ECONOMIC AND AGRONOMIC EFFECTS OF HIGH IRRIGATION LEVELS ON ALFALFA AND BARLEY

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Chapter 1

INTRODUCTION

1.1 Justification and Background for the Study

Irrigation has long been a means of increasing crop production on land otherwise deemed underproductive. This is the case in many arid portions of the western United States. However, what many irrigators might consider adequate water application could be incorrectly estimated. The problems associated with inefficient application techniques of irrigation water can often be easily identified and corrected with additional water. Overirrigation, on the other hand, is often difficult to detect as the effects are not as easily identified and quantified by the grower.

The fact that agriculture is the major consumptive use of the water resources of Wyoming (Wyoming State Engineers Office, 1973) and the United States (Murray & Reeves, 1972) suggests that improving irrigation application techniques could benefit people in agriculture as well as society in general. If irrigators employed more efficient practices, some of the water presently diverted by agriculture for surface irrigation would be available for other uses, including additional irrigation development. However, it should be pointed out that poor irrigation efficiency does not imply that the excess water is lost. In fact, much of this water is returned to some water course for reuse, but it is likely to be lower in quality.

Improving irrigation efficiency implies irrigation scheduling, which would improve the timing and amounts of water applications. Jensen (1972) stated that little change has occurred in irrigation scheduling practices in the western United States during the 25 years previous to the early 1960's. The two major reasons for lack of change were: "(1) The needs of managers of irrigated farms and the acceptability of suggested scheduling procedures have not been adequately evaluated; (2) the cost of irrigation water often has not been significant, and (3) indirect costs such as yield reductions caused by delayed irrigations and additional nitrogen requirements created by excessive water application are not easily recognized or quantified. Also, crop and soil damage costs encountered on lower-lying areas by excessive water use on upper areas are not always borne by the upper area irrigators".

Given the low cost of water relative to labor and capital, it appears that irrigators substitute water for other resources. The problem then is to determine whether or not present water applications result in significant economic losses to the irrigators. Economic losses to individual farmers associated with improper water applications could arise from:

(1) Reduced production due to high water tables where sufficient natural or artificial drainage does not exist. High water tables may reduce yields due to salt buildups in the root zone, retardation of soil warming in the spring, poor aeration in the root zone, and a reduction of plant persistence in the perennials;
(2) Increased herbicide costs resulting from weed invasions;
(3) Reduced production due to leaching of soil nutrients and increased expenditures for fertilizer used to offset soil nutrient leaching;
(4) Increased costs for drainage when adequate natural drainage does not exist.

If these losses occur, the question is: would reduction of these losses through improved irrigation efficiency and drainage offset costs of the improvements?

Preliminary work by the U.S. Bureau of Reclamation, Riverton Project, Wyo., has provided evidence that some of the excessive water application losses discussed previously do in fact occur. Seeped lands on parts of the project indicate rising water tables. Higher levels of nitrates and total dissolved solids (TDS) in drain water compared to levels in the applied water imply soil nutrient leaching. Bureau personnel have monitored alfalfa fields on the Riverton Project, where as much as 3.35 ha-m (11 acre-feet) of water were applied during the growing season. Alfalfa, a high water-using crop, requires .6 ha-m (2 acre-feet per acre) during a normal year (Trelease et al., 1970).

Ineffficient use of irrigation water resulting in high delivery requirements does not seem to be an isolated problem. Irrigation deliveries along the Big Horn River in north-central Wyoming range from 1.0 to 2.1 ha-m (Clark, 1972). Houk (1951) reported irrigation efficiencies for major farm crops in the western U.S. ranging from 20 to 50%. The U.S. Department of Agriculture (1960) reported an average farm irrigation efficiency for the western United States of 47%, with 70 to 75% farm efficiency attainable. The U.S. Bureau of Reclamation, Region 6 (1972), reported results of specific studies on the Midvale Project near Riverton, Wyo., where farm irrigation efficiencies ranged from 13.4 to 69.7% with an average of 24.3%. Water management studies by the U.S. Bureau of Reclamation, Region 7 (1972), on parts of the Bostwick Irrigation District No. 2, Kansas, found farm irrigation efficiencies ranging from 22 to 50% with an average of 41.6%.

The data within this report help identify the economic losses which may occur with overirrigation. In addition, insights into potential improvements in irrigation scheduling are discussed.

