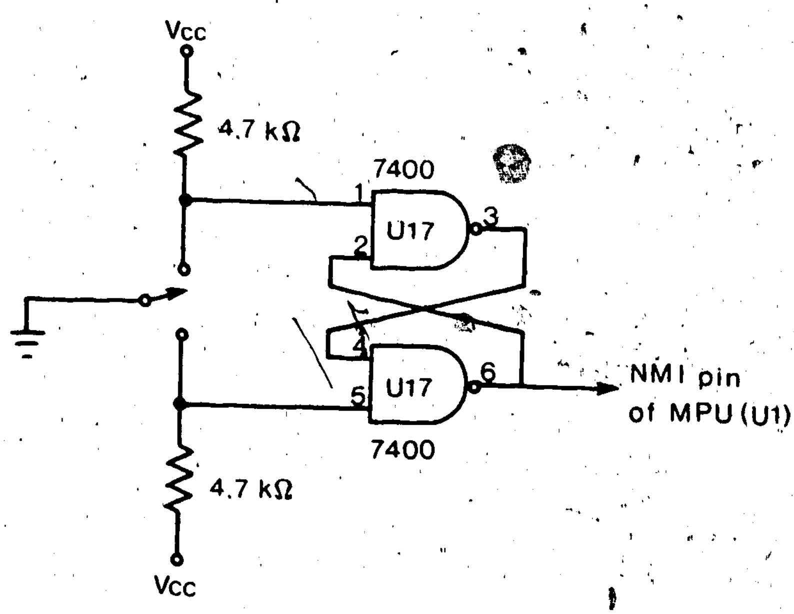
D9. Potato Sensor



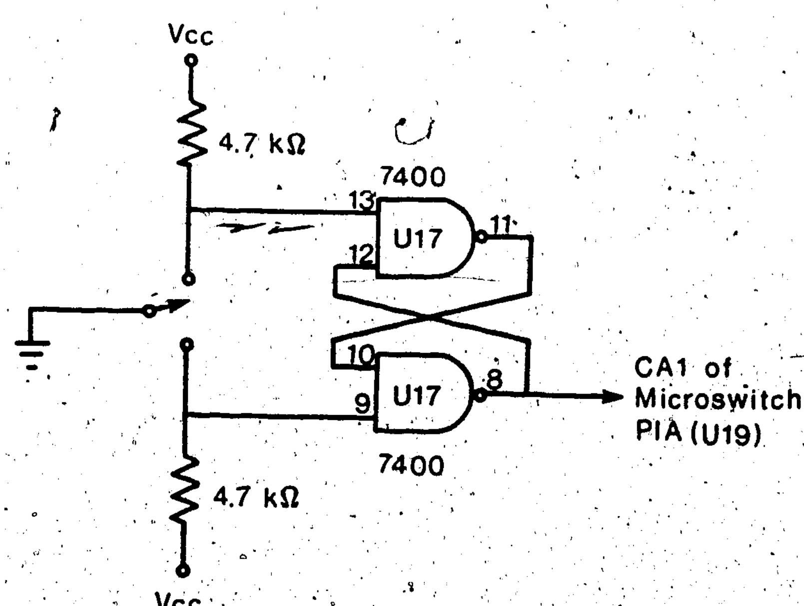
D10. Metering Event Sensor



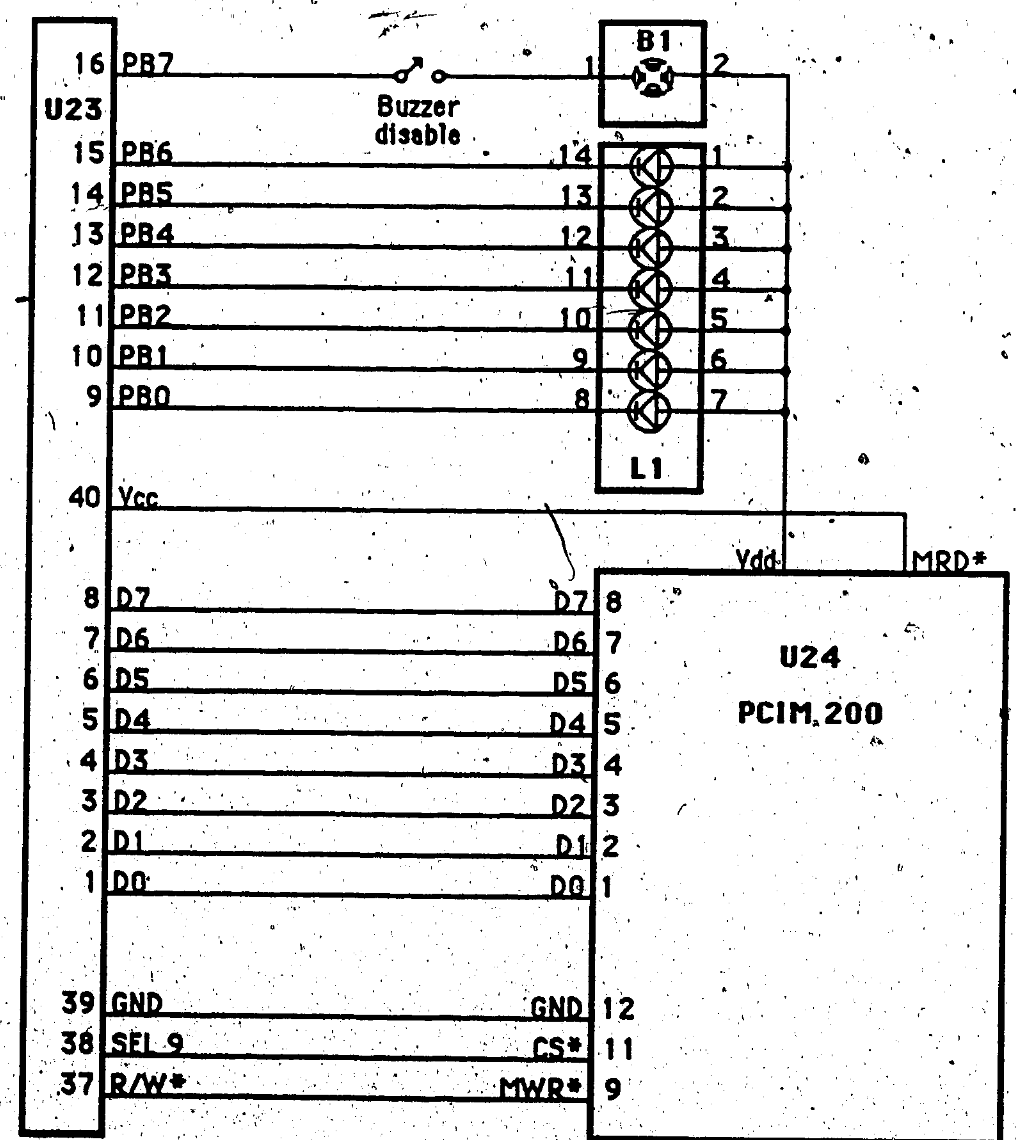
D11. Mode Change Circuit



D12. Row Change Circuit



D13. Display Circuit



12. APPENDIX E. MONITOR PROGRAM

```
PPM  ;(Potato planter monitor)                                                   M6809 Version UL202    Page   1

ILC  Object      I  STMT  Line #   Source Statement                                                   17:33:32  06-27-86

                     1      1.          NAM  PPM     ;Potato Planter Monitor
                     2      2.     * PROGRAM NAME:    PPM.M69
                     3      3.     * PURPOSE:         Potato Planter Performance Feedback
                     4      4.     * PROGRAMED FOR:   Partial fulfillment of Masters thesis project
                     5      5.     * DESIGNED FOR:    M6809 microprocessor
                     6      6.     * DATE COMPLETED:  June 27, 1986.
                     7      7.     * PROGRAMER:       Edward Hauck
                     8      8.     *<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
                     9      9.     *
                    10     10.     *
                    11     11.     * Routine addresses *
                    12     12.     *
     F800           13     13.     RESET   EQU  $F800    ;Reset
     F960           14     14.     IRQ     EQU  $F960    ;IRQ - metering & statistics update, and row change
     FC00           15     15.     NMI     EQU  $FC00    ;NMI - change modes & display
                    16     16.     *
                    17     17.     * Device addresses *
                    18     18.     *
     0000           19     19.     LCD     EQU  $0000    ;LCD address
     1000           20     20.     PIA1    EQU  $1000    ;Row 1 PIA
     2000           21     21.     PIA2    EQU  $2000    ;Row 2 PIA
     3000           22     22.     PIA3    EQU  $3000    ;Row 3 PIA
     4000           23     23.     PIA4    EQU  $4000    ;Row 4 PIA
     5000           24     24.     PIA5    EQU  $5000    ;Row 5 PIA
     6000           25     25.     PIA6    EQU  $6000    ;Row 6 PIA
     7000           26     26.     PIAS    EQU  $7000    ;Microswitch PIA
                    27     27.     * Timers
     8000           28     28.     PTM1    EQU  $8000    ;PTM 1 (display refresh - clocks  2 & 3; clock 1 unused)
     8002           29     29.     COUNT1  EQU  $8002    ;Counter 1
     8004           30     30.     COUNT2  EQU  $8004    ;Counter 2
     8006           31     31.     COUNT3  EQU  $8006    ;Counter 3
     8003           32     32.     LATCH1  EQU  $8003    ;Latch 1
     8005           33     33.     LATCH2  EQU  $8005    ;Latch 2
     8007           34     34.     LATCH3  EQU  $8007    ;Latch 3
                    35     35.     *
                    36     36.     * Variable addresses (RAM) and variable definitions *
                    37     37.     *
     D000           38     38.     DIVWS   EQU  $D000    ;(3)  Division workspace base address
     D003           39     39.     CNTR1   EQU  $D003    ;(1)  Counter used in division subroutine
     D004           40     40.     NOROWS  EQU  $D004    ;(1)  Number of rows
     D005           41     41.     ELOFFS  EQU  $D005    ;(1)  Offset to consecutive miss count for first element
     D006           42     42.     LASVAL  EQU  $D006    ;(2)  Last value displayed
     D008           43     43.     MODE    EQU  $D008    ;(1)  Display mode
     D009           44     44.     CNTR    EQU  $D009    ;(5)  Counter used in HEX to ASCII conversion
     D00F           45     45.     ZFLG    EQU  $D00F    ;(1)  Flag to keep track of leading zeros
     D010           46     46.     DISROW  EQU  $D010    ;(2)  Data block address of row displayed
     D012           47     47.     CURROW  EQU  $D012    ;(1)  Row number currently being displayed
     D013           48     48.     AUTORW  EQU  $D013    ;(1)  Mode 1 row autoincrement flag
     D014           49     49.     DISLAB  EQU  $D014    ;(2)  Address of mode label currently dislayed
     D016           50     50.     OFFSET  EQU  $D016    ;(1)  Offset from data block base address of the displayed value
     D017           51     51.     CURPIA  EQU  $D017    ;(2)  PIA corresponding to row displayed
     D019           52     52.     LKDAT1  EQU  $D019    ;(2)  Row 1 - Pointer to data block checked on a
     D01B           53     53.     LKDAT2  EQU  $D01B    ;(2)  Row 2   potato sensor malfunction test
     D01D           54     54.     LKDAT3  EQU  $D01D    ;(2)  Row 3
     D01F           55     55.     LKDAT4  EQU  $D01F    ;(2)  Row 4
```

