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AN EVALUATION OF FERTILIZER APPLICATION SYSTEMS

by

JOHN JOSEPH MAYKO

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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IN

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ABSTRACT

Commercial fertilizers are an important input for improving returns from crop production. Various methods of applying fertilizers have been developed in order to place fertilizer in a specific position within the soil.

The effectiveness of different methods of fertilizer placement varies due to soil, climatic and fertilizer factors and time of application. In general application methods such as banding which concentrate fertilizer within the soil are more effective than broadcast applications.

Thirteen different fertilizer application systems were studied with the aim of maximizing net revenue. Differences among the fertilizer application systems included types of equipment, method of fertilizer application, forms of fertilizer and time of fertilizer application. The impact of these differences upon time requirements, machinery requirements and costs, fertilizer costs and net revenue were calculated for three soil moisture conditions. Maximum net revenue for all three conditions was obtained from banding nitrogen fertilizer as anhydrous ammonia and applying phosphorus fertilizer in-row. Lowest net revenue was obtained by broadcasting all the fertilizer in the fall.

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1. INTRODUCTION

Chemical fertilizers have become an integral input for crop production in Western Canada. The increased use of fertilizers has enabled farmers to improve their productivity by producing more crop from their existing land base.

Fertilizers are used to sustain and improve crop growth and are useful, over the long run, in sustaining and replenishing the levels of the various nutrients in the soil used by crops. The reduction in area devoted to summerfallow and an increase in continuous cropping techniques have also contributed to an increase in fertilizer use.

In the past decade, a number of developments have led to an interest in various methods of fertilizer application. The expansion of area seeded to oilseed crops such as flax and canola, which can only tolerate low amounts of fertilizer in-row, led to the technique of sidebanding where the fertilizer was placed a short distance away from the seed (Ukrainetz et al 1975). However, the lack of commercial seeding equipment with sidebanding capabilities forced farmers to seek other methods. With an increase in the use of anhydrous ammonia as a nitrogen source, some farmers believed that ammonia was a more efficient source of nitrogen. Further work was undertaken to investigate and determine whether ammonia was indeed a more effective source of nitrogen or whether superiority was due to the banded placement of ammonia in the crop rooting zone.

The introduction of air seeders and their resulting popularity has led many farmers to band all the fertilizer prior to seeding so that handling of fertilizer during seeding could be eliminated. These farmers were interested in the effectiveness of fertilizer applied in this manner.

As well, the fertilizer manufacturing and distribution industry has been promoting an increase in the amount of fertilizer purchased in the fall to reduce the time and transportation constraints of having to handle the entire amount of fertilizer during the spring. This strategy is desirable in terms of spreading out the flow of fertilizer from the factory to the farm over a longer time period. However, fall purchased fertilizer must be cost effective for the farmer to do so.

The objectives of this study were to analyze a number of different methods of fertilizer application as they affect;

1. the capacity of the machinery used,
2. the time required to complete the machinery operations required for fertilizer application and for seeding,
3. the total costs of machinery required,
4. the total cost of providing crop nutrients using different forms of fertilizer purchased either in the fall or the spring,
5. the impact on crop yields, and
6. the net return to the farming enterprise.

2. LITERATURE REVIEW

2.1 IMPORTANCE OF FERTILIZERS TO CROP GROWTH

In order to obtain high crop yields, the fertility of the soil must be adequate. High levels of available plant nutrients in soils are needed to satisfy the growth requirements of crops and to increase crop tolerance to stress conditions such as drought, low temperature, salinity, root rots and other diseases (Beaton 1982).

Nitrogen (N) and phosphorus (P) are the essential elements to crop growth that are generally accepted to be deficient in most Canadian prairie soils. In the Prairie Provinces, about 90% of all the stubble cropland is deficient in nitrogen and all the cropland should receive some phosphorus (Beaton 1980). Other nutrients that are less commonly deficient are potassium (K) and sulphur (S). Potassium deficiencies occur on about 1.8 million hectares of prairie farmland and sulphur deficiencies occur on about another 1.8 million hectares (Beaton 1980). About 60 kg/ha of nitrogen, 11 kg/ha of phosphorus, 15 kg/ha of potassium and 6 kg/ha of sulphur are removed in the seed of typical wheat, oat and barley crops (Beaton 1980). Farmers must routinely apply sufficient amounts of fertilizers to compensate for these removals in order to continue to produce high yielding crops.

2.2 FERTILIZER PLACEMENT METHODS

Until approximately fifteen years ago, the application of fertilizers in Western Canada was a relatively simple practice. Phosphorus and nitrogen (up to about 20 kg/ha) were simply drilled in-row. If the nitrogen requirements were higher, then the fertilizer was broadcast on the soil surface and incorporated to avoid seed damage (Robertson et al 1982).

Methods of fertilizer application presently practised in Western Canada can be grouped into the following categories (Figure 2.1);

1. *In-row*, fertilizer is applied with the seed, at the time of seeding,
2. *Broadcast*, fertilizer is spread uniformly over the soil surface, with incorporation by a tillage operation,
3. *Top dressed*, fertilizer is broadcast on the soil surface without incorporation (used primarily for established forage crops),
4. *Banded*, fertilizer is applied in a separate operation prior to seeding, and
5. *Sidebanded*, fertilizer is banded a specified distance from the seed both vertically and horizontally at the time of seeding.

The fertilizer application methods considered in this study were those that are used in the production of most

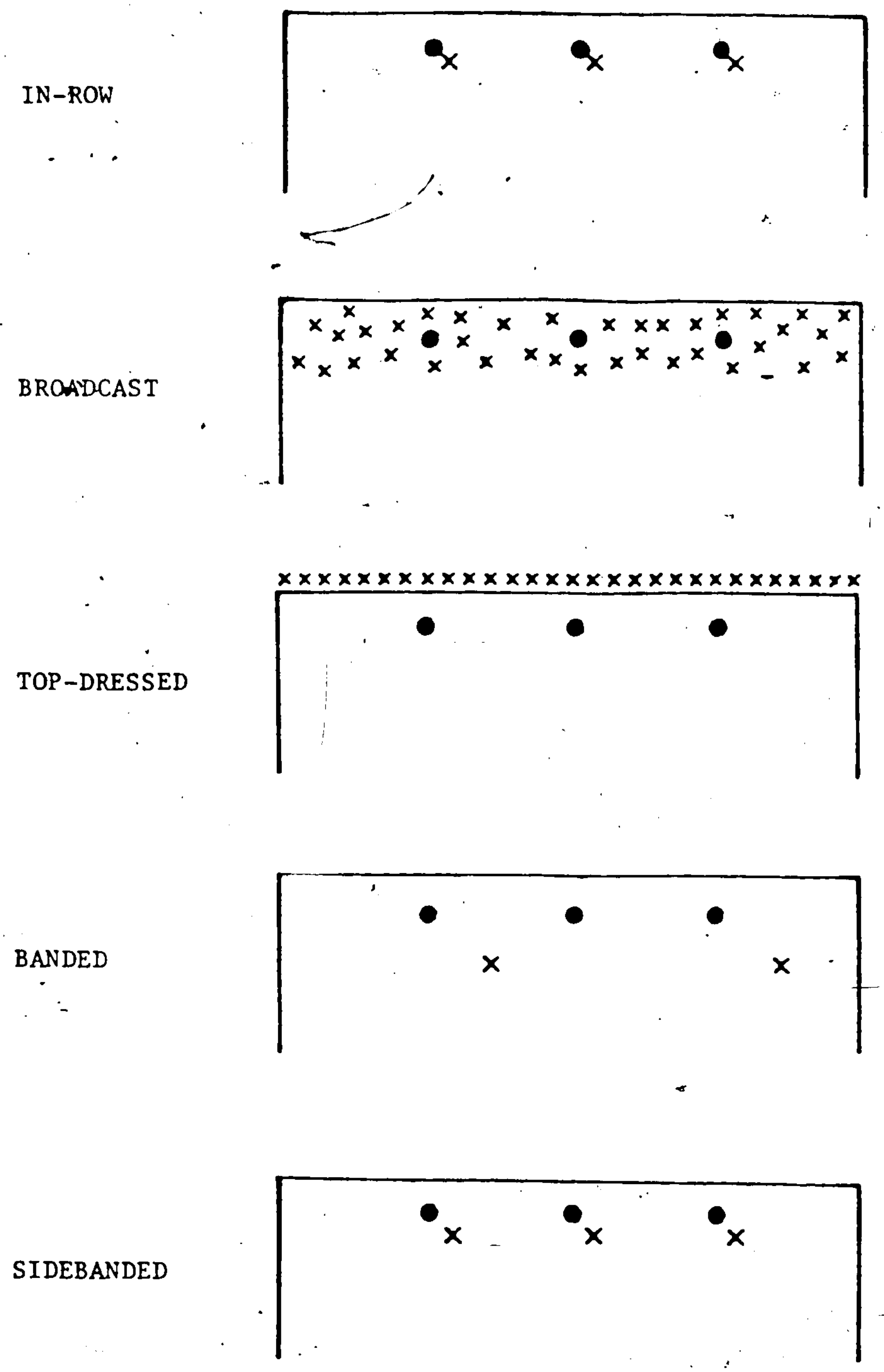

Figure 2.1 CROSS SECTION OF SOIL PROFILE SHOWING FERTILIZER PLACEMENT POSITIONS RELATIVE TO THE SEED

annual crops in Western Canada. Since forage crops were not considered in this study, top dressing of fertilizer was not evaluated.

2.3 EFFECTIVENESS OF FERTILIZER PLACEMENT METHODS

The effectiveness of a fertilizer placement method is defined as the yield increase obtained by fertilizer applied by that particular method. Fertilizer efficiency is defined as the percentage yield increase of a particular fertilizer placement method as compared to a standard. The standard fertilizer placement method used in this study is nitrogen fertilizer broadcast in the spring and phosphorus fertilizer placed in-row in the spring.

2.3.1 In-Row Placement

In earlier years, Gray and Buckingham (1930) noted that in-row applications of phosphorus fertilizers at rates of 10 and 20 kg/ha of P were more effective than broadcast applications. Later work by Bole (1966) showed that in-row placement of P fertilizers resulted in increased phosphorus uptake as compared to fertilizer that was broadcast or sidebanded 2.5 cm to the side of the seed. Because of these findings and with the generally low amounts of fertilizers that were being applied to crops, the in-row placement was essentially the sole method of applying fertilizers for three or four decades (Robertson et al 1982).

During the past fifteen years several developments have stimulated interest in other methods of applying fertilizers. One of these was the expansion in area seeded to oilseed and pulse crops. Many of these crops could tolerate only low amounts of fertilizers placed in the row (Ukrainetz et al 1975).

Work carried out by Dubetz et al (1959), Nyborg (1961), Nyborg and Hennig (1969) and Ukrainetz et al (1975) showed that application of large amounts of fertilizer in-row affected germination. Nyborg and Hennig (1969) reported that up to 40 kg/ha of P and 35 kg/ha of N as ammonium nitrate could be applied in the row of cereal crops with no reduction in yields. However, they noted that placement of excessive amounts of fertilizer in the seed row (greater than 17 kg/ha of N or 20 kg/ha of P) damaged the germination of some crops, especially rapeseed and flax. They stated that damage was caused by a direct toxic effect and by decreased osmotic potential in the soil solution. The amount of damage varied with the kind of crop, fertilizer, soil texture, soil temperature and especially soil water content. They noted that injury to germination was largely avoided when the fertilizers were broadcast or when they were banded away from the seed row.

Bailey et al (1980) stated that in-row applications of phosphorus were more effective than broadcast placements for cereal crops in Western Canada. These researchers stated that the root system of small grains does not allow these crops to take up required amounts of phosphorus fertilizers that were broadcast. Therefore, these crops benefit most from phosphorus fertilizer that is placed either in-row or very close to the seed.

Racz (1982) noted that grain yields and recovery of nitrogen from fertilizer increased when the nitrogen fertilizer was placed in-row as opposed to broadcasting. This observation was obtained when ammonium nitrate was applied at rates up to 67 kg/ha of N applied on a barley crop. However, when urea was used as the nitrogen source, rates higher than 20 kg/ha affected germination and caused seedling damage.

The amount of fertilizer that can be safely applied in-row depends upon the formulation of fertilizer that is required, the crop to be grown and the soil moisture conditions. Generally, phosphorus, at rates up to 40 kg/ha, can be safely applied in the seed row of cereal crops. Nitrogen in the form of ammonium nitrate can be safely applied in-row at rates up to 35 to 40 kg/ha of N. However, urea or anhydrous ammonia should not be applied in the seed row of cereal crops at rates exceeding 20 kg/ha of N. Again, moisture conditions play an important role in the amount of fertilizer nitrogen that can be safely applied in-row.

Also the type of seeding equipment that is used can play a role in determining the amount of fertilizer that can be safely applied in-row. Green (1984) suggests that seeders such as hoe drills or air seeders which have a wider seed row spread width allow for slightly higher fertilizer rates than seeders such as double disk drills which tend to concentrate the seed in a narrower row.

2.3.2 Broadcast

With an increase in stubble cropping, additional amounts of fertilizers (especially N) are required to obtain adequate crop yields. However, as stated earlier, application of large amounts of fertilizer in the seed row affected germination. Thus farmers began broadcasting and incorporating the additional nitrogen fertilizer that was required. With the broadcast method of application, large amounts of fertilizer could be applied in a relatively short time.

The use of this method generated a renewed interest by researchers in the effectiveness of applying phosphorus by broadcasting. Work by Bole (1966), Bole et al (1977), Smith (1977), Harapiak (1980) and Robertson et al (1982) showed that in the majority of cropping situations, broadcasting was an inefficient way of applying phosphorus fertilizers. In general, two to four times as much phosphorus must be broadcast to equal the same effectiveness as in-row phosphorus (Bole et al (1977), Racz (1982)). Racz (1982) stated that for wheat, broadcast P was only about 66% as efficient as in-row P. The reason for the relative inefficiency of broadcast applied phosphorus is that the phosphorus becomes immobilized due to phosphorus adsorption on soil surfaces (Dibb 1978). Therefore, other methods such as banding, which reduce the soil-fertilizer contact, are generally more efficient methods of phosphorus fertilizer application.

On soils that have medium to high phosphorus levels, broadcast applications can be as effective as banded applications (Dibb 1978). However, the relative effectiveness of broadcast P is dependant upon soil pH, soil texture, climatic conditions and rates of application (Harapiak 1980).

Residual effects of a high initial phosphorus application (up to 400 kg/ha of P) have been beneficial in terms of yields on a number of prairie soils (Spratt and Read 1980). The beneficial effects of one application of 400 kg/ha of P have been estimated to last about 30 years in southwestern Saskatchewan. These researchers state that building soil fertility judiciously over years is a paying investment. However, an economic analysis to substantiate these claims was not shown.

Work performed by Robertson et al (1982) showed that broadcasting a high rate of phosphorus (200 kg/ha of P) can lead to an increase in soil P levels and good crop yields. Beaton (1982) supported this concept. Since phosphorus is not prone to the same types of losses as nitrogen, this can be a way of applying phosphorus without having to worry about placement in-row. Racz (1982) also reported application of a high rate of phosphorus could be used to increase soil available phosphorus on portions of fields such as hills and knolls which are very low in available phosphorus. These areas could be fertilized with large quantities of phosphorus and then treated similarly to the remainder of the field with respect to annual phosphorus applications.

In years when farmers have extra time in the fall after harvest, fertilizers have been applied in the fall to reduce the spring workload. However, work by Ridley (1977), Harapiak (1979a), Racz (1979), Nyborg et al (1980), Bole et al (1984), Harapiak and Penney (1984) and Malhi et al (1984) showed that fall broadcast nitrogen fertilizers were prone to losses over the winter period and were not as effective as spring broadcast treatments. The loss in effectiveness of fall broadcast nitrogen as compared to spring broadcast were as great as 50% in some instances. Bole et al (1984) obtained an effectiveness rating of 76% for fall broadcast N as compared to spring broadcast. This was obtained from an average of 99 sites and was obtained from a wide range of soil zones, soil textures, fall moisture conditions, drainage conditions, dates of application and early growing season precipitations in Alberta. Heaney et al (1984) reported that nitrogen losses were due to immobilization, leaching and denitrification, with denitrification being the primary cause.

With regards to fall broadcasting of phosphorus, Racz (1982) stated that fall broadcasting is as effective as spring broadcasting. This observation could be explained because phosphorus is not prone to the same types of losses as fall applied nitrogen (leaching and denitrification).

Therefore as long as phosphorus fertilizers are applied in the late fall, the effectiveness of fall applied phosphorus should be equal to spring applied phosphorus.