1.2 Objectives of the Study

The main objective was to determine if the apparent substitution of water for labor and capital, by irrigators which results in high irrigation delivery requirements is economically sound. The specific objectives were to:

(1) Estimate the effects of excessive water application on irrigation efficiency, yields, and quality of feed barley, malt barley, and alfalfa.

(2) Estimate the effects of continual overirrigation on alfalfa persistence.

(3) Measure nutrient loss that may occur when excess amounts of water are applied. Fertilizer needs, in turn, will be related to nutrient losses.

(4) Develop a drainage model to identify an optimum drainage system for alternative levels of irrigation.

(5) Analyze the impact of alternative irrigation levels on returns to management and land.

Chapter 2

SUMMARY AND RECOMMENDATIONS

2.1 Summary of Agronomic Field Studies

Irrigation is a prerequisite to a large fraction of agriculture in Wyoming and the other western states. As the demand for water has increased with the expansion of irrigated lands the thrust has been to provide more water with little emphasis on improved irrigation efficiency. The losses a farmer may incur due to overirrigation often are not recognized because they are hard to quantify and evaluate. These losses may include reduced crop yields and quality, excessive nutrient leaching, and nonproductive land due to seep areas. The objectives of this study are aimed at determining what economic losses may occur to farmers who overirrigate. The majority of previous irrigation studies have dealt with the effects of limited water rather than excess irrigation levels. Also, the majority of irrigation research has been conducted over a relatively short period of time and on land where a water table within the root zone does not exist even though a high water table is a common occurrence on irrigated land.

The Irrigation Management Service (IMS) computer program of the U.S. Bureau of Reclamation (USBR) was used to determine when to irrigate according to the five water levels (water treatments) used on alfalfa, feed barley, and malt barley. Treatment 2 was irrigated with quantities of water sufficient to bring the soil to field capacity (FC) from 50% of available moisture (AM). Treatments 4 and 5 were irrigated at 50% AM with twice and four times the quantity of water required to bring the soil to FC, respectively. The water application for level 2 approximated that water currently recommended to users of the IMS program. Levels 4 and 5 were designed to represent rates of water application in excess of what the soil could store and the plant use. Levels 1 and 3 were irrigated to FC when 90 and 10%, respectively, of the available moisture was depleted.

Yield data indicated that plots receiving irrigation practice #1 (which received the lowest quantity of water and least number of irrigations) obtained the highest average yields for the three crops studied. The yield of alfalfa was significantly reduced by application of water levels greater than that required to return the soil to FC. The highest irrigation level (5) yielded 2 metric tons per hectare (mt/ha) less than level 1 over the 3-year study and 1½ mt/ha less than level 2, which was considered the check treatment. The additional water applied to level 5 also significantly reduced its yield when compared to level 4 even though both levels received water in excess of FC. Plots of water level 1, which were not irrigated the third growing season, obtained a significant portion of their water requirement from the water table.

The alternative irrigation levels had no significant effect on the "in vitro" dry matter digestibility (IVDMD) and protein content of the alfalfa forage. The phosphorus (P) content of the forage was reduced by the two driest irrigation levels and the alfalfa would require P supplementation when fed to some classes of livestock.

The responses of feed and malt barley to irrigation levels were similar to that of alfalfa. The yield of feed barley for the highest irrigation level (5) was reduced 18% when compared to the driest treatment (1). The protein content was also reduced by the highest level of irrigation. The protein content of all treatments could be considered low for a feed barley; however, this is apparently a characteristic of the variety 'Steptoe' which was used in this study. The IVDMD of feed barley was significantly greater for the higher levels of water application. The differences in digestibility were not sufficient to offset the detrimental reduction in yield and protein content obtained from the higher water levels.

The average yield of malt barley for the 2-year study was reduced 22% by irrigation level 5 when compared to irrigation level 1. The malting quality was not affected by irrigation treatment.

The migration of nutrients from the root zone and into the water table was substantial with the high irrigation treatments. The two most significant observations were the movement of P toward the water table with overirrigation during the 3-year alfalfa study and the rapid movement of NO_3-N from the barley root zone with the high irrigation levels. The treatment in which the barley was irrigated to FC when only 10% of the available moisture was depleted (level 3) also resulted in a significant loss of NO_3-N.