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ILC  Object      I  STMT  Line #   Source Statement                                          17:33:32  06-27-86

          D021         56    56.   LKDAT5 EQU  $D021    ;(2)  Row 5
          D023         57    57.   LKDAT6 EQU  $D023    ;(2)  Row 6
          D025         58    58.   LKPIA1 EQU  $D025    ;(2)  Row 1 - Pointer to PIA checked on a potato sensor
          D027         59    59.   LKPIA2 EQU  $D027    ;(2)  Row 2   malfunction test
          D029         60    60.   LKPIA3 EQU  $D029    ;(2)  Row 3
          D02B         61    61.   LKPIA4 EQU  $D02B    ;(2)  Row 4
          D02D         62    62.   LKPIA5 EQU  $D02D    ;(2)  Row 5
          D02F         63    63.   LKPIA6 EQU  $D02F    ;(2)  Row 6
          D031         64    64.   VALUE  EQU  $D031    ;(7)  ASCII representation of value displayed
          D039         65    65.   BUZFLG EQU  $D039    ;(1)  Buzzer flag
          D03A         66    66.   MODFLG EQU  $D03A    ;(1)  Mode change flag
          D100         67    67.   DATA1  EQU  $D100    ;(100) Data block 1 base address
          D200         68    68.   DATA2  EQU  $D200    ;(100) Data block 2 base address
          D300         69    69.   DATA3  EQU  $D300    ;(100) Data block 3 base address
          D400         70    70.   DATA4  EQU  $D400    ;(100) Data block 4 base address
          D500         71    71.   DATA5  EQU  $D500    ;(100) Data block 5 base address
          D600         72    72.   DATA6  EQU  $D600    ;(100) Data block 6 base address
          D740         73    73.   USTACK EQU  $D740    ;(40)  User stack pointer
          D800         74    74.   SSTACK EQU  $D800    ;(BQ)  System stack pointer
                       75    75.   *
                       76    76.   * Program variable offset from data block base addresses for rows 1 to 6 *
                       77    77.   *
          0000         78    78.   CNEV   EQU  $00      ;(1)  Current number of events
          0001         79    79.   CNMISS EQU  $01      ;(1)  Current number of misses
          0002         80    80.   MISLED EQU  $02      ;(1)  Consecutive miss count displayed (yellow LEDs)
          0003         81    81.   LEDDIS EQU  $03      ;(1)  LED display mask
          0004         82    82.   NEXTEL EQU  $04      ;(1)  Next element in the metering chain to be monitored
          0005         83    83.   TMIS   EQU  $05      ;(2)  Total number of misses
          0007         84    84.   TEVENT EQU  $07      ;(2)  Total number of events
          0009         85    85.   THITS  EQU  $09      ;(2)  Total successful events
          000B         86    86.   PERMIS EQU  $0B      ;(2)  Current percent misses
          000D         87    87.   PLRATE EQU  $0D      ;(2)  Current planting rate (Potato/min)
          000F         88    88.   SENFLG EQU  $0F      ;(1)  Flag for potato sensor check
          0010         89    89.   CONMIS EQU  $10      ;(1)  Number of consecutive misses
                       90    90.   *
                       91    91.   *
                       92    92.   *
                       93    93.   * <<<< Initialization routine >>>>
                       94    94.   *
                       95    95.   *  << Initialize stacks >>
                       96    96.   *
F800                   97    97.          ORG  RESET
F800 10CE D800   4     98    98.   STKINT LDS  #SSTACK        ;Load system stack
F804 CE   D740   3     99    99.          LDU  #USTACK        ;Load user stack
                      100   100.   *
                      101   101.   *  << Initialization of LCD display >>
                      102   102.   *
F807 BD   FD59   8    103   103.   LCDINT JSR  DELAY          ;Delay to latch character to display
F80A 8E   FDD2   3    104   104.          LDX  #FLAGS         ;Base address of LCD initialization flags
F80D A6   80     6    105   105.   FLGDSP LDA  ,X+            ;Next flag loaded
F80F 97   C0     4    106   106.          STA  LCD            ; and stored
F811 81   8A     2    107   107.          CMPA #$8A           ;Last flag?
F813 26   F8     3    108   108.          BNE  FLGDSP         ;No, get next one
F815 BD   FD4E   8    109   109.          JSR  CLRLCD         ;Clear display
                      110   110.   *
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PPM  ;(Potato planter monitor)                                                    M6809 Version UL202   Page   3

ILC  Object        I  STMT  Line #   Source Statement                                                  17:33:32  06-27-86

                         111   111.   * Display greeting message
F818 8E  FD90      3     112   112.         LDX  #HELFLG       ;Base address for initial message
F81B C6  10        2     113   113.         LDB  #16           ;Number of characters to dump
F81D BD  FD65      8     114   114.         JSR  DUMP          ;Transfer character string from RAM to display buffer
                         115   115.   *
                         116   116.   * << PIA RESET >>
                         117   117.   *
                         118   118.   * Reset microswitch PIA
F820 4F            2     119   119.   PIAINT CLRA
F821 B7  7001      5     120   120.         STA  PIAS+1        ;CRA - Access data direction register on A port
F824 B7  7003      5     121   121.         STA  PIAS+3        ;CRB - Access data direction register on B port
F827 B7  7000      5     122   122.         STA  PIAS          ;Port A for input
F82A B7  7002      5     123   123.         STA  PIAS+2        ;Port B for output
F82D 86  05        2     124   124.         LDA  #%00000101
F82F B7  7001      5     125   125.         STA  PIAS+1        ;Access data registers and enable CA1 (port A)
F832 86  04        2     126   126.         LDA  #%00000100
F834 B7  7003      5     127   127.         STA  PIAS+3        ;Access data registers (port B)
                         128   128.   *
                         129   129.   * PIAs corresponding to each row are initialized
F837 8E  1000      3     130   130.         LDX  #PIA1         ;Start with row 1
F83A F6  7000      5     131   131.         LDB  PIAS          ;Read microswitch for number of rows
F83D C4  BF        2     132   132.         ANDB #%10111111    ;Mask bit-6 setting (Row autoincrement input)
F83F 4F            2     133   133.   PIARES CLRA
F840 A7  01        5     134   134.         STA  1,X           ;CRA - Access data direction register on A port
F842 A7  03        5     135   135.         STA  3,X           ;CRB - Access data direction register on B port
F844 A7  84        4     136   136.         STA  ,X            ;Port A for input
F846 86  FF        2     137   137.         LDA  #%11111111
F848 A7  02        5     138   138.         STA  2,X           ;Port B for input
F84A 86  05        2     139   139.         LDA  #%00000101
F84C A7  01        5     140   140.         STA  1,X           ;Access data registers and enable CA1 (port A)
F84E 86  04        2     141   141.         LDA  #%00000100
F850 A7  03        5     142   142.         STA  3,X           ;Access data registers (port B)
F852 86  DF        2     143   143.         LDA  #%11011111
F854 A7  02        5     144   144.         STA  2,X           ;Turn off all but row select LEDs (green)
F856 30  89 1000   8     145   145.         LEAX $1000,X       ;Base address of next PIA
F85A 5A            2     146   146.         DECB               ;Last PIA?
F85B 26  E2        3     147   147.         BNE  PIARES        ;No, initialize next PIA
                         148   148.   *
                         149   149.   *
                         150   150.   * << Initialize memory locations in RAM >>
                         151   151.   *
                         152   152.   * Zero 2K memory at D000-D7FF
F85D 8E  D000      3     153   153.   MEMINT LDX  #$D000      ;Starting at RAM address
F860 6F  80        8     154   154.   NCLR1  CLR  ,X+         ;Clear each byte
F862 8C  D7FF      4     155   155.         CMPX #$D7FF        ;End of RAM?
F865 26  F9        3     156   156.         BNE  NCLR1         ;No, continue
                         157   157.   *
                         158   158.   * Initialize program variables
F867 8E  D100      3     159   159.         LDX  #DATA1        ;Base addreess of row 1 data block
F86A BF  D010      6     160   160.         STX  DISROW        ;Row 1 is first data block to be displayed
F86D 8E  1000      3     161   161.         LDX  #PIA1
F870 BF  D017      6     162   162.         STX  CURPIA        ;PIA1 corresponds to first data block displayed
F873 8E  FDA0      3     163   163.         LDX  #PMISAS
F876 BF  D014      6     164   164.         STX  DISLAB        ;Address of current mode label
F879 7F  D006      7     165   165.         CLR  LASVAL        ;Last value displayed
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ILC  Object        I  STMT  Line #  Source Statement