Broadcasting can be an effective method of applying fertilizers over large areas in a short period of time. Broadcasting is most effective for nitrogen fertilizers applied in the spring under favorable moisture conditions. Fall broadcasting of nitrogen fertilizers is generally not recommended because of high losses of nitrogen over the winter (especially in the Black and Gray soil zones of Alberta). Broadcasting of low rates of phosphorus fertilizer is an inefficient method of application on soils with low phosphorus levels. However, on soils with medium to high phosphorus levels, broadcasting phosphorus fertilizer may be an effective method of placement. This observation is supported by Robertson (1984) who states that after a number of years of applications of phosphorus fertilizers, the soil test levels of phosphorus will be increased. Robertson's hypothesis is that because of the increase in soil test levels, differences among various placements of phosphorus fertilizers will tend to diminish.

2.3.3 Banding

Banding is the method of fertilizer placement where the fertilizer is placed in a series of bands (rows, strips, ribbons) beneath the surface of the soil across the field. They may be at different spacings or at different depths but basically the fertilizer is concentrated within the bands as compared to fertilizer that is broadcast and incorporated.

Frederick Nobbe of Germany should be given credit for identifying the efficacy of the band application (Behmer 1977). In 1862, Nobbe, as cited by Behmer, noted that if "enriched" soil was placed in various patterns in a soil body, plant roots were more abundant in the enriched spots. In the United States in the early 1900's, research work continued on plant response to enriched soil zones. This work was carried out primarily in Michigan, Iowa, Kansas and Wisconsin. By the end of World War II, the superior performance of band application of fertilizers was well established in the United States (Behmer 1977).

The benefits of band placement are quoted from Behmer (1977);

"The explanation is that, when the fertilizer is placed in a band in the soil, only the surface of the bulk of fertilizer contacts soil and soil moisture, so that only a part of the fertilizer is immediately active. Thus the plant is fed well and regularly throughout a long period by the one

application, yet without excessive availability of fertilizer nutrients at any one time. Whereas when the fertilizer is broadcast, it is at once in considerable surface contact with soil and soil moisture and the soluble nutrients are more weakly, but more widely distributed: after these early stages, some of the phosphoric acid and potash becomes fixed by the soil and thereby lost from any immediate point of view. Thus, so far as greater immediate efficiency of application is concerned, the virtue of strip placement possibly rests upon the fact that there is less fixation of fertilizer if there is restricted contact with the soil."

In Canada, research into band placement of fertilizers (especially N) did not begin until the early 1970's. Nyborg (1984) began work in the early 1970's comparing banding of N fertilizers to broadcasting. In general, band application was found to be superior to broadcasting in terms of increased crop yield and fertilizer nitrogen uptake and spring application was superior to fall application.

Harapiak (1979b) stated that farmers who used anhydrous ammonia as a source of nitrogen frequently reported higher yields with the use of this product than with broadcast nitrogen. Initially, these results were attributed to;

1. solubilization of extra soil phosphorus in the ammonia band,
2. ammonia being a more efficient form of nitrogen, or

3. higher rates of nitrogen application related to the much higher analysis of the ammonia.

However, researchers who gained experience with ammonia thought that the more favorable placement deep within moist soil was an important factor. This opinion was substantiated by results from Harapiak (1979b) where deeper placement of ammonia produced the greatest increase in grain yields under poor seedbed moisture conditions. This led to further work by Harapiak to determine whether applying ammonia would result in higher yields than applying granular forms of nitrogen. However, equally effective results were obtained when granular or liquid forms were banded. Therefore, Harapiak concluded that the benefits of banding nitrogen were primarily due to the superior positional availability of the fertilizer where the plant roots could easily feed as compared to broadcast N, especially under dry conditions where the fertilizer could remain stranded in the upper soil where plant roots did not proliferate. This observation was also made by Heinonen and Huhtapolo (1978) whose Swedish work supported the claims of Harapiak of superior positional availability of banded nitrogen especially under dry conditions.

Harapiak (1979a) noted a 15% increase in fertilizer efficiency for spring banding over spring broadcasting of nitrogen and a 20% increase for late fall banding over spring broadcasting. Ridley (1977) obtained a 3% increase for spring banding, an equal rating for fall banding and a 4% loss for fall broadcasting over spring broadcasting. Racz (1979) noted a 20% increase for spring banding over spring broadcasting and a 7% loss for fall banding. Malhi et al (1984) obtained a 15% increase for both fall and spring banding on black soils, a 22% increase for fall banding and 28% increase for spring banding on dark brown and brown soils over spring broadcasting.

For deep banding of phosphorus fertilizers, Robertson et al (1982) reporting on work performed in Alberta stated that banding of phosphorus fertilizer midrow (one fertilizer band placed in the middle of two 22.5 cm seed rows) was only about 63% as efficient as phosphorus fertilizer applied in-row. In Manitoba, Racz (1982) reported that deep banded phosphorus (18 cm band spacing) was more efficient than broadcast phosphorus.

In the late 1960's, researchers in Kansas began to study the practicality of applying both nitrogen and phosphorus together for winter wheat. Their aim was to eliminate the extra handling of phosphorus fertilizer at seeding and combine the phosphorus fertilizer with the nitrogen fertilizer which was being banded with tillage implements (Murphy 1982). Their results indicated advantages for deep banding both N and P as compared to other methods which separated the N and P.

Murphy (1982) listed the following reasons for the improved efficiency (synergism) of dual NP banding;

1. Forced plant uptake of ammonium N causing a more acid condition at the root surface,
2. Greater P availability at the root surface due to the acid environment there,
3. Deeper placement of nutrients in the soil where moisture is less limiting to uptake (positional availability),
4. Possible delays in fertilizer P reactions with soil components due to the very high concentrations of ammonium nitrogen present, and
5. Possible delay of fertilizer P reactions due to diminished fertilizer-soil contact.

Houlton and Armstrong (1980), reporting on work performed in Montana, obtained a 20-60% yield increase for dual NP banding over N banded and P applied in-row. Dual NP banding showed greater yield advantages than N banded and P placed in-row under dry soil moisture conditions than under moist soil moisture conditions.

Toews (1982) and Rogalsky and Ridley (1984), working in Manitoba, reported that fall placed NP bands were as effective as N broadcast in the spring and P applied in-row.

Harapiak et al (1982) reported that fall placed dual NP bands were equal to or superior in terms of efficiency to N broadcast in the spring and P applied in-row. Again, soil moisture conditions played an important role with dry conditions showing a greater advantage than moist conditions. In this study, they also reported that the relative efficiency of NP banding in the fall should be equal to that of banding N in the spring and applying P in-row. They state that any decrease in efficiency of fall placed fertilizer would be more than offset by improved seedbed quality in the spring.

From these results there are apparent contradictions between the results obtained from the various researchers regarding the relative efficiency of banded fertilizer versus broadcast. These discrepancies are due to different geographical locations, various depths and spacings of fertilizer bands, different times of application, different soil fertility levels and different soil and growing season moisture conditions.

In general, the fertilizer bands should be placed at least 5 cm below the depth of the seed. An optimum spacing of the bands has not been determined. The spacing should be narrow enough to minimize crop streaking caused by unequal crop row feeding of the fertilizer bands and wide enough to ensure that the benefits of reduced soil-fertilizer contact are maintained. For banding of N or NP fertilizers, satisfactory results have generally been obtained with a band spacing of 30 cm and a seed row spacing of 15-20 cm. The benefits of banding over broadcasting for spring application generally decrease as the fertility level and moisture conditions of the soil increase.

With regards to geographical locations, greater benefits of banded nitrogen fertilizer are obtained in the drier southern areas of the prairies than in the moist parkland areas. The benefits of banding are inversely related to the amount of seedbed moisture and growing season precipitation. The benefits of fall banding of nitrogen as compared to spring broadcasting are greater in the southern areas than in the northern parkland areas because of lower soil moisture levels over the winter that are prevalent in the southern areas. The soil moisture and drainage conditions play an important role in the efficient use of fall banded nitrogen. High soil moisture levels during the spring thaw can lead to significant losses of nitrogen due to denitrification. Time of application is also important with late fall banding being generally more efficient than early fall banding. This is due to the fact that late fall application permits a lower rate of conversion of the nitrogen from ammonium to nitrate by soil microorganisms than early fall application. The nitrate form is the form of nitrogen which is prone to denitrification and leaching losses. Banding of phosphorus fertilizers is generally as effective as in-row placement when the phosphorus is banded in conjunction with nitrogen. The synergistic effect of ammonia on phosphorus uptake plays an important role. Again, the benefits of dual NP banding as compared to N banded and P in-row depends upon growing season moisture conditions. Greater benefits of dual NP banding are observed under dry soil moisture conditions than under favorable soil moisture conditions.

2.3.4 Sidebanding

In this study, sidebanding refers to the banding of fertilizer at a specified distance to the side of and or below from the seed. Sidebanding is normally performed using a separate set of openers mounted on the seed drill at the time of seeding. There can be one opener and therefore one band with each seed row or the openers can be spaced every other midrow, whereby one fertilizer band feeds two seed rows.

Bole (1966) noted that there is considerable reduction in P uptake from bands directly to the side of the seed compared to bands below and to the side of the seed. This is due to the fact that there is downward growth of plant roots which more readily intercept fertilizer bands that are below seed depth. Similar results were obtained from Heinonen and Huhtapalo (1978). Bole et al (1977) noted that in, general, P placed 2.5 cm to the side and below the seed was as effective as in-row placement at low rates of P application and prevented stand reduction at high rates.

Nyborg and Hennig (1969) reported that the efficiency of P fertilizers declined as the distance of the fertilizer band from the seed row increased. However, placing the fertilizer band below or to the side and below seed depth was of greater benefit than placement of the fertilizer band to the side of the seed row. This was especially true for flax and rapeseed which cannot tolerate the amount of fertilizer required for optimum yields placed in-row.

Robertson et al (1982) obtained lower yields with sidebanded (5 cm to the side and 5 cm below the seed) or midrow (45 cm fertilizer band spacing) P as compared to in-row P. However, the addition of N to the P band rather than broadcast tended to increase yields. The reasons for this are probably the same factors as for the dual NP bands as stated previously.

Therefore, as long as the bands are placed somewhat deeper than the seed, the effectiveness of sidebanded N and P should be as good as N broadcast and P in-row. There does not appear to be any benefit in sidebanding of only phosphorus fertilizers except in the case of crops such as flax and canola which can only tolerate low amounts of fertilizer placed in-row.

2.4 MACHINERY FOR FERTILIZER APPLICATION

Various types of equipment are available to apply fertilizers to soils. Because different types and physical states (e.g. granular solids, liquids, gases compressed to liquids) are available, equipment must be available to effectively place the desired forms of fertilizer in the required position within the soil with reasonable accuracy, reliability and cost. For example, the equipment requirements for handling anhydrous ammonia are quite different than those for granular phosphorus.

The following design and performance parameters for fertilizer applicators were obtained from Kepner et al (1972);

1. Uniformity of distribution over a wide range of conditions is of primary importance,
2. The metering device should have a positive dispensing action with fertilizers covering a wide range of drillabilities,
3. Discharge rate should be proportional to the forward speed of the implement so that the application rate is independent of speed,
4. Discharge rate should be independent of depth of fertilizer in the hopper and of reasonable inclinations of the distributor,
5. There should be no appreciable cyclic variations in the discharge rate,

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The metering device should have a positive dispensing action with fertilizers covering a wide range of drillabilities,

Discharge rate should be proportional to the forward speed of the implement so that the application rate is independent of speed,

Discharge rate should be independent of depth of fertilizer in the hopper and of reasonable inclinations of the distributor,

There should be no appreciable cyclic variations in the discharge rate,

1972) (Figure 2.2). Centrifugal broadcasters generally use a wire belt metering device. The metering rate is controlled by an adjustable gate above the belt. These machines are popular for broadcasting fertilizer in Western Canada because of their large capacity hoppers, relatively low cost and ease of operation. These machines are not precise in terms of uniformity of distribution across the spread width and some overlap must occur to ensure acceptable distribution across the field (Cunningham (1963), Reed and Wacker (1968), Green (1984)).

Drop type or dribble spreaders have metering units which are spaced at regular intervals along the full length of the hopper (Figure 2.3). The advantages of this machine over the centrifugal broadcaster are improved distribution of fertilizer across the width of spread and the ability to be mounted on cultivators or other tillage implements for broadcasting and incorporation of the fertilizer in a single field operation. Disadvantages include increased cost and lack of a large central hopper making filling somewhat more difficult. The metering units employed in dribble spreaders are stationary opening devices. The fertilizer is conveyed to the openings by a series of ribbed wheels, flutes, augers or impellers mounted on a shaft across the width of the machine. The rate of application is varied by either varying the size of the openings or varying the speed of the conveying devices.

Figure 2.2 CENTRIFUGAL BROADCASTER

Figure 2.3 DRIBBLE BROADCASTER

Pneumatic broadcasters are a relatively recent development in Western Canada. These machines use a centrally located hopper and an air fan to transport and distribute the fertilizer from the hopper to the openings which are spaced across the boom width (Figure 2.4). The advantages of the pneumatic broadcaster are a centrally located hopper to facilitate easy filling and an improved fertilizer distribution pattern on the soil compared to a centrifugal broadcaster. The main disadvantage is that of increased complexity because of the fan and hoses required for distribution. The use of these machines for fertilizer distribution in Western Canada is presently quite limited.

Liquid sprayers are generally field sprayers which have the components required to handle liquid fertilizers. The main advantage of a liquid sprayer is the utilization of a machine which is presently owned thereby avoiding the purchase or rental of a separate machine for applying fertilizer. Sprayer tanks and booms can also be mounted on tillage equipment to facilitate fertilization and incorporation in one operation (Green 1984). The distribution pattern of a sprayer is generally superior to that of a centrifugal broadcaster. However, the components of the sprayer such as the tank, pump, booms and nozzles must be made of materials which can withstand the corrosive effects of liquid fertilizers.

Figure 2.4 PNEUMATIC BROADCASTER

2.4.2 Banding Equipment

Equipment used in the banding of fertilizer generally falls into three categories; mechanical distributors, pneumatic distributors and gaseous distributors.

Mechanical distributors for granular fertilizers are generally adaptations of the drop type or dribble spreaders used for broadcasting fertilizers. They are usually mounted on seed drills and used for in-row or sidebanded placement but have also been mounted on cultivators for preplant banding. The advantages of these distributors are generally favorable distribution patterns and low cost. The disadvantages are the lack of a centrally mounted hopper making filling more difficult and the small size of the hoppers. The small size hoppers are especially disadvantageous when high amounts of fertilizer are to be applied at the time of seeding thereby reducing field efficiency by requiring more frequent stops for fill-ups. Mechanical distributors are also used in the distribution of liquid fertilizers on cultivators or seed drills. A ground driven pump, metering valves, distribution manifolds and a nurse tank are required. The advantage of using the liquid fertilizer system is the centrally located tank which facilitates filling.

The primary implement used in the pneumatic distribution of banded fertilizer is the air seeder (Figure 2.5). This machine uses a centrally located hopper, a

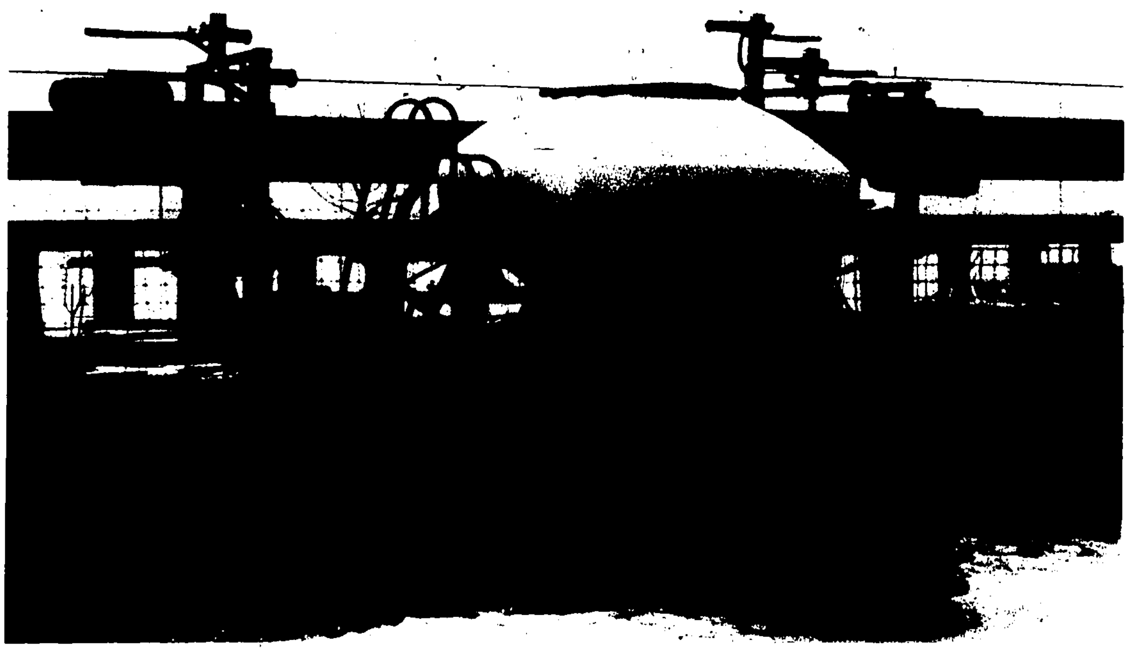

Figure 2.5 AIR SEEDER

metering mechanism, an air fan and a series of hoses mounted on a cultivator to transport and distribute the fertilizer and/or seed from the hopper to the furrow openers. The primary advantages of the air seeder are a large centrally located hopper for seed and/or fertilizer and easy transport from field to field. This machine can be used either for in-row placement of fertilizer or for a preplant banding operation. The primary disadvantage of the air seeder is the high investment cost especially if used solely for fertilizer banding.