The Campbell J-14 press and the pressure bomb technique were compared to evaluate the Campbell press as a method of predicting irrigation needs by measuring the plant water status. In this study, the press did not show the ability to separate plants according to the soil moisture level and therefore would not have been an effective tool for irrigation scheduling of alfalfa. It was observed that alfalfa plants with small leaves had a better plant water status than large-leaved plants when the soil was at 45% available moisture.

2.2 Summary of Economic Analysis

The objective of the economic portion of this study was to determine the returns to management and land for each of the five alternative irrigation levels. The yield data used in making the above calculations were obtained from plot studies conducted on the Midvale Irrigation District near Riverton, Wyo. An economic analysis of the plot yield data showed that irrigation practice #1 (level 1) provided the largest return to management and land. These results suggest that irrigators in the Midvale Irrigation District could reduce the quantity of water used and increase crop yields.

The low irrigation water use efficiencies found in the Midvale Irrigation District indicate the need for improved irrigation water management. To attempt to improve the efficiency of irrigation water use, the USBR initiated the Irrigation Management Service program in the Midvale Irrigation District in 1971. This program is commonly referred to as "irrigation scheduling" and provides irrigators with information on when to irrigate and how much water to apply. The overall goals of the program are: (1) to improve irrigation efficiencies and thereby reduce water use, (2) to increase yield and crop quality, and (3) to reduce production costs and water loss.

A statistical analysis of the yield data from farm records for alfalfa, other hay, barley, pasture, corn silage, corn grain and oats, both with and without IMS irrigation scheduling, showed that yields were generally higher when a crop was under irrigation scheduling. Of the seven crops analyzed, alfalfa, barley, and pasture had yield increases that were significant at the 10% level. An economic analysis of the yield increase for alfalfa and barley during the 1972 to 1976 period indicated that the increased yield would more than pay for the cost of the irrigation scheduling service.

Assuming that the above results are true, it might be asked why more farmers have not adopted improved irrigation management practices. There appear to be two logical explanations. First, it is often very difficult to detect the effects of overirrigation, while the effects of underirrigation are readily observed. Therefore, applying a little extra water for added insurance seems like the appropriate thing to do. Second, the water charge system for irrigation water encourages or at least does not discourage the application of additional water. Traditionally, the charge for water has been so much per acre which entitled the irrigator to so many acre-feet of water. Under this charge system, there is no incentive for the irrigator to reduce his use of water. In fact, the irrigator is encouraged to a certain extent, to use the maximum amount of water for fear of losing part of the water rights. Furthermore, water cost has been so small relative to capital and labor that farmers have substituted water for capital and labor.

It appears that irrigators need to be informed of the economic and the physical advantages of improved irrigation water management practices. The above results suggest that improved irrigation water management would not only require less water for irrigation but would also increase returns to the irrigator. In addition to informing irrigators of the benefits of improved irrigation water management, an appropriate water charge system would provide an incentive for improving irrigation efficiencies.

2.3 Summary of Drainage Analysis

Historic evidence supports the contention that drainage problems usually develop as a consequence of irrigation (Hagen et al., 1967). It has been estimated that one-half to two-thirds of all irrigated land has developed drainage problems. Israelsen and Hansen (1962) state that irrigation and drainage in arid regions are complementary practices with drainage being greatly influenced by low water application efficiencies, i.e., overirrigation. Drainage costs were estimated to be as high as $1038/ha/yr for irrigation level 5.

This study has demonstrated that severe overirrigation can cause drainage costs to be ten times greater than those expected under efficient irrigation practices. Failure to correct a drainage problem will soon require the land to be abandoned. Furthermore, with efficient irrigation practices, drainage systems on problem lands can be economically feasible, while with severe overirrigation the costs will be prohibitive.

2.4 Recommendations

These recommendations apply only to a field situation where a water table exists at approximately 18 decimeters (dm).

1. In formulating a computer program to predict the irrigation needs of an established, deep-rooted alfalfa stand, the consumption of water by the crop from the water table must be considered. The customary scheduling of irrigation of alfalfa, when 50% of the available moisture is depleted in the upper 6 dm of soil, may be too early for maximum irrigation efficiency, especially if a water table exists in the lower root zone.
2. In developing an irrigation schedule the detrimental effect of overirrigation on alfalfa and barley yields must be a primary concern.
3. An observation well should be installed in each field or at least each farm to monitor the water table so full advantage can be taken of the plant's ability to utilize water directly from the water table.
4. Irrigation districts should encourage users to meter water to each field so actual field application per irrigation can be measured.
5. Irrigation districts should encourage irrigation scheduling so those overirrigating will match actual application more closely with plant needs.
6. Limited irrigation of established alfalfa stands could possibly be used by producers to lower the water table and improve saline seep conditions if the water table is within the root zone.
7. When a producer increases irrigation efficiencies he may need to re-evaluate commercial fertilizer application rates and possibly reduce them.