F87C 86   01       2  166   166.           LDA  #01
F87E B7   D013     5  167   167.           STA  AUTORW          ;Mode 1 row autoincrement flag is set (disabled)
F881 B7   D012     5  168   168.           STA  CURROW          ;Number of data block currently displayed
F884 C6   08       2  169   169.           LDB  #PERMIS
F886 F7   D016     5  170   170.           STB  OFFSET          ;Offset from data block base of variable displayed
F889 86   DF       2  171   171.           LDA  #%11011111
F88B B7   D103     5  172   172.           STA  DATA1+LEDDIS    ;Row select bit (B6) in LED display mask on
F88E 86   FF       2  173   173.           LDA  #$FF
F890 B7   D203     5  174   174.           STA  DATA2+LEDDIS    ;Remaining LED display masks initialized to off
F893 B7   D303     5  175   175.           STA  DATA3+LEDDIS
F896 B7   D403     5  176   176.           STA  DATA4+LEDDIS
F899 B7   D503     5  177   177.           STA  DATA5+LEDDIS
F89C B7   D603     5  178   178.           STA  DATA6+LEDDIS
                      179   179.  *
                      180   180.  *  Read microswitches
                      181   181.  *    Port A - number of rows
                      182   182.  *    Port B - number of elements in each row of the metering device
F89F B6   7000     5  183   183.           LDA  PIAS            ;Read number of rows
F8A2 84   BF       2  184   184.           ANDA #%10111111      ;Bit-6 s masked out (mode 1 autoincrement input)
F8A4 B7   D004     5  185   185.           STA  NOROWS
F8A7 F6   7002     5  186   186.           LDB  PIAS+2          ;Read number of metering elements in each row
F8AA CB   11       2  187   187.           ADDB #$11            ;Add offset to next available memory for each block
F8AC F7   D005     5  188   188.           STB  ELOFFS          ;Memory offset to element missing flags
F8AF 8E   D100     3  189   189.           LDX  #DATA1          ;Base address of first data block
F8B2 E7   04       5  190   190.  OFFINT   STB  NEXTEL,X        ;Offset pointer current element in metering chain
F8B4 30   89 0100  8  191   191.           LEAX $0100,X         ;Base address of next data block
F8B8 4A            2  192   192.           DECA
F8B9 26   F7       3  193   193.           BNE  OFFINT          ;Last data block? If not initialize next data block
                      194   194.  *
                      195   195.  *  Potato sensor malfunction test checks sensor corresponding to PIA furthest
                      196   196.  *    away from interrupting PIA. Pointers to data blocks and PIA checked on
                      197   197.  *    an event are initialized for each row.
F8BB 108E FD7A     4  198   198.           LDY  #CKDAT          ;Base address for data blocks base addesses used in
F8BF B6   D004     5  199   199.           LDA  NOROWS          ;  light sensor malfunction tests
F8C2 1F   89       7  200   200.           TFR  A,B
F8C4 80   02       2  201   201.           SUBA #02             ;Offset to address of data block checked on row 1
F8C6 AE   A6       6  202   202.           LDX  A,Y             ;  interrupt
F8C8 8B   02       2  203   203.           ADDA #02             ;Number of rows
F8CA 44            2  204   204.           LSRA                 ;Number of row/2
F8CB 108E D019     4  205   205.           LDY  #LKDAT1         ;Pointer to data block checked on row 1 interrupt
F8CF AF   A1       6  206   206.  LKDAT    STX  ,Y++            ;Pointer to data block correspnding to row checked
F8D1 5A            2  207   207.           DECB                 ;All data blocks initialized?
F8D2 27   12       3  208   208.           BEQ  SETPIA          ;Yes, Initialize PIA pointers
F8D4 4A            2  209   209.           DECA
F8D5 B1   D004     5  210   210.           CMPA NOROWS          ;Last row initialised?
F8D8 26   06       3  211   211.           BNE  INCDAT          ;No, continue to next highest data block
F8DA 8E   D000     3  212   212.           LDX  #$D000          ;Reinitialize X register for next data block pointer
F8DD B6   D004     5  213   213.           LDA  NOROWS
F8E0 30   89 0100  8  214   214.  INCDAT   LEAX $0100,X         ;Pointer to next data block to checked on an event
F8E4 20   E9       3  215   215.           BRA  LKDAT           ;Initialize next data block
                      216   216.  *
F8E6 108E FD80     4  217   217.  SETPIA   LDY  #CKPIA          ;Base address for PIA pointers used in potato
F8EA B6   D004     5  218   218.           LDA  NOROWS          ;  sensor malfunction tests
F8ED 1F   89       7  219   219.           TFR  A,B
F8EF 80   02       2  220   220.           SUBA #02             ;Offset to address of data block checked on row 1
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ILC  Object      I  STMT  Line #  Source Statement                                    17:33:32  06-27-86

F8F1 AE   A6     6  221   221.           LDX  A,Y          ;  interrupt
F8F3 8B   02     2  222   222.           ADDA #02          ;Number of rows
F8F5 44          2  223   223.           LSRA              ;Number of row/2
F8F6 108E D025   4  224   224.           LDY  #LKPIA1      ;Pointer to PIA checked on row 1 interrupt
F8FA AF   A1     8  225   225.   LKPIA   STX  ,Y++         ;PIA checked on interrupt from corresponding row
F8FC 5A          2  226   226.           DECB              ;All PIA pointers initialized?
F8FD 27   0F     3  227   227.           BEQ  SETPTM       ;Yes, continue
F8FF 4A          2  228   228.           DECA
F900 26   06     3  229   229.           BNE  INCPIA       ;Last PIA initialized?
F902 8E   0000   3  230   230.           LDX  #$0000       ;Reinitialize PIA pointer address
F905 B6   D004   5  231   231.           LDA  NOROWS
F908 30   89 1000 8 232   232.   INCPIA  LEAX $1000,X      ;Pointer to next PIA checked on an event
F90C 20   EC     3  233   233.           BRA  LKPIA        ;Initialize next PIA
                    234   234.   *
                    235   235.   *
                    236   236.   *  << PTM reset >>
                    237   237.   *
                    238   238.   *   Timers 2 and 3 are cascaded together to produce an interrupt every 5 s.
                    239   239.   *
F90E 8E   AE62   3  240   240.   SETPTM  LDX  #44642
F911 BF   8004   6  241   241.           STX  COUNT2       ;Set latch 2
F914 8E   0032   3  242   242.           LDX  #50
F917 BF   8006   6  243   243.           STX  COUNT3       ;Set latch 3
F91A 8E   FFFF   3  244   244.           LDX  #65535
F91D BF   8002   6  245   245.           STX  COUNT1       ;Set latch 1
                    246   246.   *
                    247   247.   * Initialize control registers of PTMs
                    248   248.   *  Register 3
F920 86   E0     2  249   249.           LDA  #%11100000   ;B0   :T3 Clock +1
F922 B7   8000   5  250   250.           STA  PTM1         ;B1   :External clock.
                    251   251.   *                         ;B2   :16 Bit operation
                    252   252.   *                         ;B3-5:Continuous mode
                    253   253.   *                         ;B6   :Interrupt enabled
                    254   254.   *                         ;B7   :Output enabled
                    255   255.   *
                    256   256.   *  Register 2
F925 86   83     2  257   257.           LDA  #%10000011   ;B0   :Select control register 1
F927 B7   8001   5  258   258.           STA  PTM1+1       ;B1   :Use internal clock
                    259   259.   *                         ;B2   :16 Bit operation
                    260   260.   *                         ;B3-5:Continuous mode
                    261   261.   *                         ;B6   :Mask interrupts
                    262   262.   *                         ;B7   :Output enabled
                    263   263.   *
                    264   264.   *  Register 1
F92A 86   B3     2  265   265.           LDA  #%10110011   ;B0   :All timers preset
F92C B7   8000   5  266   266.           STA  PTM1         ;B1   :Use internal clock
                    267   267.   *                         ;B2   :16 Bit operation
                    268   268.   *                         ;B3-5:Single shot mode
                    269   269.   *                         ;B6   :Enable interrupt
                    270   270.   *                         ;B7   :output enabled
                    271   271.   *
                    272   272.   *
                    273   273.   *
                    274   274.   *  <<<< Main program >>>>
                    275   275.   *
```

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ILC  Object        I  STMT  Line #  Source Statement                                                    17:3[illegible]:32  06-27-86

F92F 3C   AF      21  276   276.            CWAI #%10101111   ;Stack registers and wait for an interrupt
F931 86   82       2  277   277.            LDA  #%10110010   ;First metering event just occured
F933 B7   8000     5  278   278.            STA  PTM1         ;Statistics update and display refresh timers operate
                      279   279.    *
                      280   280.    *  Turn off all row select LEDs off execpt row 1.
F936 F6   D004     5  281   281.            LDB  NOROWS
F939 5A            2  282   282.            DECB
F93A 8E   07D0     3  283   283.            LDX  #2000
F93D 86   FF       2  284   284.            LDA  #%11111111
F93F A7   02       5  285   285.    NEXOFF  STA  2,X          ;Turn off row select LED
F941 30   89 1000  8  286   286.            LEAX $1000,X
F945 5A            2  287   287.            DECB
F946 26   F7       3  288   288.            BNE  NEXOFF       ;All LEDs off? If not, next one
F948 3C   AF      21  289   289.    LOOP    CWAI #%10101111   ;Stack registers and wait for an interrupt
F94A 20   FC       3  290   290.            BRA  LOOP         ;Wait for another interrupt
                      291   291.    *
                      292   292.    *
                      293   293.    *
                      294   294.    *<<<< IRQ Service routine: Metering & statistics update, and change rows >>>>
                      295   295.    *
                      296   296.    *  << Polling routine >>
                      297   297.    *
F960                  298   298.            ORG  IRQ
                      299   299.    *       ANDCC #%01010000  ;Mask interrupts
                      300   300.    *
                      301   301.    *  Row 1 metering event (event sensor trigger)?
F960 B6   1001     5  302   302.    INT1    LDA  PIA1+1       ;Row 1 polled
F963 2A   1C       3  303   303.            BPL  INT2         ;If no interrupt, check row 2
F965 7D   D10F     7  304   304.            TST  DATA1+SENFLG ;First interrupt since statistics update?
F968 26   0D       3  305   305.            BNE  INTGO1       ;No, initialize base addresses for metering update
F96A BE   D019     6  306   306.            LDX  LKDAT1       ;Data block base address for malfunction test
F96D 10BE D025     7  307   307.            LDY  LKPIA1       ;PIA base address for malfunction test
F971 BD   FA3A     8  308   308.            JSR  MALTST       ;Check for potato sensor malfunction
F974 7C   D10F     7  309   309.            INC  DATA1+SENFLG ;Set flag indicating malfunction test complete
F977 8E   D100     3  310   310.    INTGO1  LDX  #DATA1       ;Base address of row 1 data block
F97A 108E 1000     4  311   311.            LDY  #PIA1        ;Base address of row 1 PIA
F97E 16   00C8     5  312   312.            LBRA METUPD       ;Go to metering update
                      313   313.    *
                      314   314.    *  Row 2 metering event (event sensor trigger)?
F981 B6   2001     5  315   315.    INT2    LDA  PIA2+1       ;Row 2 polled
F984 2A   1C       3  316   316.            BPL  INT3         ;If no interrupt, check row 3
F986 7D   D20F     7  317   317.            TST  DATA2+SENFLG ;First interrupt since statistics update?
F989 26   0D       3  318   318.            BNE  INTGO2       ;No, initialize base addresses for metering update
F98B BE   D01B     6  319   319.            LDX  LKDAT2       ;Data block base address for malfunction test
F98E 10BE D027     7  320   320.            LDY  LKPIA2       ;PIA base address for malfunction test
F992 BD   FA3A     8  321   321.            JSR  MALTST       ;Check for potato sensor malfunction
F995 7C   D20F     7  322   322.            INC  DATA2+SENFLG ;Set flag indicating malfunction test complete
F998 8E   D200     3  323   323.    INTGO2  LDX  #DATA2       ;Base address of row 2 data block
F99B 108E 2000     4  324   324.            LDY  #PIA2        ;Base address of row 2 PIA
F99F 16   00A7     5  325   325.            LBRA METUPD       ;Go to metering update
                      326   326.    *
                      327   327.    *  Row 3 metering event (event sensor trigger)?
F9A2 B6   3001     5  328   328.    INT3    LDA  PIA3+1       ;Row 3 polled
F9A5 2A   1C       3  329   329.            BPL  INT4         ;If no interrupt, check row 4
F9A7 7D   D30F     7  330   330.            TST  DATA3+SENFLG ;First interrupt since statistics update?
```