The primary use of a gaseous distributor is for anhydrous ammonia. The anhydrous ammonia must be released in narrow furrows and covered immediately by soil to prevent escape. A loose, friable soil with adequate moisture is required to seal the soil surface to allow time for adsorption of ammonia to the water on the soil particles (Kepner et al 1972). Distribution of anhydrous ammonia requires a pressurized, heavy steel tank for storage and transport, a metering mechanism, a series of distributors and a hose to each shank. Initially, anhydrous ammonia applicators employed relatively light shanks which required a previous tillage operation to ensure adequate soil coverage of the ammonia band. These machines were generally rented from fertilizer dealers as the costs of owning the machines for individual farmers was too high (Porteous and Andres 1983). However, during the last decade, farmers have mounted ammonia distribution kits on their cultivators and rented the nurse tanks from the fertilizer dealers. This allowed farmers to combine fertilizing and tillage operations.

As well, ammonia liquifying (Coldflo®[1]) kits have become quite popular (Figure 2.6). These kits employ a converter or converters which reduce the pressure of the ammonia to near atmospheric allowing only about 15% of the ammonia to vaporize. The heat required for the small amount of ammonia to vaporize comes from the remaining liquid causing the temperature of the liquid to drop below its boiling point. Vaporization of the cooled liquid does not occur until it warms in the soil thereby allowing for a longer period of time for the ammonia to be bound with the soil moisture. The depth of injection can be reduced by 7 to 10 cm as compared to gaseous injection, thereby reducing power requirements (Green 1984).

At present, the only equipment that is available for sidebanding of fertilizer in Western Canada are separate openers which mount on some makes and models of seed drills. These openers use the fertilizer boxes and mechanical metering mechanisms which are mounted on the seed drill. However, the present use of sidebanding equipment in Western Canada is quite limited.

There are also several hybrid systems which are employed. These systems can use components from two or more sources. For example, some farmers and fertilizer dealers

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[1]Coldflo® is a registered trademark of United States Steel Agri-Chemicals Division.

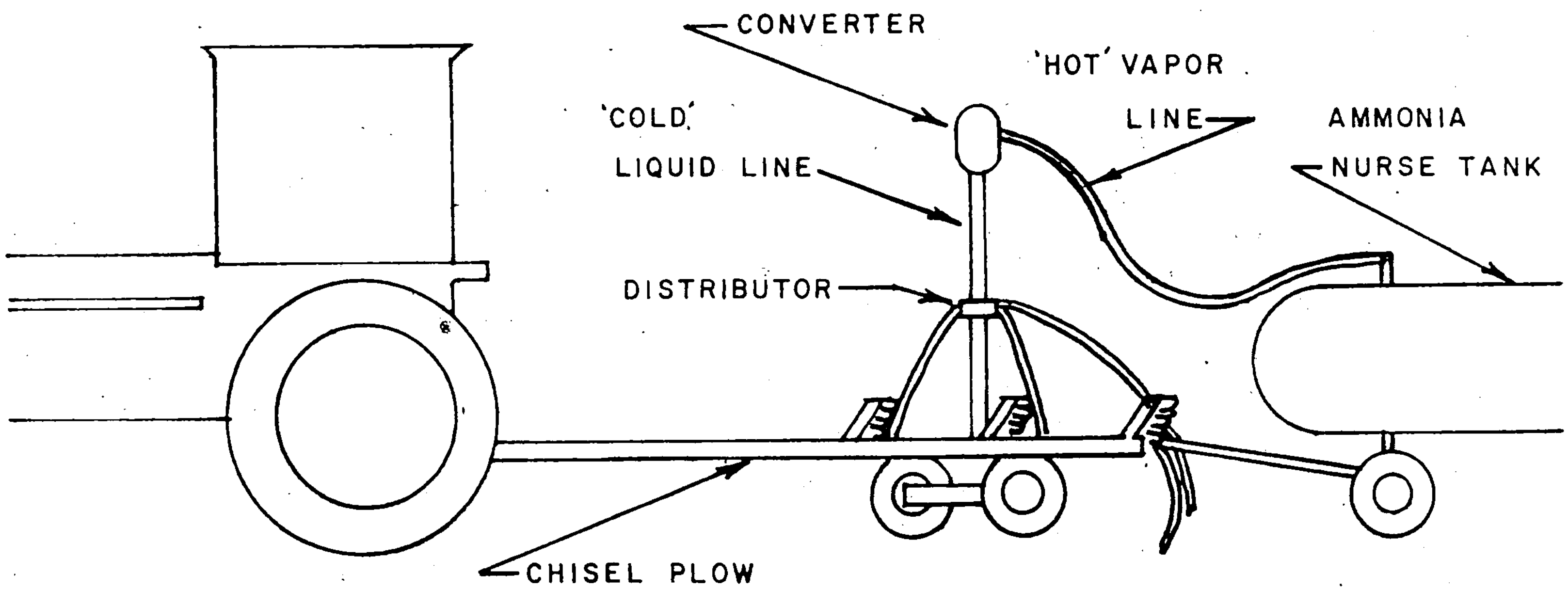

fig. 2.6

AMMONIA LIQUIFYING UNIT MOUNTED ON CULTIVATOR

are using an air seeder combined with an ammonia liquifying unit to apply granular phosphorus and anhydrous ammonia simultaneously. The advantages in developing these types of hybrids are combination of field operations and the use of preferred forms of fertilizers. The use of ammonia liquifying units with air seeders allows for the banding of anhydrous ammonia with ammonium phosphate, both of which are the least expensive forms of nitrogen and phosphorus respectively.

The type of fertilizer application equipment used by an individual farmer is dependent upon the size of the operation, the forms and prices of fertilizers which are available, the equipment that is presently owned and individual preferences. An efficient machinery system can be developed to handle most types of fertilizer for almost any type of placement.

2.5 SUMMARY OF LITERATURE REVIEW

The following conclusions are derived from review of the literature and were used in the assumptions for this study.

1. Broadcasting is not the ideal method of placement of nitrogen fertilizers (especially in the fall) and is definitely not recommended for phosphorus fertilizers except on soils with high P levels.
2. Banding is the preferred method of nitrogen application on all soils. Banding of phosphorus fertilizers in conjunction with nitrogen is an effective method of phosphorus placement except on cold, wet, P deficient soils.
3. Fall banding of nitrogen fertilizers is preferred under low soil moisture conditions to minimize spring soil moisture loss and ensure good seedbed quality. Under medium and high soil moisture conditions, fertilizer banding should be performed in the spring to minimize overwintering losses of nitrogen due to denitrification and leaching.
4. In-row placement of phosphorus fertilizer remains an effective placement method on cereal crops at low to moderate rates, especially on P deficient soils. Nitrogen fertilizer requirements cannot usually be met by in-row placement because of seedling damage especially with urea based fertilizers.
5. Sidebanding is an effective method of fertilizer

placement. The main disadvantage is the lack of adequate commercially available equipment for sidebanding. There is the added problem of providing adequate spatial distribution of the seed and fertilizer openers to ensure good trash clearance. Another disadvantage is the extra time required to handle all the fertilizer at seeding time.

3. SYSTEM DESCRIPTION

The systems of fertilizer application considered were the following;

1. N broadcast in the spring, P in-row in the spring,
2. N banded in the spring, P in-row in the spring
    a. with liquifying unit on cultivator using anhydrous ammonia as the N source,
    b. with air seeder using urea as the N source,
3. N banded in the fall, P in-row in the spring
    a. with liquifying unit on cultivator using anhydrous ammonia as the N source,
    b. with air seeder using urea as the N source,
4. N and P banded together in the fall
    a. using granular fertilizers,
    b. using liquid fertilizers,
5. N and P banded together in the spring
    a. using granular fertilizers,
    b. using liquid fertilizers,
6. N broadcast in the fall, P in-row in the spring,
7. N and P broadcast together in the fall,
8. N and P broadcast together in the spring, and
9. N and P sidebanded together with the seed drill at the time of seeding.

These systems were chosen to represent a cross section of the various fertilizer application systems that are used by farmers in Western Canada. Other combinations of time of application, placement method, fertilizer form and machinery complement are possible but those that were chosen were considered by the author to be a sufficient representation of the majority of combinations in use at the present time.

3.1 MACHINERY MANAGEMENT

3.1.1 Machinery Capacities

The term machine capacity refers to the area of land that is covered by an implement in a certain time period (e.g. ha/h). Machine capacity is a function of field speed, machine working width and field efficiency (ASAE 1984).

Field efficiency is the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity (ASAE 1984). Some reasons for a machine not working at its theoretical maximum include:

1. Machine overlap
2. Turning time at headlands
3. Materials handling (e.g. seed, fertilizer, water)
4. Machine adjustment
5. Lubrication and refueling.

The following formula for calculating machine capacity was obtained from Hunt (1983):

$$C = (S\ W\ E)/10 \qquad (3.1)$$

C= capacity (ha/h)

S= speed of machine (km/h)

W= width of machine (m)

E= field efficiency (decimal)

10= constant (to adjust for units)

3.1.2 Machinery Costs

The total cost involved with using farm equipment includes costs for ownership and operation. Ownership costs or fixed costs are mainly a function of time rather than hours of annual use (Andruchow 1982). Ownership costs include depreciation, interest on investment, taxes, insurance and housing.

Depreciation is defined as the loss in value over time due mainly to obsolescence (Andruchow 1982). Andruchow stated that although wear also contributes to depreciation, no reliable data is available as to how much varying amounts of use contribute to depreciation. Depreciation of this type would be a variable rather than a fixed cost. The depreciation of a machine can be calculated using the following formula obtained from ASAE (1984):

D= (V1-V2)/(T2-T1) (3.2)

D= depreciation ($/year)

V1= initial price ($)

V2= salvage price ($)

T1= time of machine purchase

T2= time of machine disposal

T2-T1= machine life (years)

Interest costs are a charge for the use of the money in a machine investment (ASAE 1984). They can occur in two forms (Andruchow 1982). First, there is the cost of financing a machine purchased on credit. Second, there is the tying up of money in these fixed assets, which could be earning additional funds if invested in an alternate use (e.g. interest in term deposits).

Insurance is necessary to protect against losses from hazards such as fire and accidents. Housing costs are involved with having machine sheds for the storage of equipment. These costs are justified whether the buildings are present or not, because without them, deterioration and weathering will increase repair rates (Andruchow 1982).

Variable costs are expenses which vary according to the amount of use and include fuel, lubrication, repairs and maintenance (ASAE 1984).

3.2 GENERAL ASSUMPTIONS

The assumptions that were used in developing the various systems are as follows. The area that is cultivated and seeded is 325 hectares. All the fields are uniform in size and no obstructions (e.g. sloughs, stones, trees) are present. The fields are also situated adjacent to each other. Therefore, time lost in travelling between fields is kept to a minimum. The farmer is involved in a continuous cropping system and therefore all the land is cultivated twice, once in the fall and once in the spring prior to or in conjunction with seeding.

The crop that is seeded is barley. Barley was chosen as the crop for analysis because the majority of fertilizer placement research in Western Canada has been performed using barley as the test crop. Barley allowed a direct relationship between fertilizer effectiveness and grain yields to be developed. In an actual farming operation, a farmer would probably use a rotation which included other crops. These other crops were not used in the model because of the difficulty in obtaining fertilizer effectiveness data.

Post emergence herbicides are used for weed control and therefore no additional tillage is required to control any particular weed problem. If the system includes an air seeder, the air seeder will be used for both banding and seeding. The type of seeding equipment that is used will not have any effect on the yield.

A field efficiency of 82.5% is assumed for all field operations. Extra time is allowed for the filling of seed and fertilizer hoppers.

The amounts of fertilizer used are 65 kg/ha of nitrogen and 13 kg/ha of phosphorus. These rates were chosen to replenish the nutrients taken by the previous crop (Beaton 1982) and allow for some reserve. Fertilizer products are generally designated by the amounts of nitrogen (N), phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) that are present. However, in this study, the amounts of N, P and K are expressed on an elemental basis. The fertilizer products and grades used are for nitrogen; granular urea (46-0-0), anhydrous ammonia (82-0-0) or liquid urea-ammonium nitrate (28-0-0) and for phosphorus; monoammonium phosphate (11-22-0) or liquid ammonium phosphate (10-15-0). No potassium, sulfur or micronutrients (e.g. Fe, Mg, Zn) are required. However, if required, the equipment used to apply the N and P fertilizers could also be used to apply fertilizers or fertilizer blends containing potassium, sulphur or micronutrients.

The farmer's working day was assumed to be 16 hours of which 12 hours were spent working in the field and 4 hours were spent in servicing equipment and filling trucks with fertilizer and seed. Meals were eaten during equipment fill-up times which did not require any extra time. All the fertilizer and seed were stored directly on the farm except for anhydrous ammonia and liquid fertilizers which were trucked in promptly whenever scheduled.

3.3 MACHINERY DESCRIPTION

The method used to size the various pieces of equipment for the systems is based upon the author's experiences regarding the rationale of farmers towards sizing equipment. Generally, a farmer chooses a particular piece of primary tillage equipment (usually a chisel plow) and the appropriate sized tractor for his individual conditions. The size of seed drill was chosen by the author to be slightly larger than that of the chisel plow. Other equipment such as harrow-packers were chosen to be as wide as possible for the constraints of available tractor power, field shape and size.

The sizing method used in this analysis was to base equipment width on the above rationale. This method uses a fixed size of equipment for all systems. Differences between the systems comes from the differences in time required to complete the necessary field operations.

The width of the chisel plow (cultivator) was assumed to be 9.14 m. Ground speed of the cultivator was assumed to be 8 km/h. According to tests carried out by the Prairie Agricultural Machinery Institute (PAMI) and averaged over several makes and models of chisel plows (Appendix 1), a chisel plow with a width of 9.14 m would require a tractor with a maximum PTO power rating of 135 kW at a ground speed of 10 km/h and a cultivator working depth of 75 mm. Therefore, the tractor will have enough power to pull the air seeder or ammonia nurse tank, when required, at a ground speed of 8 km/h. A set of mounted tine harrows was used with the cultivator to eliminate any additional harrowings between field operations.

The fertilizer broadcaster that was chosen is one which is commonly available in Western Canada as a rental unit from fertilizer dealers. This model has a hopper capacity of 4 tonnes and an effective spread width of 13.7 m. Ground speed of the broadcaster was assumed to be 12 km/h.

The working widths of the press drill and harrow-packer were arbitrarily chosen to be 11 m and 18.3 m respectively. According to the PAMI test reports on various press seed drills (Appendix 2), a double disk press drill requires about 8.7 kW of power per metre of width. Therefore an 11 m drill would require a tractor with a maximum PTO rating of 96 kW. With the harrow-packers, the average power requirements obtained from the PAMI reports (PAMI 1982b, 1983) are 5.34 kW/m of width. Therefore, a 18.3 m harrow-packer would require a tractor with a maximum PTO rating of 98 kW. Thus the power requirements of both the seed drill and the harrow-packer are well within the power rating of the 135 kW tractor.

A Flexicoil model 1000[2] (PAMI 1982d) air seeder was chosen for this study. This model was selected because of its large capacity seed and fertilizer tanks and because of its ability to be easily attached and detached from the cultivator. This allows the cultivator to be used without the air seeder.

The seed drill chosen for system 9 was an International Harvester Company (IHC) model 5100[2] end wheel double disk drill with a second set of openers for sidebanding of fertilizer. The width of the drill was arbitrarily chosen to be 11.2 m. This drill is the only known, reasonably priced, commercially made, conventional seed drill with optional sidebanding openers.

Each system utilized a different complement of machinery and field operations depending upon its individual requirements.

Machinery costs for each system were based upon hourly machinery rates obtained from Andruchow (1982) and multiplied by the number of hours required to complete the operation. These costs included both fixed and variable costs. The press seed drill and end wheel seed drill used in the models are each composed of three 3.66 m units. Therefore, the costs for the seed drills were obtained by multiplying the cost of the 3.66 m unit by three. The cost of the mounted harrows was obtained by multiplying the cost

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[2] The naming of brand makes and models are used for examples only. The author does not specifically endorse any mentioned brand names and models.

of the 1.52 m 3 bar tine harrow by six. The cost of the liquid fertilizer distribution kit used in Systems 4B and 5B is given in Appendix 5.

4. TIMELINESS CONSIDERATIONS

Timeliness, in the context of this study, is defined as the ability to perform a field machine operation within a time period in which there will be no yield penalty due to performing the operation either too early or too late. Timeliness then, is the ability to perform a task within an optimum time period.