8. The common recommendation of applying more water to malt than feed barley to improve malting quality was not supported by this study.
9. Further crop data and economic studies are needed on the long-range effects of irrigation scheduling.
10. Additional research regarding the impacts of irrigation scheduling on water quality is needed.

Chapter 3

WATER APPLICATION AND SOIL NUTRIENT LEVELS

3.1 Methodology for Field Data and Laboratory Analysis

The three crops used in this study were 'Thor' alfalfa, 'Steptoe' feed barley, and 'Moravian III' malt barley. The crops were grown under field conditions on the Midvale Irrigation Project at Riverton, Wyo., (Fig. 3.1). The soil series was a Lostwells sandy clay loam and the field had a slope of less than 3%. Alfalfa was established with barley as a companion crop in 1973 and data were collected in 1974, 1975, and 1976. Barley plots were planted April 13, 1975, and March 26, 1976.

3.1.1 Irrigation Rates

Five water levels for both alfalfa and barley were tested. The irrigation frequency and application rates were determined by the IMS computer program provided by the USBR at Riverton, Wyo. Soil moisture was determined in the upper 18 dm for alfalfa and from 3 to 9 dm for barley depending on its growth stage. The water level treatments were as follows:

1. 10% of available moisture (AM) remaining - irrigated to field capacity (FC)
2. 50% AM remaining - irrigated to FC
3. 90% AM remaining - irrigated to FC
4. 50% AM remaining - irrigated with two times the quantity of water required to attain FC
5. 50% AM remaining - irrigated with four times the quantity of water required to attain FC

Level 1 provided a drier irrigation level than that normally recommended for proper irrigation management. Level 2 was designed as a check, to simulate that used by the USBR in their IMS program. Level 3 required frequent irrigations of small quantities of water which kept the root profile near FC for the duration of the growing season. Treatments 4 and 5 represented the waterlogging effect that can occur intermittently as a result of high irrigation rates or as a consequence of irrigation closely followed by rainfall. The following is the water-holding capacity of the soil in the field plot area.