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ILC  Object          I  Source Statement
F9AA 26   2E         3           BNE  INTGO4            ;No, initialize base addresses for metering update
F9AC 8E   D01D       6           LDX  LKDAT3            ;Data block base address for malfunction test
F9AF 108E D029       7           LDY  LKPIA3            ;PIA base address for malfunction test
F9B3 BD   FA3A       8           JSR  MALTST            ;Check for potato sensor malfunction
F9B6 7C   D30F       7           INC  DATA3+SENFLG      ;Set flag indicating malfunction test complete
F9B9 8E   D300       3   INT3GO  LDX  #DATA3            ;Base address of row 3 data block
F9BC 108E 3000       4           LDY  #PIA3             ;Base address of row 3 PIA
F9C0 16   0066       5           LBRA METUPD            ;Go to metering update
                         *
                         *  Row 4 metering event (event sensor trigger)?
F9C3 B6   4001       5   INT4    LDA  PIA4+1            ;Row 4 polled
F9C6 2A   1C         3           BPL  INT5              ;If no interrupt, check row 5
F9C8 7D   D40F       7           TST  DATA4+SENFLG      ;First interrupt since statistics update?
F9CB 26   0D         3           BNE  INTGO4            ;No, initialize base addresses for metering update
F9CD 8E   D01F       6           LDX  LKDAT4            ;Data block base address for malfunction test
F9D0 108E D02B       7           LDY  LKPIA4            ;PIA base address for malfunction test
F9D4 BD   FA3A       8           JSR  MALTST            ;Check for potato sensor malfunction
F9D7 7C   D40F       7           INC  DATA4+SENFLG      ;Set flag indicating malfunction test complete
F9DA 8E   D400       3   INTGO4  LDX  #DATA4            ;Base address of row 4 data block
F9DD 108E 4000       4           LDY  #PIA4             ;Base address of row 4 PIA
F9E1 16   0065       5           LBRA METUPD            ;Go to metering update
                         *
                         *  Row 5 metering event (event sensor trigger)?
F9E4 B6   5001       5   INT5    LDA  PIA5+1            ;Row 5 polled
F9E7 2A   1C         3           BPL  INT6              ;If no interrupt, check row 6
F9E9 7D   D50F       7           TST  DATA5+SENFLG      ;First interrupt since statistics update?
F9EC 26   0D         3           BNE  INTGO5            ;No, initialize base addresses for metering update
F9EE 8E   D021       6           LDX  LKDAT5            ;Data block base address for malfunction test
F9F1 108E D02D       7           LDY  LKPIA5            ;PIA base address for malfunction test
F9F5 BD   FA3A       8           JSR  MALTST            ;Check for potato sensor malfunction
F9F8 7C   D50F       7           INC  DATA5+SENFLG      ;Set flag indicating malfunction test complete
F9FB 8E   D500       3   INTGO5  LDX  #DATA5            ;Base address of row 5 data block
F9FE 108E 5000       4           LDY  #PIA5             ;Base address of row 5 PIA
FA02 16   0044       5           LBRA METUPD            ;Go to metering update
                         *
                         *  Row 6 metering event (event sensor trigger)?
FA05 B6   6001       5   INT6    LDA  PIA6+1            ;Row 6 polled
FA08 2A   1C         3           BPL  POLCTD            ;If no interrupt, continue polling
FA0A 7D   D60F       7           TST  DATA6+SENFLG      ;First interrupt since statistics update?
FA0D 26   0D         3           BNE  INTGO6            ;No, initialize base addresses for metering update
FA0F 8E   D023       6           LDX  LKDAT6            ;Data block base address for malfunction test
FA12 108E D02F       7           LDY  LKPIA6            ;PIA base address for malfunction test
FA16 BD   FA3A       8           JSR  MALTST            ;Check for potato sensor malfunction
FA19 7C   D60F       7           INC  DATA6+SENFLG      ;Set flag indicating malfunction test complete
FA1C 8E   D600       3   INTGO6  LDX  #DATA6            ;Base address of row 6 data block
FA1F 108E 6000       4           LDY  #PIA6             ;Base address of row 6 PIA
FA23 16   0023       5           LBRA METUPD            ;Go to metering update
                         *
                         *  Statistics update
FA26 B6   7001       5   POLCTD  LDA  PIA5+1            ;Change row displayed request?
FA29 102A 0093       6           LBPL UPDATE            ;No, proceed with statistics update?
                         *
                         *  Change row to be displayed
FA2D B6   7000       5           LDA  PIAS              ;Dummy read to clear interrupt flag
FA30 7C   D013       7           INC  AUTORW            ;Row autoincrement off
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ILC  Object     I  STMT  Line #  Source Statement                                                    17:33:32  06-27-86