According to Briggs (1985), the seeding of barley, in general, should be completed by the end of May in Alberta before any yield reduction or yield quality penalty would be assessed. After the end of May, a yield penalty would result.

Russell (1969) compiled information which listed the probability of a given day being suitable for tillage for different locations in Alberta. These probabilities were added up over a certain time period giving the number of suitable working days likely during that time period. In this study, the spring working period was assumed to be May 1-31 inclusive, and the fall working period October 1-31 inclusive. The number of working days in May and October on medium to heavy soils for different locations in Alberta, based on Russell's probabilities, is given in Table 4.1. The average number of working days in May are 23 without much variation from region to region. Therefore, an an average of 23 working days for the month of May is assumed for the whole province. Thus, the farmer has 23 days to complete spring work before any yield reduction penalties would be assessed. The number of working days in October varies from region to region with 17.5 days in low rainfall areas to 4.8 days in high rainfall areas. Therefore, each region was assessed individually according to the number of working days available.

TABLE 4.1 NUMBER OF WORKING DAYS ON MEDIUM TO HEAVY SOILS FOR VARIOUS LOCATIONS IN ALBERTA.

LOCATION	DAYS (MAY)	DAYS (OCTOBER)
LOW RAINFALL AREAS		
CALGARY	22	15.2
LETHBRIDGE	22.9	17.7
MEDICINE HAT	24.9	19.7
AVERAGE	23.3	17.5
MEDIUM RAINFALL AREAS		
EDMONTON	22.8	12.8
VERMILION	23.5	12.7
AVERAGE	23.2	12.8
HIGH RAINFALL AREAS		
BEAVERLODGE	23.2	4.4
FAIRVIEW	23.9	5.1
AVERAGE	23.6	4.8

Source: Russell (1969)

5. SYSTEM OPERATION

The operation of the various systems and their respective order of field operations are outlined in the following sections. Details of the calculations regarding time requirements for the various field operations and their associated machinery costs are outlined in Appendix 6.

5.1 SYSTEM 1. N BROADCAST IN THE SPRING, P IN-ROW IN THE SPRING

System 1 involves the broadcasting of nitrogen in the spring prior to tillage and seeding. The phosphorus is applied in-row. This is the system which has been traditionally used in the Prairie Provinces. The field operations required from the previous harvest to seeding include;

1) fall cultivation,
2) broadcasting of N fertilizer in spring,
3) spring cultivation, and
4) seeding.

5.2 SYSTEM 2A. N BANDED IN THE SPRING WITH AMMONIA LIQUIFYING UNIT, P IN-ROW IN THE SPRING

System 2A involves banding of nitrogen in the form of anhydrous ammonia combined with spring tillage prior to seeding. The ammonia is applied using a liquifying unit which is mounted on the cultivator. A nurse tank which carries the ammonia under pressure is pulled behind the cultivator. This nurse tank is rented from the fertilizer dealer and the cost of its rental is included in the price of the ammonia. The phosphorus fertilizer is applied in-row.

The field operations required for this system are;

1) fall cultivation,
2) spring cultivation-banding, and
3) seeding.

5.3 SYSTEM 2B. N BANDED IN THE SPRING WITH AIR SEEDER, P IN-ROW IN THE SPRING

System 2B involves banding nitrogen in the form of granular urea with an air seeder combined with spring tillage prior to seeding. The phosphorus fertilizer is applied in-row. Because the farmer has the air seeder for banding, the air seeder will also be used for seeding. However, after using the air seeder for seeding, the farmer must follow with a harrow-packer to ensure adequate germination.

The order of field operations with this system are;

1) fall cultivation,
2) spring cultivation-banding,
3) seeding, and
4) harrow-packing.

5.4 SYSTEM 3A. N BANDED IN THE FALL WITH AMMONIA LIQUIFYING UNIT, P IN-ROW IN THE SPRING

System 3A involves the same time requirements as System 2A except for the nitrogen fertilizer which is applied in the fall rather than in the spring. The phosphorus is applied in the spring in-row.

Field operations that are required are;

1) fall cultivation-banding,
2) spring cultivation, and
3) seeding.

5.5 SYSTEM 3B. N BANDED IN THE FALL WITH AIR SEEDER, P IN-ROW IN THE SPRING

In System 3B, the N fertilizer is applied in the fall as urea in conjunction with the fall tillage. In spring, the farmer applies the P fertilizer in-row using the air seeder and since the air seeder is being used, no preseeding tillage is required.

Field operations required are;

1) fall cultivation-banding,
2) spring seeding, and
3) harrow-packing.

5.6 SYSTEM 4A. GRANULAR N & P DEEP BANDED IN THE FALL

System 4A involves banding of granular nitrogen and phosphorus using the air seeder in the fall in combination with fall tillage. In the spring, the farmer then seeds with the air seeder, without having to apply any fertilizer and without requiring any preseeding tillage.

Field operations that are involved with this system are;
1) fall cultivation-banding,
2) spring seeding, and
3) harrow-packing.

5.7 SYSTEM 4B. LIQUID N & P DEEP BANDED IN THE FALL

In System 4B, the fertilizer nitrogen and phosphorus are applied as liquids in the fall in conjunction with fall tillage. The farmer uses a liquid fertilizer distribution kit mounted on the cultivator and a nurse tank pulled behind the cultivator to distribute the fertilizer. In the spring, the farmer performs the preseeding tillage with the cultivator and then seeds with the press drill.

Field operations involved with this system are;
1) fall cultivation-banding,
2) spring cultivation, and
3) seeding.

5.8 SYSTEM 5A. GRANULAR N & P DEEP BANDED IN THE SPRING

System 5A involves the banding of both nitrogen and phosphorus fertilizers in the spring with the air seeder prior to seeding. The seeding operation is performed with the air seeder without any preseeding tillage.

The field operations required for this system are;

1) fall cultivation,
2) spring cultivation-NP banding,
3) seeding, and
4) harrow-packing.

5.9 SYSTEM 5B. LIQUID N & P DEEP BANDED IN THE SPRING

System 5B involves the banding of both N and P as liquid fertilizer in conjunction with spring tillage.

Order of field operations with System 5B are;

1) fall cultivation,
2) spring cultivation-banding, and
3) seeding.

5.10 SYSTEM 6. N BROADCAST IN THE FALL, P IN-ROW IN THE SPRING

The system involves the broadcasting of the nitrogen fertilizer in the late fall prior to fall cultivation. In spring, the farmer performs one cultivation prior to seeding. Phosphorus fertilizer is applied in-row at the time of seeding.

Order of field operations in this system are;

1) fall broadcasting,
2) fall cultivation,
3) spring cultivation, and
4) seeding.

5.11 SYSTEM 7. N & P BROADCAST IN THE FALL

System 7 involves the broadcasting of both nitrogen and phosphorus fertilizers in the fall prior to fall cultivation.

Field operations required for this system include;

1) fall broadcasting,
2) fall cultivation,
3) spring cultivation, and
4) seeding.

5.12 SYSTEM 8. N & P BROADCAST IN THE SPRING

In System 8, the nitrogen and phosphorus are broadcast in the spring prior to spring cultivation.

The order of field operations for this system are;

1) fall cultivation,
2) spring broadcasting,
3) spring cultivation, and

4) seeding.

Since System 8 involves the same amount of time spent in the field and uses the same equipment as System 7, the machinery costs are also the same.

5.13 SYSTEM 9. N & P SIDEBANDED IN THE SPRING

In System 9, the fertilizer is applied in the form of a granular blend at the time of seeding. The fertilizer is placed in a band to the side of and below the seed using a separate set of openers which are mounted on the seed drill. The seed drill that is used in this system is an IHC model 5100 end wheel double disk drill. Since this drill does not have packers, a separate harrow-packing operation must follow after seeding.

The order of field operations for this system are;

1) fall cultivation,
2) spring cultivation,
3) seeding-banding, and
4) harrow-packing.

6. FERTILIZER COSTS, CROP RETURNS AND GROSS REVENUE ANALYSIS

For all systems, fertilizers are applied at the rate of 65 kg/ha of N and 13 kg/ha of P. For systems using granular fertilizer or anhydrous ammonia, 60 kg/ha of N is derived from urea (46-0-0) or anhydrous ammonia (82-0-0) and 5 kg/ha of N and 13 kg/ha of P are derived from ammonium phosphate (11-22-0). For systems using liquid fertilizers, 56.3 kg/ha of N is derived from urea-ammonium nitrate (28-0-0) and 8.7 kg/ha of N and 13 kg/ha of P are derived from ammonium polyphosphate (10-15-0). These rates were chosen to replenish the nutrients taken from the previous crop (Beaton 1982) and allow for some reserve. Fertilizer prices were obtained in November 1984 from telephone conversations with several Alberta fertilizer dealers. Most dealers stated that, historically, fertilizer prices have increased an average of approximately 10% from fall to the following spring. The prices for fertilizers purchased in the spring have therefore been adjusted upwards by 10% from the fall prices. Prices for the various fertilizers used in this model are listed in Appendix 4. If applicable for a particular system, fertilizer costs have been calculated for both fall purchased and spring purchased fertilizer. Storage costs were not considered. Anhydrous ammonia and liquid fertilizers are the exception. Since specialized storage facilities are required for these products, delivery was obtained from the fertilizer dealer as required. Interest at the rate of 15% per annum was charged to fertilizer purchases from the date of delivery of the fertilizer (fall or spring) to the following harvest (12 or 5 months). A labour cost of $10 per hour is charged towards the time spent working for the various systems.

A grain yield without the use of any fertilizer is assumed to be 1.35 t/ha. A yield increase of 1.85 t/ha is assumed for the "standard" fertilizer treatment of N broadcast and P in-row. The grain yields were estimated average yields obtained from published reports from a variety of researchers (Nyborg and Hennig (1969), Nyborg and Leitch (1979), Harapiak (1980), Robertson et al (1982), Alberta Agriculture (1984) and Bole et al (1984)). These yields were taken for a typical soil in central Alberta. If desired, yields could be adjusted to suit an individual location elsewhere in the province.

The fertilizer effectiveness rating of the "standard" treatment is taken to be 100. The effectiveness rating of the other placements is expressed as a comparison against the "standard" placement. Effectiveness rating is defined as the yield increase due to a particular placement as compared to the standard expressed as a percentage or decimal. Nitrogen fertilizer effectiveness ratings were obtained from Alberta Agriculture (1984). These ratings were averages obtained from a number of research experiments conducted throughout the province. For phosphorus, the effectiveness rating was assumed to be 100 for every case where the fertilizer was placed in-row or banded in conjunction with nitrogen. The rating for broadcast P was assumed to be 66% (Racz 1982). The combined fertilizer effectiveness rating was then obtained by multiplying the nitrogen rating by the phosphorus rating. The ratings for the various systems are outlined in Table 6.1.

A barley grain price of $125 per tonne (Alberta Wheat Pool, December 1984) was used for the revenue calculations. Production calculations were made for three soil moisture conditions low, medium and high corresponding to low, medium and high soil moisture conditions respectively for the time period from late fall to the following spring early growing season for a typical soil in central Alberta. Grain production was calculated for three soil moisture conditions because fertilizer effectiveness (especially N) varies according to soil moisture conditions.

Fertilizer effectiveness, total costs and gross revenue are outlined in the following tables. Net revenue was calculated in the following manner. The grain yield was multiplied by the price for barley ($125/t) and the area in production (325 ha) to obtain the gross revenue. Subtracted from gross revenue were the costs of fertilizer and interest, machinery and labour. Details of these calculations are in Appendix 7.

TABLE 6.1 FERTILIZER EFFECTIVENESS RATINGS

System	N rating			P rating			Combined rating		
	L	M	H	L	M	H	L	M	H
1	100	100	100	100	100	100	100	100	100
2A	115	110	110	100	100	100	115	110	110
2B	115	110	110	100	100	100	115	110	110
3A	115	95	85	100	100	100	115	95	85
3B	115	95	85	100	100	100	115	95	85
4A	115	95	85	100	100	100	115	95	85
4B	115	95	85	100	100	100	115	95	85
5A	115	110	110	100	100	100	115	110	110
5B	115	110	110	100	100	100	115	110	110
6	100	85	80	100	100	100	100	85	80
7	100	85	80	66	66	66	66	56	53
8	100	100	100	66	66	66	66	66	66
9	115	110	110	100	100	100	115	110	110

Combined rating= (N rating * P rating)/100

L= low soil moisture

M= medium soil moisture

H= high soil moisture

TABLE 6.2 GROSS REVENUE AND TOTAL COSTS UNDER LOW SOIL MOISTURE CONDITIONS ($)

SYSTEM	TREATMENT	GROSS REVENUE	TOTAL COSTS FALL	TOTAL COSTS SPRING
1	N-S-BR P-S-IR	130,000	33,327	33,626
2A	N-S-BD-A P-S-IR	141,375	30,849	30,878
2B	N-S-BD-U P-S-IR	141,375	36,514	36,813
3A	N-F-BD-A P-S-IR	141,375	30,666	30,695
3B	N-F-BD-U P-S-IR	141,375	33,286	33,315
4A	N-F-BD-G P-F-BD-G	141,375	32,998	-
4B	N-F-BD-L P-F-BD-L	141,375	36,908	-
5A	N-S-BD-G P-S-BD-G	141,375	36,225	36,524
5B	N-S-BD-L P-S-BD-L	141,375	-	37,414
6	N-F-BR P-S-IR	130,000	33,327	33,356
7	N-F-BR P-F-BR	104,375	33,182	-
8	N-S-BR P-S-BR	104,375	33,182	33,481
9	N-S-SB P-S-SB	141,375	33,691	33,990

Fall= fall purchased fertilizer, Spring= spring purchased fertilizer

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

TABLE 6.3 GROSS REVENUE AND TOTAL COSTS UNDER MEDIUM SOIL MOISTURE CONDITIONS ($)

SYSTEM	TREATMENT	GROSS REVENUE	TOTAL COSTS FALL	TOTAL COSTS SPRING
1	N-S-BR P-S-IR	130,000	33,327	33,626
2A	N-S-BD-A P-S-IR	137,500	30,849	30,878
2B	N-S-BD-U P-S-IR	137,500	36,514	36,813
3A	N-F-BD-A P-S-IR	126,250	30,666	30,695
3B	N-F-BD-U P-S-IR	126,250	33,286	33,315
4A	N-F-BD-G P-F-BD-G	126,250	32,998	-
4B	N-F-BD-L P-F-BD-L	126,250	36,908	-
5A	N-S-BD-G P-S-BD-G	137,500	36,225	36,524
5B	N-S-BD-L P-S-BD-L	137,500	-	37,414
6	N-F-BR P-S-IR	118,625	33,327	33,356
7	N-F-BR P-F-BR	96,875	33,182	-
8	N-S-BR P-S-BR	104,375	33,182	33,481
9	N-S-SB P-S-SB	137,500	33,691	33,990

Fall= fall purchased fertilizer, Spring= spring purchased fertilizer

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

TABLE 6.4 GROSS REVENUE AND TOTAL COSTS UNDER HIGH SOIL MOISTURE CONDITIONS ($)

SYSTEM	TREATMENT	GROSS REVENUE	TOTAL COSTS FALL	TOTAL COSTS SPRING
1	N-S-BR P-S-IR	130,000	33,327	33,626
2A	N-S-BD-A P-S-IR	137,500	30,849	30,878
2B	N-S-BD-U P-S-IR	137,500	36,514	36,813
3A	N-F-BD-A P-S-IR	118,625	30,666	30,695
3B	N-F-BD-U P-S-IR	118,625	33,286	33,315
4A	N-F-BD-G P-F-BD-G	118,625	32,998	-
4B	N-F-BD-L P-F-BD-L	118,625	36,908	-
5A	N-S-BD-G P-S-BD-G	137,500	36,225	36,524
5B	N-S-BD-L P-S-BD-L	137,500	-	37,414
6	N-F-BR P-S-IR	115,000	33,327	33,356
7	N-F-BR P-F-BR	94,625	33,182	-
8	N-S-BR P-S-BR	104,375	33,182	33,481
9	N-S-SB P-S-SB	137,500	33,691	33,990

Fall= fall purchased fertilizer, Spring= spring purchased fertilizer

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

7. DISCUSSION OF RESULTS

7.1 TIME REQUIREMENTS

The times required to complete fertilizer application and seeding for the various systems as calculated in Appendix 6 are summarized in Tables 7.1 and 7.2. The time spent in the fall varies from 4.5 days for the systems which require only fall cultivation (Systems 1, 2A, 2B, 5A, 6B, 8, 9) to 6.9 days for systems where fertilizer is broadcast in the fall prior to fall cultivation (Systems 6, 7). The time spent in the spring varies from 7 days (System 3B) to 11.8 days (System 2B). In general, the greater the number of field operations that are required, the longer the time required to complete the operations. Operations that are combined (e.g. fertilizing and cultivating or cultivating-seeding with the air seeder) lead to less time spent in completing the operations. For example, combining nitrogen fertilizer application with cultivation in System 2A leads to a two day decrease in spring working time over System 1 where the nitrogen fertilizer is broadcast in a separate operation. Thus there is great potential in reducing time requirements by combining field operations whenever possible.