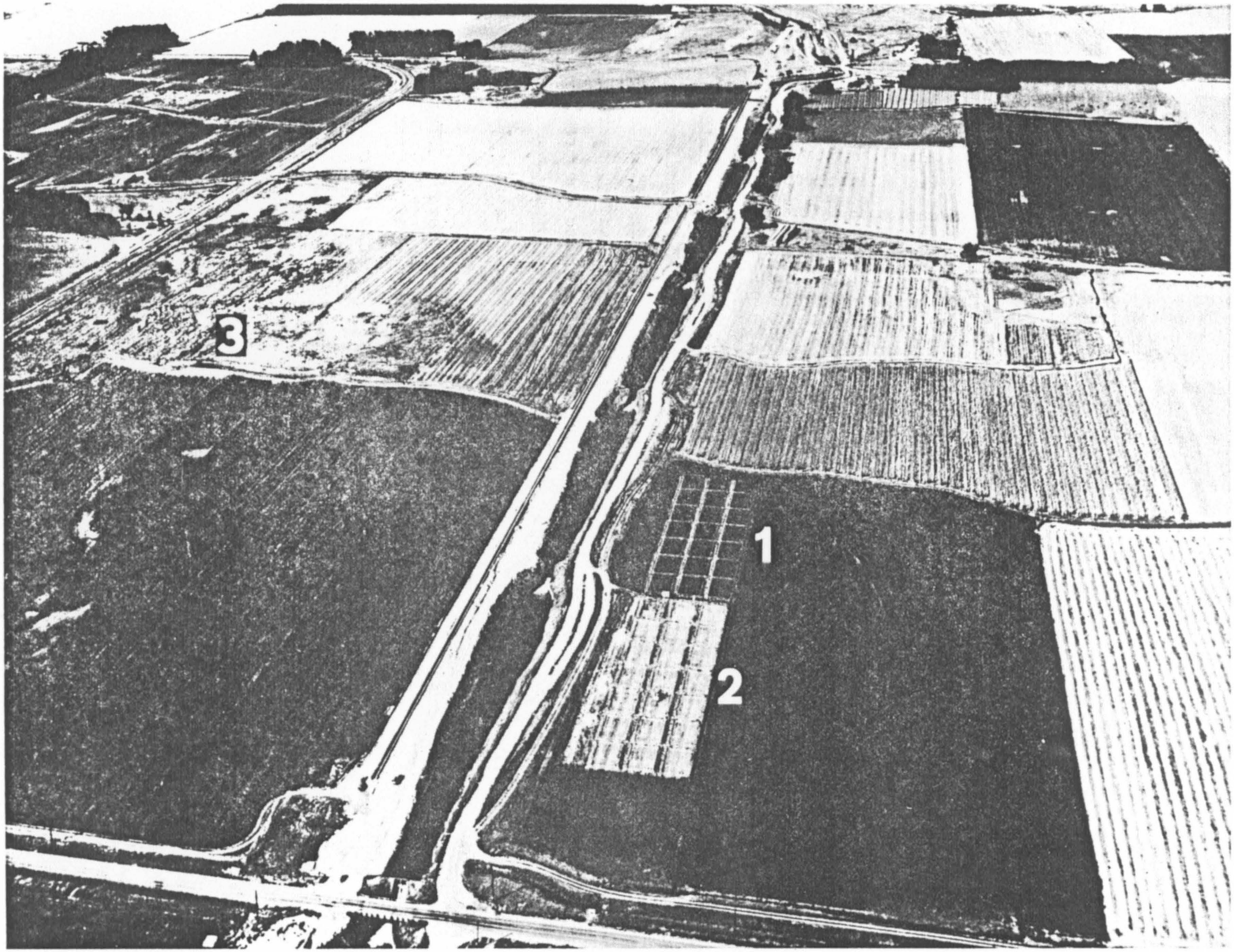


Fig. 3.1 Shown are the field plots. 1 = Alfalfa plots, 2= Barley plots, 3 = Wasteland due to excess water and saline seepage. Photo by USBR, Riverton.

Soil Depth (dm)		Water/3 dm Soil (cm)
0-3		5.1
3-6		4.1
6-9		3.8
9-12		3.8
12-15		3.8
15-18		3.8
	Total	24.4

Climatic and field data used in the IMS computer program were collected at the study site. Climatic measurements taken included daily minimum and maximum temperatures, relative humidity, pan evaporation (Epan), precipitation, wind, and solar energy. Monthly climatic data for the three growing seasons are shown in Table 3.1. The field data consisted of depth of root zone, soil water holding capacity, average root zone moisture and the crop coefficient, referring to the crop's stage of growth. Soil moisture was measured with a Troxler type Am-Be 100 μ Ci neutron probe. Gravimetric soil moisture samples were also determined periodically.

The IMS program estimated an expected evapotranspiration (ETP) for all plots, and the dates and rates of each required irrigation application. Equal amounts of water were applied to all barley and alfalfa treatments for the first application of 1974. From that point on, computer scheduling was maintained. The irrigation dates and average rates of water application for the alfalfa and barley are shown in Tables 3.2 and 3.3, respectively.

Plots were border diked to prevent runoff and irrigated with gated pipe. The plots were 9.1 x 15.2m with a 4m buffer zone between plots. Four replications in a randomized complete block design were used. The barley bordered plots were divided between the two varieties. All the soil moisture and soil nutrient samples were taken in the feed barley portion of the plots.

Table 3.1. Monthly climatic data at the field study site.

	April	May	June	July	August	Sept.	Total
				1974			
Max Temp (°C)	14	19	28	31	27	25	—
Min Temp (°C)	-1	3	8	12	18	2	—
Rain (cm)	2.51	1.47	.53	1.75	2.03	.86	9.15
Wind (km/day)	343	311	236	209	204	180	1483
Sun (Lang)	408	597	618	633	569	452	3277
Epan (cm)	—	19.45	31.72	33.53	28.09	17.35	130.14
				1975			
Max	9	16	22	30	28	24	—
Min	-4	3	5	11	8	4	—
Rain	2.16	7.44	3.96	1.09	.53	.38	15.57
Wind	184	198	193	120	154	134	983
Sun	462	490	600	627	563	517	3259
Epan	—	5.99	17.78	21.44	20.57	9.35	75.13
				1976			
Max	12	20	24	31	27		—
Min	0	3	5	10	7		—
Rain	2.21	4.06	4.24	4.80	2.31		17.62
Wind	258	188	196	134	163		939
Sun	463	522	625	619	494		2723
Epan	—	15.59	19.76	21.13	19.25		75.73

Table 3.2. Irrigation dates, water applied, and estimated deep percolation for the 3 year alfalfa study.