FA33 BD  FC6D    8  386   386           JSR  DELTRW        ;Change rows displayed
FA36 16  01EB    5  387   387.          LBRA DISPLY        ;Refresh display for new row
FA39 3B         15  388   388.          RTI
                    389   389.   *
                    390   390.   *
                    391   391.   *  << Subroutine:MALTST - Check for potato sensor malfunction >>
                    392   392.   *
                    393   393.   *  I/O   X - Data block base address
                    394   394.   *        Y - PIA base address
                    395   395.   *
FA3A A6  03      5  396   396.   MALTST LDA  LEDDIS,X      ;Row display mask
FA3C E6  A4      4  397   397.          LDB  ,Y            ;Sensor input on B7
FA3E 2A  04      3  398   398.          BPL  LOW           ;Is sensor working?
FA40 84  BF      2  399   399.          ANDA #%10111111    ;No, alter display mask to indicate malfunction (B6)
FA42 20  02      3  400   400.          BRA  STORE2
FA44 8A  40      2  401   401.   LOW    ORA  #%01000000    ;Sensor works, display mask malfunction bit off
FA46 A7  03      5  402   402.   STORE2 STA  LEDDIS,X
FA48 39          5  403   403.          RTS
                    404   404.   *
                    405   405.   *
                    406   406.   *  << Routine:METUPD- Metering event update >>
                    407   407.   *
                    408   408.   *  I/O   X - Data block base address
                    409   409.   *        Y - PIA base address
                    410   410.   *
FA49 6C  84      6  411   411.   METUPD INC  ,X            ;Current events incremented
FA4B A6  A4      4  412   412.          LDA  ,Y            ;Data on A port (potato sensor on B7)
FA4D 2B  2A      3  413   413.          BMI  HIT           ;Successful metering event? Yes, continue at HIT
                    414   414.   *
                    415   415.   *  Unsuccessful metering event
FA4F 6C  01      7  416   416.   NOSEED INC  CNMISS,X      ;Current number of misses incremented
FA51 E6  02      5  417   417.          LDB  MISLED,X      ;Number of misses displayed on metering LEDs
FA53 C1  04      2  418   418.          CMPB #04           ;Have four consecutive misses occured?
FA55 27  03      3  419   419.          BEQ  ELTST         ;Yes, increment number of consecutive misses
FA57 5C          2  420   420.          INCB               ;Number of consecutive misses incremented
FA58 E7  02      5  421   421.          STB  MISLED,X      ;Number of consecutive misses stored
                    422   422.   *
                    423   423.   *  Defective element test
FA5A A6  04      5  424   424.   ELTST  LDA  NEXTEL,X      ;Pointer to no. of consecutive misses for this element
FA5C E6  86      5  425   425.          LDB  A,X           ;Number of consecutive misses for current element
FA5E C1  04      2  426   426.          CMPB #04           ;Four consecutive misses on this element?
FA60 27  08      3  427   427.          BEQ  BUZZ          ;  Yes, buzzer flag set
FA62 7F  D039    7  428   428.          CLR  BUZFLG        ;Buzzer flag reset (off)
FA65 5C          2  429   429.          INC  B             ;Increment no. of consecutive misses for this element
FA66 E7  86      5  430   430           STB  A,X           ;Number of consecutive misses stored
FA68 20  03      3  431   431.          BRA  UPMISS
FA6A 7C  D039    7  432   432    BUZZ   INC  BUZFLG        ;Buzzer flag set (off)
                    433   433    *
                    434   434    * Number of consecutive misses incremented and checked for overflow (64 max )
FA6D A6  88 10   5  435   435    UPMISS LDA  CONMIS,X
FA70 4C          2  436   436           INCA               ;Increment number of consecutive misses
FA71 A7  88 10   5  437   437           STA  CONMIS,X
FA74 48          2  438   438           ASLA
FA75 2B  16      3  439   439           BMI  CLRMIS        ;If 64 consecutive misses have occured, record & reset
FA77 20  23      3  440   440           BRA  METCON
```

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ILC  Object       I  STMT  Line #   Source Statement                                                 17:33:32  06-27-86
                      441   441.    *
                      442   442.    * Successful metering event
FA79 E6   02      5   443   443.    HIT    LDB  MISLED,X     ;Current number of consecutive misses displayed
FA7B 27   03      3   444   444.           BEQ  CLRELM       ;Is number of misses displayed = 0? If yes goto CLRCON
FA7D 5A           2   445   445.           DECB              ;Decrease consecutive miss count (top illuminated
FA7E E7   02      5   446   446.           STB  MISLED,X     ;  yellow LED turned off)
FA80 A6   04      5   447   447.    CLRELM LDA  NEXTEL,X     ;Offset to current element's consecutive miss count
FA82 6F   86      7   448   448.           CLR  A,X          ;Clear consecutive miss count for current element
FA84 A6   88 10   6   449   449.           LDA  CONMIS,X     ;Number of consecutive misses
FA87 27   13      3   450   450.           BEQ  METCON       ;Was previous event a miss?
FA89 7F   D039    7   451   451.           CLR  BUZFLG       ;Defective element indicators off
FA8C 48           2   452   452.           ASLA              ;Yes, regard consecutive number of misses
FA8D 8B   7F      2   453   453.    CLRMIS ADDA #127         ;2 byte adjust and then offset is added
FA8F E6   86      5   454   454.           LDB  A,X
FA91 5C           2   455   455.           INCB              ;Respective consecutive of misses is incremented
FA92 E7   86      5   456   456.           STB  A,X
FA94 24   06      3   457   457.           BCC  METCON       ;Carry from addition?
FA96 4A           2   458   458.           DECA              ;Yes
FA97 6C   86      7   459   459.           INC  A,X          ;Increment MSB of consecutive miss counter
FA99 6F   88 10   7   460   460.           CLR  CONMIS,X     ;Consecutive number of miss count is cleared
                      461   461.    *
                      462   462.    * Update pointer to next element checked for 4 consecutive misses
FA9C E6   04      5   463   463.    METCON LDB  NEXTEL,X     ;Pointer to current element in this row
FA9E 5A           2   464   464.           DECB              ;Pointer to next element to be monitored in this row
FA9F C1   11      2   465   465.           CMPB #$11         ;Has the metering chain made a complete revolution?
FAA1 26   03      3   466   466.           BNE  DISLED       ;No, store pointer
FAA3 F6   D005    5   467   467.           LDB  ELOFFS       ;Yes, reset pointer for 1st element in row
FAA6 E7   04      5   468   468.    DISLED STB  NEXTEL,X     ;Store pointer
                      469   469.    *
                      470   470.    * LEDs are refreshed
FAA8 36   20      5   471   471.           PSHU Y            ;PIA base address stacked
FAAA 108E FD88    4   472   472.           LDY  #TABLE       ;Table for consecutive no. of missess to LED format
FAAE A6   02      5   473   473.           LDA  MISLED,X     ;Number of misses displayed
FAB0 E6   A6      5   474   474.           LDB  A,Y          ;New metering display mask
FAB2 E4   03      5   475   475.           ANDB LEDDIS,X     ;Combine status LED mask with metering LED mask
FAB4 7D   D039    7   476   476.           TST  BUZFLG       ;Malfunctioning element?
FAB7 27   02      3   477   477.           BEQ  ONGO
FAB9 C4   2F      2   478   478.           ANDB #%00101111   ;Yes, sensor malfunction LEDs and buzzer on
FABB 37   20      5   479   479.    ONGO   PULU Y            ;Retrieve PIAs base address
FABD E7   22      5   480   480.           STB  2,Y          ;Display mask sent to LEDs
FABF 3B          15   481   481.           RTI
                      482   482.    *
                      483   483.    *
                      484   484.    * << Routine:UPDATE - Statistics update for each data block (every 5 sec) >>
                      485   485.    *
                      486   486.    * Check mode 1 row autoincrement toggel
FAC0 F6   7000    5   487   487.    UPDATE LDB  PIAS         ;Row autoincrement toggel on B6 of microswitch PIA
FAC3 C5   40      2   488   488.           BITB #%01000000   ;Mode 1 (%Miss) row autoincrement?
FAC5 27   05      3   489   489.           BEQ  RINC         ;Yes
FAC7 7F   D013    7   490   490.           CLR  AUTORW       ;No reset row autoincrement flag
FACA 20   05      3   491   491.           BRA  UPSTRT
FACC C6   01      2   492   492.    RINC   LDB  #$01         ;Row autoincrement, set flag
FACE F7   D013    5   493   493.           STB  AUTORW
                      494   494.    *
FAD1 F6   D004    5   495   495.    UPSTRT LDB  NOROWS       ;Number of rows
```

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ILC  Object        I  STMT  Line #  Source Statement                                                     17:33:32  06-27-86