Time requirements of the various systems as they relate to machine operations also varies. In general, seeding with the press drill is faster than seeding with the air seeder

TABLE 7.1 TIME REQUIREMENTS OF THE VARIOUS SYSTEMS (HOURS)

SYSTEM	TREATMENT	FALL	SPRING	Total
1	N-S-BR P-S-IR	54	134.2	188.2
2A	N-S-BD-A P-S-IR	54	109.2	163.2
2B	N-S-BD-U P-S-IR	54	142	196
3A	N-F-BD-A P-S-IR	56.5	106.5	163
3B	N-F-BD-U P-S-IR	57.4	84.6	142
4A	N-F-BD-G P-F-BD-G	58.7	80.3	139
4B	N-F-BD-L P-F-BD-L	62.3	104.1	166.4
5A	N-S-BD-G P-S-BD-G	54	139	193
5B	N-S-BD-L P-S-BD-L	54	112.4	166.4
6	N-F-BR P-S-IR	81.7	106.5	188.2
7	N-F-BR P-F-BR	83.3	104.1	187.4
8	N-S-BR P-S-BR	54	133.4	187.4
9	N-S-SB P-S-SB	54	136.3	190.3

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

TABLE 7.2 TIME REQUIREMENTS OF THE VARIOUS SYSTEMS (DAYS)

SYSTEM	TREATMENT	FALL	SPRING	Total
1	N-S-BR P-S-IR	4.5	11.2	15.7
2A	N-S-BD-A P-S-IR	4.5	9.1	13.6
2B	N-S-BD-U P-S-IR	4.5	11.8	16.3
3A	N-F-BD-A P-S-IR	4.7	8.9	13.6
3B	N-F-BD-U P-S-IR	4.8	7	11.8
4A	N-F-BD-G P-F-BD-G	4.9	6.7	11.6
4B	N-F-BD-L P-F-BD-L	5.2	8.7	13.9
5A	N-S-BD-G P-S-BD-G	4.5	11.6	16.1
5B	N-S-BD-L P-S-BD-L	4.5	9.4	13.9
6	N-F-BR P-S-IR	6.8	8.9	15.7
7	N-F-BR P-F-BR	6.9	8.7	15.6
8	N-S-BR P-S-BR	4.5	11.1	15.6
9	N-S-SB P-S-SB	4.5	11.4	15.9

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

providing the number of field passes remains the same. However, when seeding with the air seeder is combined with preseeding tillage, time requirements favour the air seeder over the press drill. Seeding with the air seeder requires a subsequent harrow-packing operation to ensure good soil-seed contact. Therefore, combining harrow-packing with the air seeding operation could result in even greater time savings.

Broadcasting generally required more time than banding, when banding was combined with a cultivation operation. The exceptions were Systems 2B and 5A which used the air seeder for seeding. These systems necessitated a second cultivation and a harrow-packing operation which led to greater time requirements.

There have been suggestions by some researchers (Harapiak 1984b) that in-row application of fertilizers can lead to significant time delays during seeding. However, comparing System 3B with 4A, in-row application of phosphorus required only 0.3 days longer to complete seeding operations. Therefore, as long as the proper management and equipment is used (drill-fills, fertilizer hoppers), time delays involved with in-row fertilizer application can be minimal.

The time required to apply liquid fertilizer was slightly higher than for granular fertilizer. The time difference involved however was relatively small, in the range of 0.3 days.

The application of phosphorus fertilizer in conjunction with nitrogen fertilizer generally required less time than the application of the products separately. However, the amount of extra time that was required was small. For example, System 3B required only 0.3 days longer to apply phosphorus fertilizer in-row than System 4A where the phosphorus was banded with the nitrogen.

The use of anhydrous ammonia as an N source in System 2A led to 2.5 days less time spent in spring than System 2B which used urea as the N source. This was primarily due to less handling of the fertilizer product and the elimination of the harrow-packing operation in System 2A as compared to System 2B.

The number of available working days in the fall to perform field work is limited, especially in the high rainfall areas. This time limitation generally restricts fall work to cultivation or perhaps cultivation-banding. Any other field operations could not be performed because of this time limitation. In the low and medium rainfall areas, fall time is not as constrained and if desired, a greater amount of field work can be performed in the fall.

In the spring, the number of available working days is generally about equal across the province and all of the systems field operations can be performed within the required time. Therefore, no penalty costs with respect to late seeding would be incurred. However, the systems which required less time to complete field operations allow for greater flexibility if unfavorable weather conditions are encountered or if additional field operations are required (e.g. incorporation of pre-emergence herbicides).

7.2 MACHINERY COSTS

Machinery costs for the various systems as calculated in Appendix 6 are summarized in Table 7.3. The costs varied from $10,345 for Systems 2A and 3A to $14,293 for System 2B. System costs were directly related to the number of hours required to complete the required operations and to the complement of equipment that was used.

The air seeder is a relatively expensive machine to operate. Systems which required two passes of the air seeder as well as a pass with the cultivator (Systems 2B and 5A) had the highest machinery costs. The advantage of the air seeder comes from combining field operations. When seeding is combined with preseeding tillage as in Systems 3B and 4A, machinery costs decrease because fewer hours are required to complete field operations. Systems 2A and 3A which used the ammonia liquifying unit to apply nitrogen and the seed drill to apply phosphorus had the lowest machinery costs. The ammonia liquifying unit is the most inexpensive method of applying and incorporating nitrogen fertilizer to cultivated soil.

The machinery costs of liquid fertilizer application kits are higher than ammonia liquifying kits or broadcasters

TABLE 7.3 MACHINERY COSTS FOR THE VARIOUS SYSTEMS ($/year)

SYSTEM	TREATMENT	FIXED COSTS	VARIABLE COSTS	TOTAL COSTS
1	N-S-BR P-S-IR	5619	5565	11,184
2A	N-S-BD-A P-S-IR	5278	5067	10,345
2B	N-S-BD-U P-S-IR	7716	6577	14,293
3A	N-F-BD-A P-S-IR	5278	5067	10,345
3B	N-F-BD-U P-S-IR	6504	5101	11,605
4A	N-F-BD-G P-F-BD-G	6359	4988	11,347
4B	N-F-BD-L P-F-BD-L	6620	5763	12,383
5A	N-S-BD-G P-S-BD-G	7572	6462	14,034
5B	N-S-BD-L P-S-BD-L	6620	5763	12,383
6	N-F-BR P-S-IR	5619	5565	11,184
7	N-F-BR P-F-BR	5532	5515	11,047
8	N-S-BR P-S-BR	5532	5515	11,047
9	N-S-SB P-S-SB	5948	5579	11,527

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

but lower than air seeders.

Time of fertilizer application (fall vs spring) had no effect upon machinery costs except in cases where field operations were combined (e.g. System 2B vs 3B).

7.3 FERTILIZER COSTS

Fertilizer costs for the various systems as calculated in Appendix 7 are summarized in Table 7.4. Included in the fertilizer costs are the interest charges for the fertilizer which are calculated from the time of purchase to the subsequent harvest. If applicable, costs were calculated for both fall and spring purchased fertilizer. Details of fertilizer prices are in Appendix 4.

Anhydrous ammonia is the lowest cost form of nitrogen fertilizer. Therefore, systems which involved the use of ammonia as the nitrogen source (Systems 2A and 3A) had the lowest fertilizer and interest costs. Granular nitrogen fertilizer (urea) is intermediate in cost. Liquid fertilizer (nitrogen and phosphorus) is the most expensive formulation of fertilizer. Systems which used liquid fertilizer (4B and 5B) had the highest fertilizer and interest costs. These costs are substantial; in the range of $4,000 more than systems which used anhydrous ammonia and granular phosphorus. Therefore, the use of liquid fertilizer in Alberta will probably be limited until the price difference between liquid and other fertilizer forms narrows.

TABLE 7.4 FERTILIZER AND INTEREST COSTS FOR THE VARIOUS SYSTEMS ($)

SYSTEM	TREATMENT	FALL PURCHASED	SPRING PURCHASED
1	N-S-BR P-S-IR	20,261	20,560
2A	N-S-BD-A P-S-IR	18,874	18,903
2B	N-S-BD-U P-S-IR	20,261	20,560
3A	N-F-BD-A P-S-IR	18,691	18,720
3B	N-F-BD-U P-S-IR	20,261	20,290
4A	N-F-BD-G P-F-BD-G	20,261	-
4B	N-F-BD-L P-F-BD-L	22,387	-
5A	N-S-BD-G P-S-BD-G	20,261	20,560
5B	N-S-BD-L P-S-BD-L	-	23,343
6	N-F-BR P-S-IR	20,261	20,290
7	N-F-BR P-F-BR	20,261	-
8	N-S-BR P-S-BR	20,261	20,560
9	N-S-SB P-S-SB	20,261	20,5[illegible]

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

Fertilizer purchased in the fall is generally cheaper than spring purchased fertilizer. In most instances, the difference in fertilizer costs is relatively small ($300). If storage facilities are available for fall purchased fertilizer, fall purchased fertilizer would be advantageous. In addition, the farmer would have a guaranteed supply and would be protected against problems such as transportation restrictions which could affect fertilizer availability and price in the spring. As well, fall fertilizer delivery is advantageous for the fertilizer manufacturing and distribution system from the standpoint of evening out the flow of fertilizer throughout the year. The disadvantage of purchasing fertilizer in the fall is inflexibility in terms of being able to change forms of fertilizers or analyses if cropping situations or fertilizer recommendations change.

7.4 GRAIN YIELDS

Grain yields, for the various systems, as calculated in Appendix 7 using the previously stated assumptions regarding fertilizer efficiencies, are tabulated in Table 7.5. Grain yields were calculated for three soil moisture conditions low, medium, and high, referring to the amount of soil moisture present during the period from late fall to the following early growing season for a typical soil in central Alberta.

TABLE 7.5 GRAIN YIELDS FOR THE VARIOUS SYSTEMS (t/ha).

SYSTEM	TREATMENT	LOW	MEDIUM	HIGH
1	N-S-BR P-S-IR	3.20	3.20	3.20
2A	N-S-BD-A P-S-IR	3.48	3.39	3.39
2B	N-S-BD-U P-S-IR	3.48	3.39	3.39
3A	N-F-BD-A P-S-IR	3.48	3.11	2.92
3B	N-F-BD-U P-S-IR	3.48	3.11	2.92
4A	N-F-BD-G P-F-BD-G	3.48	3.11	2.92
4B	N-F-BD-L P-F-BD-L	3.48	3.11	2.92
5A	N-S-BD-G P-S-BD-G	3.48	3.39	3.39
5B	N-S-BD-L P-S-BD-L	3.48	3.39	3.39
6	N-F-BR P-S-IR	3.20	2.92	2.83
7	N-F-BR P-F-BR	2.57	2.39	2.33
8	N-S-BR P-S-BR	2.57	2.57	2.57
9	N-S-SB P-S-SB	3.48	3.39	3.39

Low, medium and high refer to the amount of soil moisture from late fall to the following early growing season.

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

For all soil moisture conditions, lowest yields were obtained from System 7 where all the fertilizer was broadcast in the fall. The highest yields under low soil moisture conditions were Systems 2A-5B and 9 where the nitrogen fertilizer was banded, either alone or in conjunction with phosphorus. There were no differences due to timing of fertilizer applications (fall or spring) under low soil moisture conditions. This was true for both broadcast and banded applications. The difference between the lowest and highest yielding systems was 0.91 t/ha.

Under medium soil moisture conditions, highest yields were obtained from Systems 2A, 2B, 5A, 5B and 9 where the nitrogen was banded in the spring and the phosphorus was either placed in-row or banded in conjunction with nitrogen. Under medium soil moisture conditions, there were differences between fall and spring applications with spring applications yielding about 15% higher than fall applications. This was primarily due to denitrification and leaching losses of fall applied nitrogen as compared to spring applications. Banded applications were more efficient than broadcast applications. The difference between the lowest and highest yielding systems was 1.0 t/ha.

For high soil moisture conditions, the differences between fall and spring applications were even more substantial than under medium soil moisture conditions. Fall fertilizer applications were about 20-25% less effective than spring applications. Again, banded applications were more efficient than broadcast applications. The difference in yield between the lowest and highest yielding systems was 1.06 t/ha.

In summary, banded fertilizer applications produced a greater yield response than broadcast applications. The yield response increase ranged from 10-15% for nitrogen applications and up to 50% for phosphorus applications. Fall nitrogen applications were as equally effective as spring applications under low soil moisture conditions but fall nitrogen applications were inferior under medium and high soil moisture conditions. Banded phosphorus applications were generally as effective as in-row applications especially when nitrogen was banded in conjunction with phosphorus.

7.5 NET REVENUE

Net revenue for the various systems, based upon previously assumed fertilizer effectiveness ratings, as calculated in Appendix 7, are summarized in Tables 7.6, 7.7 and 7.8 and are ranked in order of decreasing net revenue.

For low soil moisture conditions, highest net revenue was obtained from System 3A ($110,709) followed closely by System 2A ($110,526). There were slight differences in net revenue between fall and spring purchased fertilizer (0-$300). Lowest net revenue was obtained from Systems 7 and 8 ($71,193). Under low soil moisture conditions, broadcast

TABLE 7.6 NET REVENUE FOR THE VARIOUS SYSTEMS UNDER LOW SOIL MOISTURE CONDITIONS ($).

SYSTEM	TREATMENT	FALL PURCHASED FERTILIZER	SPRING PURCHASED FERTILIZER
3A	N-F-BD-A P-S-IR	110,709	110,680
2A	N-S-BD-A P-S-IR	110,526	110,497
4A	N-F-BD-G P-F-BD-G	108,377	-
3B	N-F-BD-U P-S-IR	108,089	108,060
9	N-S-SB P-S-SB	107,684	107,385
5A	N-S-BD-G P-S-BD-G	105,150	104,851
2B	N-S-BD-U P-S-IR	104,861	104,562
4B	N-F-BD-L P-F-BD-L	104,467	-
5B	N-S-BD-L P-S-BD-L	-	103,961
6	N-F-BR P-S-IR	96,673	96,644
1	N-S-BR P-S-IR	96,673	96,374
8	N-S-BR P-S-BR	71,193	70,894
7	N-F-BR P-F-BR	71,193	-

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

TABLE 7.7 **NET REVENUE FOR THE VARIOUS SYSTEMS UNDER MEDIUM SOIL MOISTURE CONDITIONS ($).**

SYSTEM	TREATMENT	FALL PURCHASED FERTILIZER	SPRING PURCHASED FERTILIZER
2A	N-S-BD-A P-S-IR	106,651	106,622
9	N-S-SB P-S-SB	103,809	103,510
5A	N-S-BD-G P-S-BD-G	101,275	100,976
2B	N-S-BD-U P-S-IR	100,986	100,687
5B	N-S-BD-L P-S-BD-L	-	100,086
1	N-S-BR P-S-IR	96,673	96,374
3A	N-F-BD-A P-S-IR	95,584	95,555
4A	N-F-BD-G P-F-BD-G	93,252	-
3B	N-F-BD-U P-S-IR	92,964	92,935
4B	N-F-BD-L P-F-BD-L	89,342	-
6	N-F-BR P-S-IR	85,298	85,269
8	N-S-BR P-S-BR	71,193	70,894
7	N-F-BR P-F-BR	63,693	-

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

TABLE 7.8 NET REVENUE FOR THE VARIOUS SYSTEMS UNDER HIGH SOIL MOISTURE CONDITIONS ($).

SYSTEM	TREATMENT	FALL PURCHASED FERTILIZER	SPRING PURCHASED FERTILIZER
2A	N-S-BD-A P-S-IR	106,651	106,622
9	N-S-SB P-S-SB	103,809	103,510
5A	N-S-BD-G P-S-BD-G	101,275	100,976
2B	N-S-BD-U P-S-IR	100,986	100,687
5B	N-S-BD-L P-S-BD-L	-	100,086
1	N-S-BR P-S-IR	96,673	96,374
3A	N-F-BD-A P-S-IR	87,959	87,930
4A	N-F-BD-G P-F-BD-G	85,627	-
3B	N-F-BD-U P-S-IR	85,339	85,310
4B	N-F-BD-L P-F-BD-L	81,717	-
6	N-F-BR P-S-IR	81,673	81,644
8	N-S-BR P-S-BR	71,193	70,894
7	N-F-BR P-F-BR	61,443	-

Treatment abbreviations: N-nitrogen, P-phosphorus, S-spring applied, F-fall applied, BR-broadcast, BD-banded, IR-in-row, SB-sidebanded, A-anhydrous ammonia, U-urea, G-granular, L-liquid.

fertilizers led to a 35-40% decrease in net revenue as compared to banded nitrogen and in-row phosphorus. Net revenues were comparable for both spring and fall fertilizer applications.