Water Level	Dates	Water applied (cm)	Estimated Deep Percolation (cm)
	1974		
1	5/15, 6/28, 8/02	61.1	0
2	5/16, 6/12, 6/28, 7/15, 8/02, 8/27	79.6	0
3	5/16, 5/22, 5/31, 6/07, 6/14, 6/28 7/05, 7/12, 7/19, 8/02, 8/12, 8/19 8/26, 8/30	85.8	.2
4	5/16, 6/12, 7/02, 7/18, 8/05, 8/30	155.1	69.8
5	5/18, 6/14, 7/02, 7/19, 8/05, 8/29	303.3	218
Rainfall*		9.2	
ET =	94.5 cm		
	1975		
1	7/21, 9/10	43.7	0
2	6/13, 7/10, 8/20, 9/08	55.4	0
3	6/06, 6/13, 6/24, 6/30, 7/03, 7/09 7/15, 7/22, 7/25, 7/29, 7/31, 8/05 8/15, 8/20, 8/25, 9/02, 9/10	76.7	7.2
4	6/13, 7/07, 7/11, 8/21	80.0	10.5
5	6/13, 7/10, 8/21	157.7	88.2
Rainfall*		15.3	
ET =	84.8 cm		
	1976		
1	—	0	0
2	6/15, 8/03	16.8	0
3	5/13, 5/21, 5/28, 6/08, 6/30, 7/12 7/17, 8/10, 8/18, 8/25	50.8	9.7
4	5/29, 6/15, 8/03	47.8	6.7
5	6/15, 8/03	89.9	48.8
Rainfall*		17.6	
ET =	58.7 cm		

*Rainfall during the growing season.

Table 3.3. Irrigation dates, water applied, and estimated deep percolation for the 2 year feed and malt barley study.

Water Level	Dates	Water applied (cm)	Estimated Deep Percolation
	1975		
1	6/24, 7/07	22.1	0
2	6/12, 6/24, 7/01, 7/10, 7/16	34.8	0
3	6/06, 6/12, 6/16, 6/24, 6/30 7/03, 7/07, 7/15, 7/23, 7/25	47.0	9.6
4	6/12, 6/24, 7/01, 7/10, 7/16	66.3	28.9
5	6/12, 6/24, 7/01, 7/10, 7/16	132.6	95.2
Rainfall*		12.8	
ET =	50.2 cm		
	1976		
1	6/08, 6/30	24.1	0
2	5/27, 6/18, 6/30	19.8	0
3	5/13, 5/16, 5/30, 6/08, 6/30, 7/06	33.0	1.6
4	5/30, 6/10, 6/30	36.6	5.2
5	5/27, 6/10, 6/30	72.6	41.2
Rainfall*		17.6	
ET =	49.0 cm		

*Rainfall during the growing season

3.1.2 Soil and Water Nutrient Levels

Soil samples in the alfalfa plots were collected at 3 dm intervals down to 15 dm at the beginning and to 18 dm at the end of the 3-year study. Samples were collected from the same area within a plot both years. Samples were analyzed for NO_3-N, P, and K by the Agricultural Consultants Laboratory, Brighton, Colo. At the end of the 1975 growing season, the barley plots were sampled to 15 dm for NO_3-N to evaluate differential N leaching for the five water levels. In 1976, the barley plots were sampled for NO_3-N on June 1, July 1, and August 1 to study the rate of nutrient leaching.

The irrigation water was periodically sampled for quality over the 3-year period. The water table was also periodically monitored for depth and water quality. Deep percolation was estimated as follows: TOTAL IRRIGATION WATER APPLIED + RAINFALL - EVAPOTRANSPIRATION = DEEP PERCOLATION.

3.1.3 Alfalfa Plant Water Status

Data were collected comparing the pressure bomb technique for evaluating plant water relations to the Campbell J-14 press method. The Campbell press was of interest as a potentially simple and practical means of using plant water stress to predict irrigation needs. Rhodes and Matsuda (1976) found that Campbell press measurements related to the relative water content of several species.