FAD4 8E   1000     3  496   496.           LDX  #PIA1          ;Base address of row 1 PIA
FAD7 108E D100     4  497   497.           LDY  #DATA1         ;Base address of row 1 data block
FADB BD   FAF0     8  498   498.    UPDCTD JSR  CALC           ;Statistics calculations
FADE 6F   2F       7  499   499.           CLR  SENFLG,Y       ;Sensor malfunction check flag reset
FAE0 5A            2  500   500.           DECB
FAE1 27   0A       3  501   501.           BEQ  FINISH         ;All rows updated? If so, refresh display
FAE3 30   89 1000  8  502   502.           LEAX $1000,X        ;Base address of next row PIA in X
FAE7 31   A9 0100  8  503   503.           LEAY $0100,Y        ;Base address for next row's data base
FAEB 20   EE       3  504   504.           BRA  UPDCTD         ;Update next row
FAED 16   0134     5  505   505.    FINISH LBRA DISPLY         ;LCD display refresh
                      506   506.    *
                      507   507.    *
                      508   508.    *  << Subroutine:CALC - Calculations for statistics update & event sensor test >>
                      509   509.    *
                      510   510.    *  I/O  B - Data block number to be updated
                      511   511.    *       X - PIA base address
                      512   512.    *       Y - Data block base address
                      513   513.    *
                      514   514.    *  1. Planting rate (metering events/min)
                      515   515.    *
FAF0 36   14       6  516   516.    CALC   PSHU B,X            ;Stack
FAF2 A6   A4       4  517   517.           LDA  ,Y             ;Current number of events
FAF4 C6   0C       2  518   518.           LDB  #12            ;Interrupts occur at 5 sec intervals, therefore
FAF6 3D           11  519   519.           MUL                 ;  multiplying by 12 gives events/min
FAF7 ED   2D       6  520   520.           STD  PLRATE,Y       ;Store in planting rate memory location
                      521   521.    *
                      522   522.    *  2. Current percent misses
                      523   523.    *
FAF9 36   10       5  524   524.           PSHU X              ;Stack PIA address corresponding to data block
FAFB E6   A4       4  525   525.           LDB  ,Y             ;Current number of events
FAFD 8E   D002     3  526   526.           LDX  #DIVWS+2
FB00 E7   84       4  527   527.           STB  ,X             ;Divisor placed in division workspace
FB02 8E   D000     3  528   528.           LDX  #DIVWS         ;Base address of divison workspace
FB05 86   64       2  529   529.           LDA  #100
FB07 E6   21       5  530   530.           LDB  1,Y            ;Number of misses
FB09 3D           11  531   531.           MUL                 ;Multiplied by 100
FB0A ED   84       5  532   532.           STD  ,X             ;Dividend placed in division workspace
FB0C BD   FB50     8  533   533.           JSR  DIVISN         ;Divide
FB0F 5D            2  534   534.           TSTB                ;Quotient = 0?
FB10 2A   01       3  535   535.           BPL  ENDDIV         ;No
FB12 5F            2  536   536.           CLRB                ;Divison by 0 % misses, quotient set to 0
FB13 4F            2  537   537.    ENDDIV CLRA
FB14 ED   2B       6  538   538.           STD  PERMIS,Y       ;Store % misses
FB16 37   10       5  539   539.           PULU X              ;PIA base address restored
                      540   540.    *
                      541   541.    *  3. Update total number of events and check for malfunctioning element sensor
                      542   542.
FB18 A6   A4       4  543   543.           LDA  ,Y             ;Current number of events (number added)
FB1A 26   06       3  544   544.           BNE  EVGO           ;Has an event occurred in last 5 sec?
FB1C C6   EF       2  545   545.           LDB  #%11101111     ;No, event sensor malfunction mask set to on
FB1E E4   23       5  546   546.           ANDB LEDDIS,Y       ;LED display mask updated
FB20 20   04       3  547   547.           BRA  STORE
FB22 C6   10       2  548   548.    EVGO   LDB  #%00010000     ;Sensor functioning, malfunction mask reset to off
FB24 EA   23       5  549   549.           ORB  LEDDIS,Y       ;LED display mask updated
FB26 E7   23       5  550   550.    STORE  STB  LEDDIS,Y       ;LED display mask stored
```

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ILC  Object     I  STMT  Line #  Source Statement                                   17:33:32  06-27-86

FB28 E4  02     5  551   551.          ANDB 2,X           ;Mask combined with display LEDs
FB2A E7  02     5  552   552.          STB  2,X           ;LED display is refreshed
FB2C 30  27     5  553   553.          LEAX TEVENT,Y      ;Address of total number of events (number added to)
FB2E BD  FB47   8  554   554.          JSR  ADD           ;Add current events to total events
FB31 6F  A4     6  555   555.          CLR  ,Y            ;Zero number of current events
                   556   556.  *
                   557   557.  *  4. Update total number of misses
                   558   558.  *
FB33 30  25     5  559   559.          LEAX TMIS,Y        ;Address of total number of misses (number to add to)
FB35 A6  21     5  560   560.          LDA  CNMISS,Y      ;Current number of misses
FB37 BD  FB47   8  561   561.          JSR  ADD           ;Add current misses to total misses
FB3A 6F  21     7  562   562.          CLR  CNMISS,Y      ;Zero current misses
                   563   563.  *
                   564   564.  *  5. Update total number of successful metering events (plants)
                   565   565.  *
FB3C 30  25     5  566   566.          LEAX TMIS,Y        ;Address of total number of misses (number to subtract)
FB3E EC  27     6  567   567.          LDD  TEVENT,Y      ;Total number of events (number to subtract from)
FB40 A3  84     6  568   568.          SUBD ,X            ;Subtract
FB42 ED  29     6  569   569.          STD  THITS,Y       ;Store result
FB44 37  14     6  570   570.          PULU B,X           ;Restore current data block number (row)
FB46 39         5  571   571.          RTS                ;End of update calculations for this data block
                   572   572.  *
                   573   573.  *
                   574   574.  *  << Subroutine:ADD - Addition of 1 byte number to a 2 byte number >>
                   575   575.  *
                   576   576.  *  I/P  A - Number to add
                   577   577.  *       X - Address of number to add to
                   578   578.  *
                   579   579.  *  O/P  X - 2 byte addition result
                   580   580.  *
FB47 AB  01     5  581   581.  ADD     ADDA 1,X           ;LSB added
FB49 A7  01     5  582   582.          STA  1,X           ;LSB store
FB4B 24  02     3  583   583.          BCC  OUT           ;Result < 128, no carry
FB4D 6C  84     6  584   584.          INC  ,X            ;Add 1 to MSB
FB4F 39         5  585   585.  OUT     RTS
                   586   586.  *
                   587   587.  *
                   588   588.  *  << Subroutine:DIVISN - Division >>
                   589   589.  *
                   590   590.  *  I/P  X - Base address of division work space
                   591   591.  *
                   592   592.  *  O/P  A - Remainder
                   593   593.  *       B - Quotient
                   594   594.  *
FB50 86  08     2  595   595.  DIVISN  LDA  #08           ;Count=8
FB52 B7  D003   5  596   596.          STA  CNTR1
FB55 EC  84     5  597   597.          LDD  ,X            ;Get dividend
FB57 58         2  598   598.  DIVIDE  ASLB               ;Shift dividend, Quotient
FB58 49         2  599   599.          ROLA
FB59 A1  02     5  600   600.          CMPA 2,X           ;Trial subtraction successful?
FB5B 25  03     3  601   601.          BCS  CHKCNT        ;No
FB5D A0  02     5  602   602.          SUBA 2,X           ;Yes, subtract and set bit in quotient
FB5F 5C         2  603   603.          INCB
FB60 7A  D003   7  604   604.  CHKCNT  DEC  CNTR1
FB63 26  F2     3  605   605.          BNE  DIVIDE
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ILC  Object       I  STMT  Line #  Source Statement

FB65 39           5  606   606.           RTS
                     607   607.    *
                     608   608.    *
                     609   609.    *
FC00                 610   610.           ORG NMI
                     611   611.    *
                     612   612.    * <<<< NMI service routine - Change modes and refreshes display >>>>
                     613   613.    *
                     614   614.    *  << Routine:CMODE - Change modes >>
                     615   615.    *
FC00 B6   D008    5  616   616.    CMODE  LDA  MODE        ;Current mode
FC03 4C           2  617   617.           INCA             ;Next mode
FC04 81   05      2  618   618.           CMPA #05         ;Reseed to mode 0?
FC06 26   04      3  619   619.           BNE  HERE        ;No
FC08 4F           2  620   620.           CLRA             ;Yes
FC09 7C   D013    7  621   621.           INC  AUTORW      ;Set row autoincrement flag (no mode change)
FC0C B7   D008    5  622   622.    HERE   STA  MODE
FC0F 8E   FD86    3  623   623.           LDX  #MODOFF     ;Base address of data block offset for display value
FC12 E6   86      5  624   624.           LDB  A,X         ;Data block offset for display value
FC14 F7   D016    5  625   625.           STB  OFFSET
FC17 48           2  626   626.           ASLA             ;Mode X 2
FC18 108E FD70    4  627   627.           LDY  #LCDMES     ;Base address for mode labels
FC1C AE   A6      6  628   628.           LDX  A,Y         ;Address of mode label
FC1E BF   D014    6  629   629.           STX  DISLAB
FC21 7C   D03A    7  630   630.           INC  MODFLG      ;Display update indicated
                     631   631.    *
                     632   632.    *  << Routine:DISPLY - Refresh display >>
                     633   633.    *
FC24 7D   D008    7  634   634.    DISPLY TST  MODE
FC27 26   08      3  635   635.           BNE  DISCTD      ;Mode 0 (%Misses)?
FC29 7D   D013    7  636   636.           TST  AUTORW      ;Yes
FC2C 26   03      3  637   637.           BNE  DISCTD      ;Row autoincrement?
FC2E BD   FC6D    8  638   638.           JSR  DELTRW      ;Yes, change rows
                     639   639.    *
FC31 7D   D03A    7  640   640.    DISCTD TST  MODFLG
FC34 27   0A      3  641   641.           BEQ  VALDMP
FC36 BE   D014    6  642   642.           LDX  DISLAB      ;Address of mode label
FC39 C6   0A      2  643   643.           LDB  #10         ;Number of characters in mode label
FC3B BD   FD65    8  644   644.           JSR  DUMP        ;Mode label dumped to LCD display
FC3E 20   04      3  645   645.           BRA  VDCTD
FC40 86   0A      2  646   646.    VALDMP LDA  #%00001010
FC42 97   00      4  647   647.           STA  LCD
FC44 BE   D010    6  648   648.    VDCTD  LDX  DISROW      ;Data block base address
FC47 F6   D016    5  649   649.           LDB  OFFSET      ;Offset from data block base
FC4A EC   85      6  650   650.           LDD  B,X         ;Value to be displaed
FC4C 10B3 D006    8  651   651.           CMPD LASVAL      ;Has value to be displayed changed from last display
FC50 27   0E      3  652   652.           BEQ  TIMOUT      ;No, service timers
FC52 FD   D006    6  653   653.           STD  LASVAL      ;Displayed value is stored
FC55 BD   FCB1    8  654   654.           JSR  HEXCON      ;Convert value to be displayed to ASCII
FC58 8E   D031    3  655   655.           LDX  #VALUE      ;Base address of ASCII display value
FC5B C6   06      2  656   656.           LDB  #06         ;Number of characters in value label
FC5D BD   FD65    8  657   657.           JSR  DUMP        ;Value dumped to display