Under medium soil moisture conditions, the highest net revenue was obtained from System 2A ($106,651) and the lowest net revenue was obtained from System 7 ($63,693). The net income from System 7 was 40% less than System 2A. Broadcasting of fertilizers (especially P) produced the lowest yields and therefore had the lowest net revenues. Spring fertilizer applications were generally more effective than fall applications and banded fertilizer applications were more effective than broadcast applications.

System 2A produced the highest net revenues under high soil moisture conditions ($106,651) and System 7 produced the lowest net revenues ($61,443). The ranking of the various systems with respect to net revenue for high soil moisture conditions was similar to the ranking under medium soil moisture conditions. However, fall applied fertilizers produced even lower net revenues for high soil moisture conditions than medium soil moisture conditions. This is due to higher overwintering losses (denitrification, leaching) assumed for higher soil moisture conditions as compared to medium soil moisture conditions.

8. SUMMARY AND CONCLUSIONS

A literature review was undertaken to study different methods of fertilizer application in terms of their effectiveness in increasing grain yields. The aim was to develop a series of fertilizer effectiveness ratings for use in estimating grain yields from different methods of fertilizer application. A review of the different types of equipment available for fertilizer placement was also undertaken.

This information was used to develop thirteen systems of fertilizer application which included variables such as method of fertilizer placement, form of fertilizer used, time of fertilizer application and machinery complement used. Time requirements, machinery costs, fertilizer costs, grain yields and net revenue for the various systems were calculated and compared.

The following conclusions were based upon the analysis of the operation and performance of the various systems.

1. Combining field operations (e.g. cultivation and fertilizer placement, cultivation and seeding) is an effective method of reducing time requirements and machinery costs.
2. The air seeder is a good implement for seeding when used to reduce the number of field passes. However, when used for the same number of field passes as a conventional seed drill, the machinery costs are higher than for a

conventional drill. The air seeder is an effective machine for banding of granular fertilizer. However, the seeding operation should also be performed with the air seeder in order to spread out the high fixed costs over a greater number of hours of use.

3. The application of phosphorus fertilizer in-row in the spring does not require an excessive amount of time as compared to straight seeding as long as the proper equipment (drill-fills, augers, large capacity fertilizer wagons) are used in the handling of fertilizer.
4. The highest net revenue was obtained from either Systems 2A or 3A where the nitrogen fertilizer was banded in the spring or fall respectively in the form of anhydrous ammonia and phosphorus fertilizer was placed in-row. System 3A produced the highest net revenue under low soil moisture conditions and System 2A produced the highest net revenue under medium and high soil moisture conditions.
5. Lowest net revenue for all soil moisture conditions was obtained from System 7 where all the fertilizer was broadcast in the fall. This system produced only 55-65% as much net income as the systems which produced the highest net revenue.
6. Anhydrous ammonia is the least expensive form of nitrogen fertilizer and will probably remain so in the forseeable future because of lower manufacturing costs.

Granular urea is the cheapest form of granular nitrogen because of its high analysis and is an ideal fertilizer for farmers who prefer granular fertilizers for banding. Granular phosphorus (monoammonium phosphate) is the least expensive form of phosphorus fertilizer. Liquid fertilizers (nitrogen and phosphorus) are the most expensive forms of fertilizer. Liquid fertilizer products result in about a 20% [illegible]ease in fertilizer costs as compared to the use [illegible]rous ammonia and monoammonium phosphate as the [illegible]s of N and P respectively. Therefore, the use of liquid fertilizer products will likely remain limited in Alberta until the price difference between liquid and granular fertilizer products narrows.

7. Fall purchased fertilizer is generally more economical than spring purchased fertilizer. There are the added a[illegible]tages for the farmer of guaranteed supply and price [illegible] advantage for the fertilizer industry of sp[illegible]ng out the [illegible]anufacturing and distribution processes of fertilizer over a greater portion of the year.

The method of fertilizer application that should be employed is dependent upon the factor that is chosen to be optimized. Differences among growing seasons in terms of available time, machinery availability and suitability, fertilizer costs and available soil moisture are important factors which should be consid[illegible] before choosing a particular method of fertilizer application. The method of fertilizer application ultimately chosen should be one that is expected to maximize net revenue i[illegible]ms of the given constraints present at the time.

9. RECOMMENDATIONS FOR FURTHER WORK

As a result of the various observations and conclusions obtained from this study, a number of recommendations for further work have been developed.

1. Equipment with proper trash clearance and penetration capabilities and large seed and fertilizer hoppers should be developed to facilitate sidebanding of fertilizers in conjunction with the seeding operation.
2. Equipment should be developed to facilitate banding of fertilizers for zero tilled and forage crops to maximize crop response to fertilizer and minimize soil disturbance.
3. The relationship between depth and spacing of fertilizer bands to crop response should be developed.
4. Further work towards the development of yield curves for different crops under different soil moisture conditions for various areas in the province should be undertaken.
5. Further work on crop response from various fertilizer placements should be performed on other crops such as canola. The amount of fertilizer research performed on canola is small in comparison to the importance of canola to the prairies.
6. The addition of other nutrients (K, S, micronutrients) in a common band with N and P and their influence on fertilizer uptake and crop growth should be studied.

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APPENDIX 1. POWER REQUIREMENTS OF VARIOUS CHISEL PLOWS TESTED BY PAMI.

Make & Model	Working Width (m)	Power Required (kW)	Power Required (kw/m)
John Deere 1610	10.2	153	15
Bush Hog CP7815	12	180	15
Co-op Implements 204	8.3	122	14.7
Lely S-8-6	6.6	97	14.7
Friggstad C5-43	13.1	193	14.7
Massey Ferguson 128	10	147	14.7
Melroe 505	8.2	120	14.6
Leon CP77-334	10.4	153	14.7
Morris CP631	11.3	167	14.8
Wilrich 13CPW	11.3	167	14.8
Edwards CSF-833	9.9	145	14.6
Average	10.1	149.5	14.8

Power requirements presented are maximum PTO ratings and have been adjusted to include tractive efficiency and represent a tractor operating at 80% maximum power on a level field.

APPENDIX 2. SEED DRILL PARAMETERS AS TESTED BY PAMI.

Make & Model	Power required (kW/m)	Capacities (L/m) Seed Box	Capacities (L/m) Fertilizer Box
IHC 620	9.22	233	135
JD 9350	7.58	201	143
MF 63	8.61	167	131
MORRIS M10	9.33	213	137
Averages	8.69	204	137

APPENDIX 3. CALCULATION OF AUGER CAPACITIES

The capacities of the various augers were derived in the following manner:

1. The capacities of various 18 cm augers in wheat and oats were obtained from PAMI reports (PAMI 1978d, 1978e, 1978f, 1981c).
2. The capacity in barley was obtained by averaging the capacities obtained in wheat and oats (36.2 + 27.3 + 49.2 + 31.8 + 37.5 + 25.5 + 43.7 + 32.9)/8= 35.5 t/h.
3. The capacities of the 12.7 cm drill fills (PAMI 1984A, 1984B) in barley were obtained in a similar manner (21.2 + 16.9 + 14.6 + 9.6)/4= 15.6 t/h.
4. The capacity of the 12.7 cm drill fill in fertilizer was obtained by averaging the values given in the report for fertilizer (8.8 + 10.1)/2= 9.5 t/h.
5. Since the 18 cm auger was not tested in fertilizer by PAMI, its capacity was derived in the following manner. The capacities of the 12.7 cm drill fills in fertilizer averaged out to be 0.583 times the capacity in wheat. Therefore, this same ratio of 0.583 was multiplied by the average capacity of the 18 cm augers in wheat which equals 24300 kg/h.

APPENDIX 4. FERTILIZER PRICES.

FERTILIZER PRICES $/t

Product	Fall price	cost/kg	Spring price	cost/kg
82-0-0	413	0.50	454	0.55
46-0-0	264	0.57	290	0.63
11-22-0	357	N 0.57 P 1.32	392	N 0.63 P 1.43
28-0-0	180	0.64	198	0.71
10-15-0	286	N 0.64 P 1.50	315	N 0.71 P 1.65

cost/kg= cost per kg of nutrient

Fertilizer prices were obtained from telephone conversations with several Alberta fertilizer dealers, (November, 1984)

APPENDIX 5. CALCULATION OF MACHINERY COSTS FOR A LIQUID FERTILIZER DISTRIBUTION KIT

Cost of kit includes flow divider, pump, filter, polyethylene tank, nurse tank pump, manifold, lines and shank tips for a 9.14 m cultivator.

The cost of the kit ($9500) was obtained over a telephone conversation in January 1985 with Green Drop Fertilizers, Calgary, Alberta.

Depreciation= (Original cost - Residual value)/Years of use
=($9500 - $0)/15= $633/year

Interest= ((Original cost + Residual value)/2) * Int. rate
= (($9500 + $0)/2) * (0.15)= $713/year

Insurance and housing= Original cost * 1%
= $9500 * 0.01= $95/year

Total annual fixed costs= $1441

Hourly fixed costs= $1441/60 h= $24/h

Variable costs= repairs

Repair rate= $1.24/h/$1000 of original cost
= $1.24/h * 9.5= $12/h

Total hourly costs= fixed + variable
= $24 + $12= $36/h

The formulas for depreciation, interest, insurance and housing, and repairs were obtained from (Andruchow 1982).

APPENDIX 6. CALCULATION OF TIME REQUIREMENTS AND MACHINERY COSTS

SYSTEM 1. N BROADCAST IN THE SPRING, P IN-ROW IN THE SPRING

The time required for cultivation is obtained using equation 3.1.

C= (S W E)/10

C= effective capacity (ha/h)

S= 8 km/h

W= 9.14 m

E= 0.825

C=(8*9.14*0.825)/10= 6.03 ha/h

Hours for cultivation= 325 ha/(6.03ha/h)= 54 h

Time required for broadcasting of nitrogen:

C= (S W E)/10

S= 12 km/h

W= 13.7 m

E= 0.825

C=(12*13.7*0.825)/10= 13.56 ha/h

Hours for broadcasting= 325 ha/(13.56 ha/h)= 24 h

Time required for filling of broadcaster:

N application rate= 60 kg/ha

amount of fertilizer to be applied

60 kg/ha*(1 kg fert/0.46 kg of N)*325 ha= 42391 kg

number of spreaders required

42390 kg/(4000 kg/spreader)= 11 spreaders

Time required to auger fertilizer into spreader using 18 cm auger:

capacity of auger= 24300 kg/h (Appendix 3)

(4000 kg/spreader)*(1 h/24300 kg)= 0.166 h/spreader

assume 0.166 h/spreader for setting up

fill-up time= 0.166 + 0.166= 0.332 h/spreader

Hours for filling of broadcaster

11 loads * 0.332 h/load= 3.7 h

Total time required for broadcasting of N fertilizer

24 h + 3.7 h= 27.7 h

Time required for seeding

field time

C= (S W E)/10

S= 8 km/h

W= 11 m

E= 0.825

C= (8*11*0.825)/10= 7.26 ha/h

field time= 325 ha/(7.26 ha/h)= 44.8 h

filling time

seeding rate= 90 kg/ha

density of seed= 0.62 kg/L

seed drill capacity= 2244 L * (0.62 kg/L)= 1391 kg

area seeded with one drill

1391 kg/(90 kg/ha)= 15.4 ha

capacity of drill fill in grain= 15600 kg/h (App. 3)

time to fill drill with grain

1391 kg/(15600 kg/h)= 0.089 h

fertilizing rate (P)= 13 kg/ha

amount of fertilizer applied

(13 kg/ha of P)*(1 kg fert/0.22 kg of P)=

59 kg/ha

amount of fertilizer loaded per drill

(59 kg/ha)*(15.4 ha/drill)= 909 kg

capacity of drill fill in fertilizer= 9500 kg/h

(Appendix 3)

time required to fill drill with fertilizer

(909 kg/drill)/(9500 kg/h)= 0.096 h

setting up time= 0.166 h/drill

total filling time per drill= 0.089+0.096+0.166= 0.351 h

number of drills-fills required= 325 ha/(15.4 ha/drill)= 22 drill-fills

filling time (over season)= 22 drills*(0.351 h/drill)= 7.7 h

Total time for seeding= 44.8 h + 7.7 h= 52.5 h

Total time for System 1

Fall- 54 h

Spring- 134.2 h

Total- 188.2 h

Yearly machinery costs ($) for System 1 (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	188.2	2104	3836	5940
Cultivator	108	1029	712	1741
Mounted harrows	108	188	39	227
Broadcaster	27.7	250	125	375
Seed drill	52.5	2048	853	2901
Total		5619	5565	11,184

SYSTEM 2A. N BANDED IN THE SPRING WITH AMMONIA LIQUIFYING UNIT, P IN-ROW IN THE SPRING

Time required for fall cultivation= 54 h (from System 1)

Time required for spring cultivation-banding

field time= 54 h (from System 1)

time required for tank fill-ups

volume of tank = 4000 L

specific gravity of anhydrous ammonia= 0.635 kg/L

mass of NH_3 per tank= 4000 L * (0.635 kg/L)= 2540 kg

total amount of NH_3 required

60 kg/ha of N * 325 ha *

(1 kg NH_3/0.82 kg of N)= 23780 kg

number of tanks required

23780 kg/ 2540 kg/tank= 10 tanks

assume 0.25 h fill-up time per tank

total time required for tank fill-ups

0.25 h/tank * 10 tanks= 2.5 h

Total time required for spring cultivation-banding

54 h + 2.5 h= 56.5 h

Time required for seeding= 52.5 h (from System 1)

Total time required for System 2A

Fall	54 h
Spring	109 h
Total	163 h

Yearly machinery costs ($) for System 2A (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	163	1823	3321	5144
Cultivator	110.5	1053	728	1781
Mounted harrows	110.5	192	40	232
Cold flo kit	56.5	162	125	287
Seed drill	52.5	2048	853	2901
Total		5278	5067	10,345

SYSTEM 2B. N BANDED IN THE SPRING WITH AIR SEEDER, P IN-ROW IN THE SPRING

Time required for fall cultivation= 54 h (System 1)

Time required for spring cultivation-banding

field coverage time= 54 h

time required for tank fill-ups

tank volume= 6526 L

density of urea= 0.78 kg/L

tank capacity= 6526 L * (0.78 kg/L)= 5090 kg

capacity of 18 cm auger= 24300 kg/h (Appendix 3)

time per load= 5090 kg/load * (1 h/24300 kg)= 0.209 h

set up time = 0.166 h/load

number of loads required

325 ha*60 kg/ha of N * (1 kg fert/0.46 kg of N)* (1 load/ 5090 kg fert)= 9 loads

time required for tank fill-ups

9 loads * (0.209 + 0.166) h/load= 3.4 h

Time required for spring cultivation-banding

54 h + 3.4 h= 57.4 h

Time required for seeding

field coverage time= 54 h

fill-up times

grain

grain tank volume= 3318 L

density of grain= 0.62 kg/L

grain tank capacity= 3318 L * (0.62 kg/L)= 2057 kg

capacity of drill fill= 15600 kg/h (Appendix 3)

time required to fill grain tank

2057 kg/(15600 kg/h)= 0.132 h

seeding rate= 90 kg/ha

area seeded per tank= 2057kg/(90 kg/ha)= 22 ha

fertilizer

amount required to fill per tank

13 kg of P/ha * (1 kg fert/0.22 kg of P) *

22 ha= 1294 kg

capacity of drill fill in fertilizer= 9500 kg/h

time required to fill fertilizer tank

1294 kg/(9500 kg/h)= 0.136 h

total fill-up time per tank

0.132 h + 0.136 h + 0.166 h= 0.434 h

number of tankfuls required

325 ha * (1 tank/ 22 ha)= 15 tanks

Total fill-up time over season

15 tanks * 0.434 h/tank= 6.5 h

Total seeding time = 54 h + 6.5 h= 60.5 h

Time required for harrow-packing

Machine capacity

C= (S W E)/10

S= 9 km/h

W= 18.3 m

E= 0.825 m

C= (9*18.3*0.825)/10= 13.6 ha/h

Time required for harrow packing= 325 ha/(13.6 ha/h)= 24 h

Total time required for System 2B

Fall cultivating	54	h
Spring cultivating-banding	57.4	h
Seeding	60.5	h
Harrow packing	24	h
Total	196	h

Yearly machinery costs ($) for System 2B (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	196	2192	3994	6186
Cultivator	172	1639	1134	2773
Mounted harrows	172	299	62	361
Air seeder	118	3008	1272	4280
Harrow-packer	24	578	115	693
Total		7716	6577	14,293

SYSTEM 3A. N BANDED IN THE FALL WITH AMMONIA LIQUIFYING UNIT, P IN-ROW IN THE SPRING

Fall cultivation-banding= 56.5 h

(same as System 2A, spring cultivation-banding)

Spring cultivation= 54 h (System 1)

Seeding= 52.5 h (System 1)