The effects of leaflet size and thickness on the water status of the plant were investigated. Plant tissues from plants grown under water levels 1 and 3 were used. The average available soil moisture at the time of sampling for water level 1 was as follows:

Soil Depth (dm)		Available Soil Moisture %
0-3		19
3-6		0
6-9		5
9-12		44
12-15		100
15-18		100
	Mean	45

The soil moisture for water level 3 was at FC. The top 30 cm of an alfalfa stem in the early bud to early bloom stage was used for the pressure bomb xylem pressure measurement. A leaf from the same plant located at the third node with an expanded leaf from the top of the plant was used for the Campbell press measurement. The press-petiole measurement was defined as the Campbell press pressure required for exudate to be forced from the petiole. The press-leaf measurement was defined as the pressure required to change the color of the leaf. All measurements were taken on clear days between 2:00 and 3:00 PM. Air temperature ranged from 30 to 33° C and the relative humidity from 45 to 60%. The leaf area of all leaves was measured with an AAM-5 area meter, leaves dried at 80° C, and average leaflet size and specific leaf weight (SLW) determined.

3.2 Results and Discussion of Water Application and Evapotranspiration

Water application rates (and number of irrigations) for alfalfa were considerably higher in 1974 than for the other 2 years. This was due to higher air temperatures and wind velocity and lower rainfall (Table 3.1). The water table (free water) increased from below 24 dm in 1975 to 15 dm in 1976. The capillary movement of water up to 6 to 9 dm from the soil surface resulted in a lower irrigation demand in 1976 than the other years for both alfalfa and barley (Tables 3.2 and 3.3). The alfalfa growing season was also shorter in 1976. The estimated deep percolation rates (Table 3.2) are lower than what actually occurred because a portion of the plant transpiration was water extracted from the water table rather than from applied water. This was especially true for the last 2 years of the alfalfa study as the root depth increased.

In 1976, the mean soil moisture in the upper 18 dm for alfalfa water level 1 was never depleted to 10%; therefore, it was not irrigated. The entire ET for this treatment came from precipitation and the water table. The available soil moisture in the upper 6 dm was very low most of the growing season. This forced the alfalfa to obtain soil nutrients and water from the lower root zones. The effect of this treatment on the alfalfa growth and quality will be discussed in Chapter 4.

3.3 Results and Discussion of the Effect of Irrigation Level on Soil Nutrients

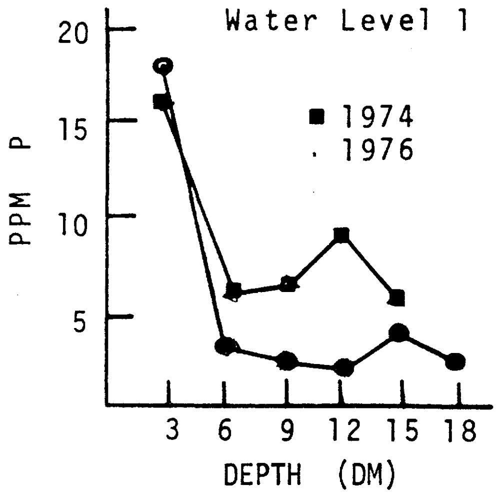
The level of N, P, and K in the plant root zone was determined to evaluate the effect of irrigation application frequency and rates on fertilizer requirements. The soil data also provided an indication of the quantity of nutrients that were leached from the root zone into the water table.