                     658   658.    *
                     659   659.    *  Display & calculate timers are serviced for 5 sec count down
FC60 B6   8001    5  660   660.    TIMOUT LDA  PTM1+1      ;Clear interrupt flag
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ILC  Object       I  STMT  Line #  Source Statement                                        17:33:32  06-27-86

FC63 BE   8007    6  661   661.           LDX  LATCH3         ;Reload timer 3
FC66 8E   0032    3  662   662.           LDX  #50
FC69 BF   8006    6  663   663.           STX  COUNT3
FC6C 3B          15  664   664.           RTI
                     665   665.    *
                     666   666.    *
                     667   667.    *  << Subroutine:DELTRW - Next row displayed >>
                     668   668.    *
FC6D BE   D010    6  669   669.    DELTRW LDX  DISROW         ;Base address of data block currently displayed
FC70 A6   03      5  670   670.           LDA  LEDDIS,X
FC72 8A   20      2  671   671.           ORA  #%00100000
FC74 A7   03      5  672   672.           STA  LEDDIS,X       ;Row select LED of current row off
FC76 86   20      2  673   673.           LDA  #%00100000
FC78 108E D017    7  674   674.           LDY  CURPIA
FC7C AA   22      5  675   675.           ORA  2,Y
FC7E A7   22      5  676   676.           STA  2,Y            ;Row display LED turned off
FC80 B6   D012    5  677   677.           LDA  CURROW
FC83 4C           2  678   678.           INCA                ;Row number currently displayed is incremented
FC84 B1   D004    5  679   679.           CMPA NOROWS         ;Initialize to row 1?
FC87 23   08      3  680   680.           BLS  NOBACK
FC89 8E   D100    3  681   681.           LDX  #DATA1         ;Yes; reinitialize data block and PIA addresses
FC8C 108E 1000    4  682   682.           LDY  #PIA1
FC90 86   01      2  683   683.           LDA  #01
FC92 20   08      3  684   684.           BRA  STOROW
FC94 30   89 0100 8  685   685.    NOBACK LEAX $0100,X        ;Increment data block and PIA addresses
FC98 31   A9 1000 8  686   686.           LEAY $1000,Y
FC9C BF   D010    6  687   687.    STOROW STX  DISROW         ;Update display status variables
FC9F 10BF D017    7  688   688.           STY  CURPIA
FCA3 B7   D012    5  689   689.           STA  CURROW
FCA6 C6   DF      2  690   690.           LDB  #%11011111     ;Row select LED masked to on
FCA8 E4   03      5  691   691.           ANDB LEDDIS,X
FCAA E7   03      5  692   692.           STB  LEDDIS,X       ;LED display mask updated
FCAC E4   22      5  693   693.           ANDB 2,Y
FCAE E7   22      5  694   694.           STB  2,Y            ;Row select LED turned on
FCB0 39           5  695   695.           RTS
                     696   696.    *
                     697   697.    *
                     698   698.    *  << Subroutine:HEXCON - Select and convert value for LCD display >>
                     699   699.    *
                     700   700.    *
                     701   701.    *  Convert hexidecimal representation of number to decimal counters
FCB1 1083 2710    5  702   702.    HEXCON CMPD #10000         ;Compare value to 10,000
FCB5 25   08      3  703   703.           BLO  NEXT2          ;If less, no digit in ten thousands
FCB7 83   2710    4  704   704.           SUBD #10000         ;Subtract 10,000
FCBA 7C   D009    7  705   705.           INC  CNTR           ;10,000 counter is incremented
FCBD 20   F2      3  706   706.           BRA  HEXCON         ;Try again
FCBF 1083 03E8    5  707   707.    NEXT2  CMPD #1000          ;Compare value to 1,000
FCC3 25   08      3  708   708.           BLO  NEXT3          ;If less, no digit in thousands
FCC5 83   03E8    4  709   709.           SUBD #1000          ;Subtract 1,000
FCC8 7C   D00A    7  710   710.           INC  CNTR+1         ;1,000 counter is incremented
FCCB 20   F2      3  711   711.           BRA  NEXT2          ;Try again
FCCD 1083 0064    5  712   712.    NEXT3  CMPD #100           ;Compare value to 100
FCD1 25   08      3  713   713.           BLO  NEXT4          ;If less, no digit in hundreds
FCD3 83   0064    4  714   714.           SUBD #100           ;Subtract 1000
FCD6 7C   D00B    7  715   715.           INC  CNTR+2         ;100 counter is incremented
```

```
ILC  Object      I  STMT  Line #  Source Statement

FCD9 20   F2     3  716   716.           BRA  NEXT3          ;Try again
FCDB 1083 000A   5  717   717.    NEXT4  CMPD #10            ;Compare value to 10
FCDF 25   08     3  718   718.           BLO  NEXT5          ;If less, no digit in tens
FCE1 83   000A   4  719   719.           SUBD #10            ;Subtract 10
FCE4 7C   D00C   7  720   720.           INC  CNTR+3         ;10 counter is incremented
FCE7 20   F2     3  721   721.           BRA  NEXT4          ;Try again
FCE9 F7   D00D   5  722   722.    NEXT5  STB  CNTR+4         ;Remainder stored in 1 counter
                    723   723.    *
                    724   724.    * Conversion of decimal numbers to ASCII format stored starting at memory
                    725   725.    *   location VALUE
FCEC 7F   D00F   7  726   726.           CLR  ZFLG           ;Flag used to delete leading zeros
FCEF 86   20     2  727   727.           LDA  #$20           ;ASCII blank
FCF1 B7   D031   5  728   728.           STA  VALUE          ;Space between labels and numbers
FCF4 86   30     2  729   729.           LDA  #%00110000     ;Base for ASCII conversion
FCF6 1F   89     7  730   730.           TFR  A,B
FCF8 FB   D009   5  731   731.           ADDB CNTR           ;First digit
FCFB BD   FD3D   8  732   732.           JSR  LDZERO         ;Check for leading zeros
FCFE F7   D032   5  733   733.           STB  VALUE+1
FD01 1F   89     7  734   734.           TFR  A,B
FD03 FB   D00A   5  735   735.           ADDB CNTR+1         ;Second digit
FD06 BD   FD3D   8  736   736.           JSR  LDZERO         ;Check for leading zeros
FD09 F7   D033   5  737   737.           STB  VALUE+2
FD0C 1F   89     7  738   738.           TFR  A,B
FD0E FB   D00B   5  739   739.           ADDB CNTR+2         ;Third digit
FD11 BD   FD3D   8  740   740.           JSR  LDZERO         ;Check for leading zeros
FD14 F7   D034   5  741   741.           STB  VALUE+3
FD17 1F   89     7  742   742.           TFR  A,B
FD19 FB   D00C   5  743   743.           ADDB CNTR+3         ;Fourth digit
FD1C BD   FD3D   8  744   744.           JSR  LDZERO         ;Check for leading zeros
FD1F 7C   D00F   7  745   745.           INC  ZFLG           ;No more blanks allowed
FD22 F7   D035   5  746   746.           STB  VALUE+4
FD25 1F   89     7  747   747.           TFR  A,B
FD27 FB   D00D   5  748   748.           ADDB CNTR+4         ;Fifth digit
FD2A F7   D036   5  749   749.           STB  VALUE+5
FD2D 7F   D009   7  750   750.           CLR  CNTR           ;Clears counters for next conversion
FD30 7F   D00A   7  751   751.           CLR  CNTR+1
FD33 7F   D00B   7  752   752.           CLR  CNTR+2
FD36 7F   D00C   7  753   753.           CLR  CNTR+3
FD39 7F   D00D   7  754   754.           CLR  CNTR+4
FD3C 39          5  755   755.           RTS
                    756   756.    *
                    757   757.    *
                    758   758.    *  << Subroutine:LDZERO - Check for leading zeros on display >>
                    759   759.    *
FD3D 7D   D00F   7  760   760.    LDZERO TST  ZFLG           ;Was there a previous non zero number
FD40 26   08     3  761   761.           BNE  YESEND         ;If there was return
FD42 C1   30     2  762   762.           CMPB #$30           ;Is this charactre a zero?
FD44 26   04     3  763   763.           BNE  NOTEND         ;No
FD46 C6   20     2  764   764.           LDB  #$20           ;ASCII blank
FD48 20   03     3  765   765.           BRA  YESEND
FD4A 7C   D00F   7  766   766.    NOTEND INC  ZFLG           ;Set flag for non-zero number
FD4D 39          5  767   767.    YESEND RTS
                    768   768.    *  << Subroutine:CLRLCD - Clear LCD display >>
                    769   769.    *
FD4E 86   8A     2  770   770.    CLRLCD LDA  #%10001010     ;Clear LCD flag
```

```
ILC  Object          I  STMT  Line #   Source Statement                                                         17:33:32  06-27-86
FD50 97   00         4   771   771.          STA  LCD           ;Send to LCD
FD52 4F              2   772   772.          CLRA
FD53 97   00         4   773   773.          STA  LCD
FD55 BD   FD59       8   774   774.          JSR  DELAY         ;Delay character latched to LCD display
FD58 39              5   775   775.          RTS
                         776   776.   *
                         777   777.   *
                         778   778.   *  << Subroutine:DELAY - 0.786 milli sec delay for LCD to latch character >>
                         779   779.   *
                         780   780.   *  I/P  X - Address of character sent to display
FD59 36   10         5   781   781.   DELAY  PSHU X             ;Stack
FD5B 8E   015E       3   782   782.          LDX  #350          ;Initial count down value
FD5E 30   1F         5   783   783.   WAIT   LEAX -1,X          ;Count down
FD60 26   FC         3   784   784.          BNE  WAIT          ;Delay complete? If not, continue count down
FD62 37   10         5   785   785.          PULU X             ;Restore
FD64 39              5   786   786.          RTS
                         787   787.   *
                         788   788.   *
                         789   789.   *  << Subroutine:DUMP - Contents of memory locations dumped to LCD display >>
                         790   790.   *
                         791   791.   *  I/P  B - Number of memory locations to dump
                         792   792.   *       X - Address of first memory location to dump
                         793   793.   *
FD65 A6   80         6   794   794.   DUMP   LDA  ,X+           ;Load character to dump
FD67 97   00         4   795   795.          STA  LCD           ;Send to display
FD69 BD   FD59       8   796   796.          JSR  DELAY         ;Allow time for LCD latch
FD6C 5A              2   797   797.          DECB
FD6D 26   F6         3   798   798.          BNE  DUMP          ;Last character? If not, continue dump
FD6F 39              5   799   799.          RTS
                         800   800.   *
                         801   801.   *
                         802   802.   *
                         803   803.   *  <<< ROM Data >>>
                         804   804.   *
                         805   805.   *  < Addresses of mode labels >
                         806   806.   *
FD70 FDA0FDAAFDB4        807   807.   LCDMES FDB PMISAS,NEVAS,NMISAS,PLANTS,PMAS
FD76 FDBEFDC8
                         808   808.   *
                         809   809.   *  < Data block pointers to for malfunctioning potato sensor check >
                         810   810.   *
FD7A D20003000400        811   811.   CKDAT  FDB DATA2,DATA3,DATA4
                         812   812.   *
                         813   813.   *  < PIA pointers for malfunctioning potato sensor check >
                         814   814.   *
FD80 200030004000        815   815.   CKPIA  FDB PIA2,PIA3,PIA4
                         816   816.   *
                         817   817.   *  < Table - Offsets from data blocks base of number to display >
                         818   818.   *
FD86 0807050900          819   819.   MODOFF FCB $08,$07,$05,$09,$0D
                         820   820.   *
                         821   821.   *  < Table - Number of consecutive misses metering mask >
                         822   822.   *
FD8B FFFEFCF8F0          823   823.   TABLE  FCB %11111111,%11111110,%11111100,%11111000,%11110000
                         824   824.   *
```