Total time required for System 3A

Fall	56.5 h
Spring	106.5 h
Total	163 h

Yearly machinery costs for System 3A= $10,345
(same as System 2A)

SYSTEM 3B. N BANDED IN THE FALL WITH AIR SEEDER, P IN-ROW IN THE SPRING

Fall cultivation-banding= 57.4 h (same as System 2B,spring)

Seeding= 60.5 h (same as System 2B)

Harrow-packing= 24 h (same as System 2B)

Total time

Fall	57.4	h
Spring	84.5	h
Total	142	h

Yearly machinery costs ($) for System 3B (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	142	1588	2894	4482
Cultivator	118	1125	777	1902
Mounted harrows	118	205	43	248
Air seeder	118	3008	1272	4280
Harrow-packer	24	578	115	693
Total		6504	5101	11,605

SYSTEM 4A. GRANULAR N & P DEEP BANDED IN THE FALL

Fall cultivation-NP banding

field coverage time= 54 h (System 1)

fill-up time

volume of tank= 6526 L

applying N&P blend of 46-0-0 and 11-22-0

amount of 46-0-0 required

60 kg of N/ha * (1 kg fert/0.46 kg of N)=

130 kg/ha

amount of 11-22-0 required

13 kg of P/ha * (1 kg fert/0.22 kg of P)=

59 kg/ha

rate of blend required

130 kg/ha + 59 kg/ha= 189 kg/ha

density of fertilizer blend

(130 kg * (0.78 kg/L)) + (59 kg * (0.85 kg/L))/189=

0.80 kg/L

capacity of tank= 6526 L * (0.80 kg/L)= 5221 kg

capacity of 18 cm auger in fertilizer=

24300 kg/h (Appendix 3)

time to fill 1 tank

5220 kg/h * (1 h/24300 kg/t)= 0.215 h

0.215h + 0.166 h (set up)= 0.381 h

area covered with 1 tank

(5221 kg/tank)/(189 kg/ha)= 27.6 ha

number of tanks required= 325 ha/(27.6 ha/tank)= 12 tanks

total tank fill-up time required

12 tanks * 0.381 h/tank= 4.6 h

Total time required for fall cultivation-NP banding

54 h + 4.6 h= 58.6 h

Time required for seeding

field coverage time= 54 h (System 1)

grain fill-up time

volume of tank= 6526 L

density of barley= 0.62 kg/L

capacity of tank= 6526 L * 0.62 kg/L= 4046 kg

seeding rate= 90 kg/ha

area covered per tank= 4046 kg/(90 kg/ha)= 45 ha

capacity of 18 cm auger in barley=

35500 kg/h (Appendix 3)

time to fill 1 tank

4046 kg/tank * (1 h/35500 kg)= 0.114 h

0.114 h + 0.166 h (set up)= 0.28 h/tank

number of tanks required

325 ha/(45 ha/tank)= 8 tanks

total fill-up time= 0.28 h/tank * 8 tanks= 2.3 h

Total time required for seeding= 54 h + 2.3 h= 56.3 h

Time required for harrow-packing= 24 h (System 2B)

Total system time

Fall 58.6 h

Spring 80.3 h

Total 139 h

Yearly machinery costs ($) for System 4A (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	139	1554	2832	4386
Cultivator	115	1096	759	1855
Mounted harrows	115	200	42	242
Air seeder	115	2931	1240	4171
Harrow-packer	24	578	115	693
Total		6359	4988	11,347

SYSTEM 4B. LIQUID N & P DEEP BANDED IN THE FALL

Fall cultivation-banding

field coverage time= 54 h

fill-up time

applying N & P blend of 28-0-0 and 10-15-0

amount of 10-15-0 fertilizer required

13 kg of P/ha * (1 kg fert/0.15 kg of P)=

87 kg/ha

amount of N in 87 kg of 10-15-0= 87 * 0.10= 8.7 kg

amount of 28-0-0 fertilizer required

65 kg/ha - 8.7 kg/ha= 56.3 kg/ha

56.3 kg of N/ha * (1 kg fert/0.28 kg of N)=

201 kg/ha

total amount of blend required= 201 + 87= 288 kg/ha

density of fertilizer blend

(201 kg * (1.28 kg/L)) + (87 kg * (1.42 kg/L))/288

=1.32 kg/L

volume of nurse tank= 5680 L

capacity of nurse tank= 5680 L * 1.32 kg/L= 7500 kg

area covered per tank= 7500 kg/(288 kg/ha)= 26 ha

number of tanks required

325 ha/(26 ha/tank)= 13 tanks

capacity of nurse tank pump= 12000 L/h

time required to fill nurse tank

5680 L/(12000 L/h)= 0.473 h + 0.166 h (set up)

= 0.639 h/tank

total fill-up time= 13 tanks * 0.639 h/tank= 8.3 h

Total time required for fall cultivation-NP banding

54 h + 8.3 h= 62.3 h

Spring cultivation

time required= 54 h

Seeding

field coverage time= 44.8 h (System 1)

fill-up time

seed= 0.089 h/drill (System 1)

setup= 0.15 h/drill (no fertilizer to handle)

number of fill-ups required= 22 (System 1)

total fill-up time= 22 * (0.089 + 0.15)= 5.3 h

Total seeding time= 44.8 h + 5.3 h= 50.1 h

Total time required for System 4B

Fall	62.3 h
Spring	104.1 h
Total	166.4 h

Yearly machinery costs ($) for System 4B

((Andruchow 1982) and Appendix 5)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	166.4	1861	3391	5252
Cultivator	116.3	1108	767	1875
Mounted harrows	116.3	202	42	244
Liquid kit	62.3	1495	748	2243
Seed drill	50.1	1954	815	2769
Total		6620	5763	12,383

SYSTEM 5A. GRANULAR N & P DEEP BANDED IN THE SPRING

Fall cultivation

time required= 54 h (System 1)

Spring cultivation-NP banding

time required= 58.6 h

(System 4, fall cultivation-banding)

Seeding

time required= 56.3 h (System 4)

Harrow-packing

time required= 24 h (System 2B)

Total system time

Fall 54 h

Spring 139 h

Total 193 h

Yearly machinery costs ($) for System 5A (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	193	2159	3932	6091
Cultivator	169	1610	1114	2724
Mounted harrows	169	294	61	355
Air seeder	115	2931	1240	4171
Harrow-packer	24	578	115	693
Total		7572	6462	14,034

SYSTEM 5B. LIQUID N & P DEEP BANDED IN THE SPRING

Fall cultivation

time required= 54 h (System 1)

Spring cultivation-banding

time required= 62.3 h (System 4B, fall cultivation-band)

Seeding

time required= 50.1 h (System 1)

Total time required for System 5B

Fall	54 h
Spring	112.4 h
Total	166.4 h

Yearly machinery costs for System 5B= $12,383

(same as System 4B)

SYSTEM 6. N BROADCAST IN THE FALL, P IN-ROW IN THE SPRING

Fall broadcasting

time required= 27.7 h (System 1)

Fall cultivation

time required= 54 h (System 1)

Spring cultivation

time required= 54 h (System 1)

Seeding

time required= 52.5 h (System 1)

Time required for System 6

Fall 81.7 h

Spring 106.5 h

Total 188.2 h

Yearly machinery costs for System 6= $11,184

(same as System 1)

SYSTEM 7. N & P BROADCAST IN THE FALL

Fall broadcasting

field coverage time = 24 h (System 1)

fill-up time

amount of fertilizer blend to be applied

189 kg/ha (same as System 4)

189 kg/ha * 325 ha= 61425 kg

number of loads to be applied

61425 kg/(4000 kg/load)= 16 loads

time required to fill one load= 0.332 h (System 1)

total fill-up time= 16 loads * 0.332 h/load= 5.3 h

Total broadcasting time= 24 h + 5.3 h= 29.3 h

Fall cultivation

time required= 54 h (System 1)

Spring cultivation

time required= 54 h (System 1)

Seeding

field coverage time= 44.8 h (System 1)

fill-up time

seed= 0.089 h/drill (System 1)

set up= 0.15 h/drill (no fertilizer to handle)

number of fill-ups required= 22 (System 1)

total fill-up time= 22 * (0.089+0.15)= 5.3 h

Total seeding time= 44.8 h + 5.3 h= 50.1 h

Time required for System 7

Fall	83.3 h
Spring	104.1 h
Total	187.4 h

Yearly machinery costs ($) for System 7 (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	187.4	2096	3818	5914
Cultivator	108	1029	712	1741
Mounted harrows	108	188	39	227
Broadcaster	29.3	265	131	396
Seed drill	50.1	1954	815	2769
Total		5532	5515	11,047

SYSTEM 8. N & P BROADCAST IN THE SPRING

Fall cultivation

time required= 54 h (System1)

Spring broadcasting

time required= 29.3 h (System 7)

Spring cultivation

time required= 54 h (System 1)

Seeding

time required= 50.1 h (System 7)

Time required for System 8

Fall	54	h
Spring	133.4	h
Total	187.4	h

Yearly machinery costs for System 8= $11,047 (System 7)

Since System 8 involves the same amount of time spent in the field and uses the same equipment as System 7, the machinery costs are also the same.

SYSTEM 9. N & P SIDEBANDED IN THE SPRING

Fall cultivation

time required= 54 h (System 1)

Spring cultivation

time required= 54 h (System 1)

Seeding-banding

field coverage time

C= (S W E)/10

S= 8 km/h

W= 11.2 m

E= 0.825

C= (8*11.2*0.825)/10= 7.4 ha/h

field coverage time= 325 ha/(7.4 ha/h)= 43.9 h

fill-up time

capacity of drill= 1083 kg of seed and 1804 kg of fertilizer

require 90 kg/ha of seed and 189 kg/ha of fertilizer blend

Therefore, fertilizer is the limiting factor.

area covered by one drill= 1804 kg/(189 kg/ha)= 9.5 ha

amount of fertilizer required per drill= 1804 kg

capacity of drill fill in fertilizer= 9500 kg/h

time required to fill drill with fertilizer

1804 kg/(9500 kg/h)= 0.19 h

amount of grain required per drill

90 kg/ha * 9.5 ha= 855 kg

capacity of drill fill in grain= 15600 kg/h

(Appendix 3)

time required to fill drill with grain

855 kg/(15600 kg/h)= 0.055 h

set up time required= 0.166 h/drill

number of fill-ups required

325 ha/(9.5 ha/fill-up)= 35

total time for fill-ups= 35 * (0.19+0.055+0.166)h= 14.4 h

Total seeding time= 43.9 h + 14.4 h= 58.3 h

Harrow-packing time= 24 h (System 2B)

Time required for System 9

Fall 54 h

Spring 136.3 h

Total 190.3 h

Yearly machinery costs ($) for System 9 (Andruchow 1982)

Machine	Hours of Use	Fixed Cost	Variable Cost	Total Cost
Tractor	190.3	2128	3878	6006
Cultivator	108	1029	712	1741
Mounted harrows	108	188	39	227
Harrow-packer	24	578	115	693
Seed drill	58.3	2025	835	2860
Total		5948	5579	11,527

The cost of the end wheel seed drill was adjusted upwards by 19% from the table value to allow for the cost of the second set of openers required for sidebanding. The cost of the sidebanding openers was obtained by telephone conversation with an IHC sales representative in Edmonton, Alberta.

APPENDIX 7. CALCULATION OF TOTAL COSTS AND NET REVENUE

SYSTEM 1. N BROADCAST IN THE SPRING, P IN-ROW IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 100

Grain yield= 1.35 t/ha + 1.85 t/ha(1.00)= 3.2 t/ha

Production= 3.2 t/ha * 325 ha= 1040 t

Gross revenue= 1040 t * $125/t= $130,000

Fertilizer cost (spring purchased)

(65 kg of N/ha * $.63/kg of N) +

(13 kg of P/ha * $1.43/kg of P)=

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Fertilizer cost (fall purchased)

(65 kg of N/ha * $.57/kg of N) +

(13 kg of P/ha * $1.32/kg of P)=

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,184

Labour cost= 188.2 h * $10/h= $1,882

Total costs (spring purchased fertilizer)= $33,626

Total costs (fall purchased fertilizer)= $33,327

Net revenue (spring purchased fertilizer)

$130,000 - $33,626= $96,374

Net revenue (fall purchased fertilizer)

$130,000 - $33,327= $96,673

Medium Soil Moisture

Calculations for the medium soil moisture condition are assumed to be the same as for the low soil moisture condition because the same fertilizer effectiveness rating is used.

High Soil Moisture

Calculations for the high soil moisture condition are assumed to be the same as for the low soil moisture condition because the same fertilizer effectiveness rating is used.

SYSTEM 2A. N BANDED IN THE SPRING WITH AMMONIA LIQUIFYING UNIT, P IN-ROW IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (spring purchased)

(60 kg of N/ha * $.55/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P/ha * $1.43/kg of P)=

$54.74/ha * 325 ha= $17,791

Interest cost on spring purchased fertilizer

$17,791 * 0.15 * (5/12)= $1,112

Fertilizer cost (fall purchased P, N must be purchased in the spring as the farmer cannot store it)

(60 kg of N/ha * $.55/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P/ha * $1.32/kg of P)=

$53.01/ha * 325 ha= $17,228

Interest cost on spring purchased N, fall purchased P

($10,725 * 0.15 * (5/12)) + ($6,503 * 0.15)= $1,646

Machinery cost= $10,345

Labour cost= 163 h * $10/h= $1,630

Total costs (spring purchased fertilizer)= $30,878

Total costs (fall purchased P, spring purchased N)= $30,849

Net revenue (spring purchased fertilizer)

$141,375 - $30,878= $110,497

Net revenue (fall purchased P, spring purchased N)

$141,375 - $30,849= $110,526

Medium Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(1.10)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Total costs (spring purchased fertilizer)= $30,878

(same as for Low Soil Moisture)

Total costs (fall purchased P, spring purchased N)= $30,849

(same as for Low Soil Moisture)

Net revenue (spring purchased fertilizer)

$137,500 - $30,878= $106,622

Net revenue (fall purchased P, spring purchased N)

$137,500 - $30,849= $106,651

High Soil Moisture

The fertilizer effectiveness rating for high soil moisture is the same as for medium soil moisture. Therefore the cost and revenue calculations are the same as well.

SYSTEM 2B. N BANDED IN THE SPRING WITH AIR SEEDER, P IN-ROW IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (spring purchased fertilizer)

(65 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Fertilizer cost (fall purchased fertilizer)

(65 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $14,293

Labour cost= 196 h * $10/h= $1,960

Total costs (spring purchased fertilizer)= $36,813

Total costs (fall purchased fertilizer)= $36,514

Net revenue (spring purchased fertilizer)

$141,375 - $36,813= $104,562

Net revenue (fall purchased fertilizer)

$141,375 - $36,514= $104,861

Medium Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(1.10)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (spring purchased fertilizer)

(65 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Fertilizer cost (fall purchased fertilizer)

(65 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $14,293

Labour cost= 196 h * $10/h= $1,960

Total costs (spring purchased fertilizer)= $36,813

Total costs (fall purchased fertilizer)= $36,514

Net revenue (spring purchased fertilizer)

$137,500 - $36,813= $100,687

Net revenue (fall purchased fertilizer)

$137,500 - $36,514= $100,986

High Soil Moisture

The fertilizer effectiveness rating for high soil moisture is the same as medium soil moisture. Therefore, the revenue and cost calculations are the same as for medium soil moisture.