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ILC  Object          I  STMT  Line #   Source Statement                                    17:33:32  06-27-86

                        825   825.     *  < Display messages and mode labels >
                        826   826.     *
FD90 3D504F544154       827   827.     HELFLG FCC '=POTATO=MONITOR='
FD96 4F3D4D4F4E49
FD9C 544F523D
FDA0 25204D495353       828   828.     PMISAS FCC '% MISSES  '
FDA6 45532020
FDAA 4E4F2E204556       829   829.     NEVAS  FCC 'NO. EVENTS'
FDB0 454E5453
FDB4 4E4F2E204D49       830   830.     NMISAS FCC 'NO. MISSES'
FDBA 53534553
FDBE 4E4F2E20504C       831   831.     PLANTS FCC 'NO. PLANTS'
FDC4 414E5453
FDC8 504F5441544F       832   832.     PMAS   FCC 'POTATO/MIN'
FDCE 2F4D494E
                        833   833.     *
                        834   834.     *  < Flags for LCD initialization >
                        835   835.     *
FDD2 686B616D6265       836   836.     FLAGS  FCB $68,$6B,$61,$6D,$62,$65,$67,$6E,$00,$8A
FDD8 676E008A
                        837   837.     *
                        838   838.     *
                        839   839.     *  <<<< System vectors assigned >>>>
                        840   840.     *
FFF0                    841   841.           ORG $FFF0
FFF0 000000000000       842   842.           FDB 0,0,0,0,IRQ,0,NMI,RESET
FFF6 0000F8600000
FFFC FC00F800
0000                    843   843.           END
```

SYMBOL	VALUE	DEFN	REFERENCES
ADD	FB47	581	554 561
AUTORW	D013	48	167 385 490 493 621 636
BUZFLG	D039	65	428 432 451 476
BUZZ	FA6A	432	427
CALC	FAF0	516	498
CHKCNT	FB60	604	601
CKDAT	FD7A	811	198
CKPIA	FD80	815	217
CLRELM	FA80	447	444
CLRLCD	FD4E	770	109
CLRMIS	FA8D	453	439
CMODE	FC00	616	
CNEV	0000	78	
CNMISS	0001	79	416 560 562
CNTR	D009	44	705 710 715 720 722 731 735 739 743 748 750 751 752 753 754
CNTR1	D003	39	596 604
CONMIS	0010	89	435 437 449 460
COUNT1	8002	29	245
COUNT2	8004	30	241
COUNT3	8006	31	243 663
CURPIA	D017	51	162 674 688
CURROW	D012	47	168 677 689
DATA1	D100	67	159 172 189 304 309 310 497 681
DATA2	D200	68	174 317 322 323 811
DATA3	D300	69	175 330 335 336 811
DATA4	D400	70	176 343 348 349 811
DATA5	D500	71	177 356 361 362
DATA6	D600	72	178 369 374 375
DELAY	FD59	781	103 774 796
DELTRW	FC6D	669	386 638
DISCTD	FC31	640	635 637
DISLAB	D014	49	164 629 642
DISLED	FAA6	468	466
DISPLY	FC24	634	387 505
DISROW	D010	46	160 648 669 687
DIVIDE	FB57	598	605
DIVISN	FB50	595	533
DIVWS	D000	38	526 528
DUMP	FD65	794	114 644 657 798
ELOFFS	D005	41	188 467
ELTST	FA5A	424	418
ENDDIV	FB13	537	535
EVGO	FB22	548	544
FINISH	FAED	505	501
FLAGS	FDD2	836	104
FLGDSP	F800	105	108
HELFLG	FD90	827	112
HERE	FC0C	622	619
HEXCON	FCB1	702	654 706
HIT	FA79	443	413
INCDAT	F8E0	214	211
INCPIA	F908	232	229
INTG01	F977	310	305
INTG02	F998	323	318
INTG04	F9DA	349	331 344

SYMBOL	VALUE	DEFN	REFERENCES
INTG05	F9FB	362	357
INTG06	FA1C	375	370
INT1	F960	302	
INT2	F981	315	303
INT3	F9A2	328	316
INT3GO	F9B9	336	
INT4	F9C3	341	329
INT5	F9E4	354	342
INT6	FA05	367	355
IRQ	F960	14	298 842
LASVAL	D006	42	165 651 653
LATCH1	8003	32	
LATCH2	8005	33	
LATCH3	8007	34	661
LCD	0000	19	106 647 771 773 795
LCDINT	F807	103	
LCDMES	FD70	807	627
LDZERO	FD3D	760	732 736 740 744
LEDDIS	0003	81	172 174 175 176 177 178 396 402 475 546 548 550 670 672 691 692
LKDAT	F8CF	206	215
LKDAT1	D019	52	205 306
LKDAT2	D01B	53	319
LKDAT3	D01D	54	332
LKDAT4	D01F	55	345
LKDAT5	D021	56	358
LKDAT6	D023	57	371
LKPIA	F8FA	225	233
LKPIA1	D025	58	224 307
LKPIA2	D027	59	320
LKPIA3	D029	60	333
LKPIA4	D02B	61	346
LKPIA5	D02D	62	359
LKPIA6	D02F	63	372
LOOP	F948	289	290
LOW	FA44	401	398
MALTST	FA3A	396	308 321 334 347 360 373
MEMINT	F85D	153	
METCON	FA9C	463	440 450 457
METUPD	FA49	411	312 325 338 351 364 377
MISLED	0002	80	417 421 443 446 473
MODE	D008	43	616 622 634
MODFLG	D03A	66	630 640
MODOFF	FD86	819	623
NCLR1	F860	154	156
NEVAS	FDAA	829	807
NEXOFF	F93F	285	288
NEXTEL	0004	82	190 424 447 463 468
NEXT2	FCBF	707	703 711
NEXT3	FCCD	712	708 716
NEXT4	FCDB	717	713 721
NEXT5	FCE9	722	718
NMI	FC00	15	610 842
NMISAS	FD84	830	807
NOBACK	FC94	685	680
NOROWS	D004	40	185 199 210 213 218 231 281 495 679

SYMBOL	VALUE	DEFN	REFERENCES
NOSEED	FA4F	416	
NOTEND	FD4A	766	763
OFFINT	F8B2	190	193
OFFSET	D016	50	170 625 649
ONGO	FABB	479	477
OUT	FB4F	585	583
PERMIS	0008	86	169 538
PIAINT	F820	119	
PIARES	F83F	133	147
PIAS	7000	26	120 121 122 123 125 127 131 183 186 380 384 487
PIA1	1000	20	130 161 302 311 496 682
PIA2	2000	21	315 324 815
PIA3	3000	22	328 337 815
PIA4	4000	23	341 350 815
PIA5	5000	24	354 363
PIA6	6000	25	367 376
PLANTS	FDBE	831	807
PLRATE	000D	87	520
PMAS	FDC8	832	807
PMISAS	FDA0	828	163 807
POLCTD	FA26	380	368
PTM1	8000	28	250 258 266 278 660
RESET	F800	13	97 842
RINC	FACC	492	489
SENFLG	000F	88	304 309 317 322 330 335 343 348 356 361 369 374 499
SETPIA	F8E6	217	208
SETPTM	F90E	240	227
SSTACK	D800	74	98
STKINT	F800	98	
STORE	FB26	550	547
STORE2	FA46	402	400
STOROW	FC9C	687	684
TABLE	FD88	823	472
TEVENT	0007	84	553 567
THITS	0009	85	569
TIMOUT	FC60	660	652
TMIS	0005	83	559 566
UPDATE	FAC0	487	381
UPDCTD	FADB	498	504
UPMISS	FA6D	435	431
UPSTRT	FAD1	495	491
USTACK	D740	73	99
VALDMP	FC40	646	641
VALUE	D031	64	655 728 733 737 741 746 749
VDCTD	FC44	648	645
WAIT	FD5E	783	784
YESEND	FD4D	767	761 765
ZFLG	D00F	45	726 745 760 766

13. APPENDIX F. MONITOR MEMORY MAPS

F1. Monitor System Memory Map

Address	Device
0000	PCIM 200 LCD
1000-1003	6821 PIA (Row 1)
2000-2003	6821 PIA (Row 2)
3000-3003	6821 PIA (Row 3)
4000-4003	6821 PIA (Row 4)
5000-5003	6821 PIA (Row 5)
6000-6003	6821 PIA (Row 6)
7000-7003	6621 PIA (Microswitches)
8000-8007	6840 PTM
D000-D7FF	6116 RAM
E008-E009	6850 ACIA
E00A-E00B	6850 ACIA
F000-F7FF	2716 EPROM
F800-FFFF	2716 EPROM

F2. Program Memory Map

Address	Routine	Description
F800-F92E	STKINT	Initialization
F92F-F94B		Main program
F960-FA39	IRQ	IRQ polling routine
FA3A-FA48	MALTST	Potato sensor malfunction test
FA49-FABF	METUPD	Metering update
FAC0-FAEF	UPDATE	Statistics update
FAF0-FB46	CALC	Statistics calculations
FB47-FB4F	ADD	Addition
FB50-FB65	DIVISN	Division
FC00-FC23	CMODE	Change modes
FC24-FC6C	DISPLY	Display refresh
FC6D-FCB0	DELTRW	Change rows
FCB1-FD3C	HEXCON	Code conversion
FD3D-FD4D	LDZERO	Strip leading zeros
FD45-FD58	CLRLCD	Clear LCD
FD59-FD64	DELAY	Delay
FD65-FD6F	DUMP	Character dump to LCD

F3. System Vector Memory Map

Address	Description
F800-F94B	Reset
F960-FB65	IRQ service routine
FC00-FD6F	NIM service routine

F4. ROM Data Memory Map

Address	Description
FD70-FD79	Mode descriptor addresses
FD7A-FD7F	Data block addresses for potato sensor malfunction test
FD80-FD85	PIA addresses for potato sensor malfunction test
FD86-FD8A	Offsets from data block base addresses for performance statistics
FD8B-FD8F	Consecutive miss metering masks
FD90-FDD1	Mode descriptors
FDD2-FDDC	Flags for LCD initialization
FFF0-FFFF	System vectors

F5. RAM Memory Map

Address	Description
D000-D039	Program variables (excluding variables in data blocks)
D100-D1FF	Row 1 data block
D200-D2FF	Row 2 data block
D300-D3FF	Row 3 data block
D400-D4FF	Row 4 data block
D500-D5FF	Row 5 data block
D600-D6FF	Row 6 data block
D700-D73F	User stack
D740-D7FF	System stack

F6. Data Block Memory Map

Address	Description
D#00-D#10	Data block variables (see lines 78-89 in the program listing in Appendix D)
D#11-D#FF	Metering element consecutive miss data

- Data block row number