SYSTEM 3A. N BANDED IN THE FALL WITH AMMONIA LIQUIFYING UNIT, P IN-ROW IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * \$125/t= \$141,375

Fertilizer cost (fall purchased N, spring purchased P)

(60 kg of N/ha * \$.50/kg of N) +

(5 kg of N/ha * \$.63/kg of N) +

(13 kg of P * \$1.43/kg of P)= \$51.74/ha

\$51.74/ha * 325 ha= \$16,816

Interest cost on fall purchased N, spring purchased P

(\$9,750 * 0.15) + (\$7,066 * 0.15 * (5/12))= \$1,904

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * \$.50/kg of N) +

(5 kg of N/ha * \$.57/kg of N) +

(13 kg of P * \$1.32/kg of P)= \$50.01/ha

\$50.01/ha * 325 ha= \$16,253

Interest cost on fall purchased fertilizer

\$16,253 * 0.15= \$2,438

Machinery cost= \$10,345

Labour cost= 163 h * \$10/h= \$1,630

Total costs (spring purchased fertilizer)= \$30,695

Total costs (fall purchased fertilizer)= \$30,666

Net revenue (spring purchased fertilizer)

\$141,375 - \$30,695= \$110,680

Net revenue (fall purchased fertilizer)

\$141,375 - \$30,666= \$110,709

Medium Soil Moisture

Fertilizer effectiveness rating= 95

Grain yield= 1.35 t/ha + 1.85 t/ha(0.95)= 3.108 t/ha

Production= 3.108 t/ha * 325 ha= 1010 t

Gross revenue= 1010 t * $125/t= $126,250

Fertilizer cost (fall purchased N, spring purchased P)

(60 kg of N/ha * $.50/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $51.74/ha

$51.74/ha * 325 ha= $16,816

Interest cost on fall purchased N, spring purchased P

($9,750 * 0.15) + ($7,066 * 0.15 * (5/12))= $1,904

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.50/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $50.01/ha

$50.01/ha * 325 ha= $16,253

Interest cost on fall purchased fertilizer

$16,253 * 0.15= $2,438

Machinery cost= $10,345

Labour cost= 163 h * $10/h= $1,630

Total costs (spring purchased fertilizer)= $30,695

Total costs (fall purchased fertilizer)= $30,666

Net revenue (spring purchased fertilizer)

$126,250 - $30,695= $95,555

Net revenue (fall purchased fertilizer)

$126,250 - $30,666= $95,584

High Soil Moisture

Fertilizer effectiveness rating= 85

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 2.92 t/ha

Production= 2.92 t/ha * 325 ha= 949 t

Gross revenue= 949 t * $125/t= $118,625

Fertilizer cost (fall purchased N, spring purchased P)

(60 kg of N/ha * $.50/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $51.74/ha

$51.74/ha * 325 ha= $16,816

Interest cost on fall purchased N, spring purchased P

($9,750 * 0.15) + ($7,066 * 0.15 * (5/12))= $1,904

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.50/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $50.01/ha

$50.01/ha * 325 ha= $16,253

Interest cost on fall purchased fertilizer

$16,253 * 0.15= $2,438

Machinery cost= $10,345

Labour cost= 163 h * $10/h= $1,630

Total costs (spring purchased fertilizer)= $30,695

Total costs (fall purchased fertilizer)= $30,666

Net revenue (spring purchased fertilizer)

$118,625 - $30,695= $87,930

Net revenue (fall purchased fertilizer)

$118,625 - $30,666= $87,959

SYSTEM 3B. N BANDED IN THE FALL WITH AIR SEEDER, P IN-ROW IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (fall purchased N, spring purchased P)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $55.94/ha

$55.94/ha * 325 ha= $18,181

Interest cost on fall purchased N, spring purchased P

($11,115 * 0.15) + ($7,066 * 0.15 * (5/12))= $2,109

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,605

Labour cost= 142 h * $10/h= $1,420

Total costs (spring purchased fertilizer)= $33,315

Total costs (fall purchased fertilizer)= $33,286

Net revenue (spring purchased fertilizer)

$141,375 - $33,315= $108,060

Net revenue (fall purchased fertilizer)

$141,375 - $33,286= $108,089

Medium Soil Moisture

Fertilizer effectiveness rating= 95

Grain yield= 1.35 t/ha + 1.85 t/ha(0.95)= 3.108 t/ha

Production= 3.108 t/ha * 325 ha= 1010 t

Gross revenue= 1010 t * $125/t= $126,250

Fertilizer cost (fall purchased N, spring purchased P)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $55.94/ha

$55.94/ha * 325 ha= $18,181

Interest cost on fall purchased N, spring purchased P

($11,115 * 0.15) + ($7,066 * 0.15 * (5/12))= $2,109

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,605

Labour cost= 142 h * $10/h= $1,420

Total costs (spring purchased fertilizer)= $33,315

Total costs (fall purchased fertilizer)= $33,286

Net revenue (spring purchased fertilizer)

$126,250 - $33,315= $92,935

Net revenue (fall purchased fertilizer)

$126,250 - $33,286= $92,964

High Soil Moisture

Fertilizer effectiveness rating= 85

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 2.92 t/ha

Production= 2.92 t/ha * 325 ha= 949 t

Gross revenue= 949 t * $125/t= $118,625

Fertilizer cost (fall purchased N, spring purchased P)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $55.94/ha

$55.94/ha * 325 ha= $18,181

Interest cost on fall purchased N, spring purchased P

($11,115 * 0.15) + ($7,066 * 0.15 * (5/12))= $2,109

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,605

Labour cost= 142 h * $10/h= $1,420

Total costs (spring purchased fertilizer)= $33,315

Total costs (fall purchased fertilizer)= $33,286

Net revenue (spring purchased fertilizer)

$118,625 - $33,315= $85,310

Net revenue (fall purchased fertilizer)

$118,625 - $33,286= $85,339

SYSTEM 4A. GRANULAR N & P DEEP BANDED IN THE FALL

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,347

Labour cost= 139 h * $10/h= $1,390

Total costs= $32,998

Net revenue= $141,375 - $32,998= $108,377

Medium Soil Moisture

Fertilizer effectiveness rating= 95

Grain yield= 1.35 t/ha + 1.85 t/ha(0.95)= 3.108 t/ha

Production= 3.108 t/ha * 325 ha= 1010 t

Gross revenue= 1010 t * $125/t= $126,250

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,347

Labour cost= 139 h * $10/h= $1,390

Total costs= $32,998

Net revenue= $126,250 - $32,998= $93,252

High Soil Moisture

Fertilizer effectiveness rating= 85

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 2.92 t/ha

Production= 2.92 t/ha * 325 ha= 949 t

Gross revenue= 949 t * $125/t= $118,625

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,347

Labour cost= 139 h * $10/h= $1,390

Total costs= $32,998

Net revenue= $118,625 - $32,998= $85,627

SYSTEM 4B. LIQUID N & P DEEP BANDED IN THE FALL

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (fall purchased fertilizer)

(65 kg of N/ha * $.64/kg of N) +

(13 kg of P * $1.50/kg of P)= $61.10/ha

$61.10/ha * 325 ha= $19,858

Interest cost on fall purchased fertilizer

$19,858 * 0.15= $2,979

Machinery cost= $12,383

Labour cost= 168.8 h * $10/h= $1,688

Total costs= $36,908

Net revenue= $141,375 - $36,908= $104,467

Medium Soil Moisture

Fertilizer effectiveness rating= 95

Grain yield= 1.35 t/ha + 1.85 t/ha(0.95)= 3.108 t/ha

Production= 3.108 t/ha * 325 ha= 1010 t

Gross revenue= 1010 t * $125/t= $126,250

Fertilizer cost (fall purchased fertilizer)

(65 kg of N/ha * $.64/kg of N) +

(13 kg of P * $1.50/kg of P)= $61.10/ha

$61.10/ha * 325 ha= $19,858

Interest cost on fall purchased fertilizer

$19,858 * 0.15= $2,979

Machinery cost= $12,383

Labour cost= 168.8 h * $10/h= $1,688

Total costs= $36,908

Net revenue= $126,250 - $36,908= $89,342

High Soil Moisture

Fertilizer effectiveness rating= 85

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 2.92 t/ha

Production= 2.92 t/ha * 325 ha= 949 t

Gross revenue= 949 t * $125/t= $118,625

Fertilizer cost (fall purchased fertilizer)

(65 kg of N/ha * $.64/kg of N) +

(13 kg of P * $1.50/kg of P)= $61.10/ha

$61.10/ha * 325 ha= $19,858

Interest cost on fall purchased fertilizer

$19,858 * 0.15= $2,979

Machinery cost= $12,383

Labour cost= 168.8 h * $10/h= $1,688

Total costs= $36,908

Net revenue= $118,625 - $36,908= $81,717

SYSTEM 5A. GRANULAR N & P DEEP BANDED IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased fertilizer)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $14,034

Labour cost= 193 h * $10/h= $1,930

Total costs (spring purchased fertilizer)= $36,524

Total costs (fall purchased fertilizer)= $36,225

Net revenue (spring purchased fertilizer)

$141,375 - $36,524= $104,851

Net revenue (fall purchased fertilizer)

$141,375 - $36,225= $105,150

Medium Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(1.10)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased fertilizer)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $14,034

Labour cost= 193 h * $10/h= $1,930

Total costs (spring purchased fertilizer)= $36,524

Total costs (fall purchased fertilizer)= $36,225

Net revenue (spring purchased fertilizer)

$137,500 - $36,524= $100,976

Net revenue (fall purchased fertilizer)

$137,500 - $36,225= $101,275

High Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(1.10)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased fertilizer)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $14,034

Labour cost= 193 h * $10/h= $1,930

Total costs (spring purchased fertilizer)= $36,524

Total costs (fall purchased fertilizer)= $36,225

Net revenue (spring purchased fertilizer)

$137,500 - $36,524= $100,976

Net revenue (fall purchased fertilizer)

$137,500 - $36,225= $101,275

SYSTEM 5B. LIQUID N & P DEEP BANDED IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (spring purchased fertilizer)

(65 kg of N/ha * $.71/kg of N) +

(13 kg of P * $1.65/kg of P)= $67.60/ha

$67.60/ha * 325 ha= $21,970

Interest cost on spring purchased fertilizer

$21,970 * 0.15 * (5/12)= $1,373

Machinery cost= $12,383

Labour cost= 168.8 h * $10/h= $1,688

Total costs= $37,414

Net revenue

$141,375 - $37,414= $103,961

Medium Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(1.10)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (spring purchased fertilizer)

(65 kg of N/ha * $.71/kg of N) +

(13 kg of P * $1.65/kg of P)= $67.60/ha

$67.60/ha * 325 ha= $21,970

Interest cost on spring purchased fertilizer

$21,970 * 0.15 * (5/12)= $1,373

Machinery cost= $12,383

Labour cost= 168.8 h * $10/h= $1,688

Total costs= $37,414

Net revenue

$137,500 - $37,414= $100,086

High Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(1.10)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (spring purchased fertilizer)

(65 kg of N/ha * $.71/kg of N) +

(13 kg of P * $1.65/kg of P)= $67.60/ha

$67.60/ha * 325 ha= $21,970

Interest cost on spring purchased fertilizer

$21,970 * 0.15 * (5/12)= $1,373

Machinery cost= $12,383

Labour cost= 168.8 h * $10/h= $1,688

Total costs= $37,414

Net revenue

$137,500 - $37,414= $100,086

SYSTEM 6. N BROADCAST IN THE FALL, P IN-ROW IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 100

Grain yield= 1.35 t/ha + 1.85 t/ha(1.00)= 3.2 t/ha

Production= 3.2 t/ha * 325 ha= 1040 t

Gross revenue= 1040 t * $125/t= $130,000

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased P)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $55.94/ha

$55.94/ha * 325 ha= $18,181

Interest cost on fall purchased N, spring purchased P

($11,115 * 0.15) + ($7,066 * 0.15 * (5/12))= $2,109

Machinery cost= $11,184

Labour cost= 182.2 h * $10/h= $1,882

Total costs (spring purchased fertilizer)= $33,356

Total costs (fall purchased fertilizer)= $33,327

Net revenue (spring purchased fertilizer)

$130,000 - $33,356= $96,644

Net revenue (fall purchased fertilizer)

$130,000 - $33,327= $96,673

Medium Soil Moisture

Fertilizer effectiveness rating= 85

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 2.92 t/ha

Production= 2.92 t/ha * 325 ha= 949 t

Gross revenue= 949 t * $125/t= $118,625

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased P)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $55.94/ha

$55.94/ha * 325 ha= $18,181

Interest cost on fall purchased N, spring purchased P

($11,115 * 0.15) + ($7,066 * 0.15 * (5/12))= $2,109

Machinery cost= $11,184

Labour cost= 182.2 h * $10/h= $1,882

Total costs (spring purchased fertilizer)= $33,356

Total costs (fall purchased fertilizer)= $33,327

Net revenue (spring purchased fertilizer)

$118,625 - $33,356= $85,269

Net revenue (fall purchased fertilizer)

$118,625 - $33,327= $85,298

High Soil Moisture

Fertilizer effectiveness rating= 80

Grain yield= 1.35 t/ha + 1.85 t/ha(0.80)= 2.83 t/ha

Production= 2.83 t/ha * 325 ha= 920 t

Gross revenue= 920 t * $125/t= $115,000

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased P)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $55.94/ha

$55.94/ha * 325 ha= $18,181

Interest cost on fall purchased N, spring purchased P

($11,115 * 0.15) + ($7,066 * 0.15 * (5/12))= $2,109

Machinery cost= $11,184

Labour cost= 182.2 h * $10/h= $1,882

Total costs (spring purchased fertilizer)= $33,356

Total costs (fall purchased fertilizer)= $33,327

Net revenue (spring purchased fertilizer)

$115,000 - $33,356= $81,644

Net revenue (fall purchased fertilizer)

$115,000 - $33,327= $81,673

SYSTEM 7. N & P BROADCAST IN THE FALL

Low Soil Moisture

Fertilizer effectiveness rating= 66

Grain yield= 1.35 t/ha + 1.85 t/ha(0.66)= 2.57 t/ha

Production= 2.57 t/ha * 325 ha= 835 t

Gross revenue= 835 t * $125/t= $104,375

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,047

Labour cost= 187.4 h * $10/h= $1,874

Total costs= $33,182

Net revenue= $104,375 - $33,182= $71,193

Medium Soil Moisture

Fertilizer effectiveness rating= 56

Grain yield= 1.35 t/ha + 1.85 t/ha(0.56)= 2.386 t/ha

Production= 2.386 t/ha * 325 ha= 775 t

Gross revenue= 775 t * $125/t= $96,875

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,047

Labour cost= 187.4 h * $10/h= $1,874

Total costs= $33,182

Net revenue= $96,875 - $33,182= $63,693

High Soil Moisture

Fertilizer effectiveness rating= 53

Grain yield= 1.35 t/ha + 1.85 t/ha(0.53)= 2.33 t/ha

Production= 2.33 t/ha * 325 ha= 757 t

Gross revenue= 757 t * $125/t= $94,625

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Machinery cost= $11,047

Labour cost= 187.4 h * $10/h= $1,874

Total costs= $33,182

Net revenue= $94,625 - $33,182= $61,443

SYSTEM 8. N & P BROADCAST IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 66

Grain yield= 1.35 t/ha + 1.85 t/ha(0.66)= 2.571 t/ha

Production= 2.571 t/ha * 325 ha= 836 t

Gross revenue= 836 t * $125/t= $104,500

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased P)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $11,047

Labour cost= 187.4 h * $10/h= $1,874

Total costs (spring purchased fertilizer)= $33,481

Total costs (fall purchased fertilizer)= $33,182

Net revenue (spring purchased fertilizer)

$104,500 - $33,481= $71,019

Net revenue (fall purchased fertilizer)

$104,500 - $33,182= $71,318

Medium Soil Moisture

The fertilizer effectiveness rating for medium soil moisture is the same as for low soil moisture. Therefore, the revenue and cost figures are the same as for low soil moisture.

High Soil Moisture

The fertilizer effectiveness rating for high soil moisture is the same as for low soil moisture. Therefore, the revenue and cost figures are the same as for low soil moisture.

SYSTEM 9. N & P SIDEBANDED IN THE SPRING

Low Soil Moisture

Fertilizer effectiveness rating= 115

Grain yield= 1.35 t/ha + 1.85 t/ha(1.15)= 3.48 t/ha

Production= 3.48 t/ha * 325 ha= 1131 t

Gross revenue= 1131 t * $125/t= $141,375

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased fertilizer)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $11,527

Labour cost= 190.3 h * $10/h= $1,903

Total costs (spring purchased fertilizer)= $33,990

Total costs (fall purchased fertilizer)= $33,691

Net revenue (spring purchased fertilizer)

$141,375 - $33,990= $107,385

Net revenue (fall purchased fertilizer)

$141,375 - $33,691= $107 684

Medium Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased fertilizer)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $11,527

Labour cost= 190.3 h * $10/h= $1,903

Total costs (spring purchased fertilizer)= $33,990

Total costs (fall purchased fertilizer)= $33,691

Net revenue (spring purchased fertilizer)

$137,500 - $33,990= $103,510

Net revenue (fall purchased fertilizer)

$137,500 - $33,691= $103,809

High Soil Moisture

Fertilizer effectiveness rating= 110

Grain yield= 1.35 t/ha + 1.85 t/ha(0.85)= 3.385 t/ha

Production= 3.385 t/ha * 325 ha= 1100 t

Gross revenue= 1100 t * $125/t= $137,500

Fertilizer cost (fall purchased fertilizer)

(60 kg of N/ha * $.57/kg of N) +

(5 kg of N/ha * $.57/kg of N) +

(13 kg of P * $1.32/kg of P)= $54.21/ha

$54.21/ha * 325 ha= $17,618

Interest cost on fall purchased fertilizer

$17,618 * 0.15= $2,643

Fertilizer cost (spring purchased fertilizer)

(60 kg of N/ha * $.63/kg of N) +

(5 kg of N/ha * $.63/kg of N) +

(13 kg of P * $1.43/kg of P)= $59.54/ha

$59.54/ha * 325 ha= $19,351

Interest cost on spring purchased fertilizer

$19,351 * 0.15 * (5/12)= $1,209

Machinery cost= $11,527

Labour cost= 190.3 h * $10/h= $1,903

Total costs (spring purchased fertilizer)= $33,990

Total costs (fall purchased fertilizer)= $33,691

Net revenue (spring purchased fertilizer)

$137,500 - $33,990= $103,510

Net revenue (fall purchased fertilizer)

$137,500 - $33,691= $103,809