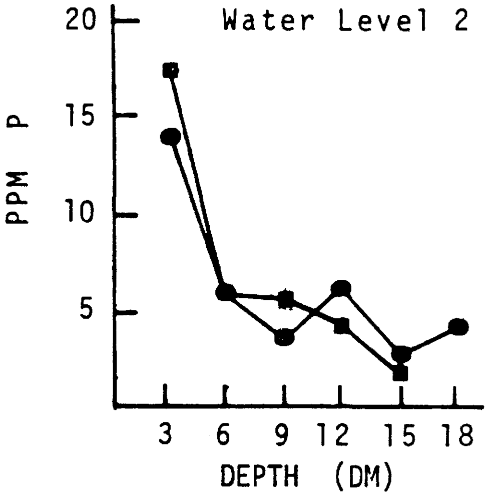
3.3.1 Alfalfa Soil Analyses

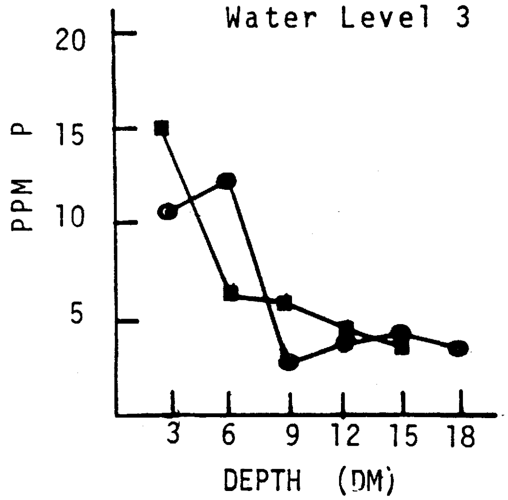
Soil P at the beginning of the field study and at the end of three growing seasons is shown in Fig. 3.2. Soil P for water level 1, which was the driest treatment, indicated that the alfalfa plant did not use a significant amount of P from the upper 3 dm. The lack of soil moisture in the upper 3 dm during most of the growing season for this water level was probably the reason for the P being taken up from the lower soil profiles. In the fall of 1973, 112 kg/ha of P was applied to the soil surface. This application of P and the slow breakdown of P to an available form explains why the P level was slightly higher at the 3 dm level for level 1 after 3 years than it was at the beginning of the study. Plants irrigated with level 2, which over the 3 years was irrigated more than twice as often as level 1, apparently removed the majority of the P from the upper 3 dm of soil.

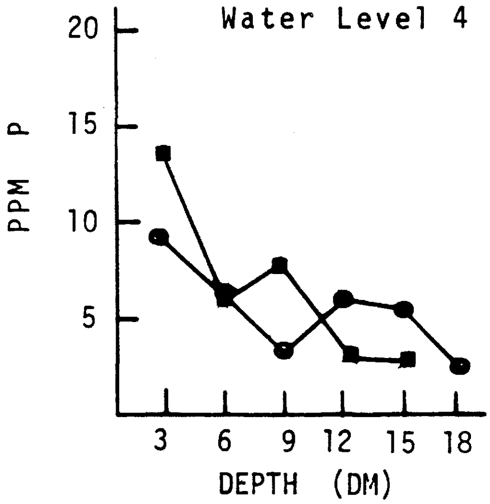
The P level after 3 years of water level 3 showed a significant decrease in the 0-3 dm soil zone and an increase in the 3-6 dm zone (Fig. 3.2). Water was applied 41 times during the three growing seasons for this water treatment. Therefore, the soil profile was near FC almost continually which would have allowed the plant to remove most of its P from the 0-3 dm zone. The increase in P at the 3-6 dm zone suggests P may have been leached from the upper soil zone.

Plants from water levels 4 and 5, which were irrigated with two and four times the quantity of water required to reach FC, respectively, apparently also used P from the upper soil profile. More significant was the migration of P from the upper soil zone to









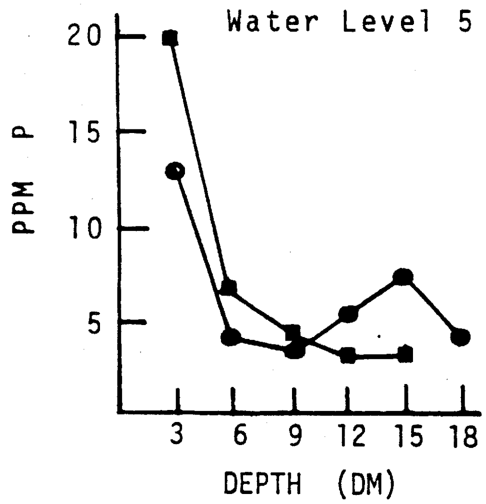


Fig. 3.2. Soil P at the beginning and after 3 alfalfa growing seasons for five irrigation levels.

the 9-15 dm zone for water levels 4 and 5.

It is evident from the soil P data that irrigation frequency and volume will affect the availability of P to the alfalfa plant. The dry upper soil zone in water level 1 significantly limited the uptake of P by the plant. (This will be covered in detail in Chapter 4.) The movement of P associated with the two highest irrigation levels would create a need for additional applications of commercial fertilizer to alfalfa as well as to the crops which follow in the rotation.

The level of soil K at the beginning and end of the 3 alfalfa growing seasons is shown in Fig. 3.3. The general decrease in K for water levels 2 through 5 was probably due to a combination of plant use, root die off, and movement into the water table. The level of K in the upper 9 dm was not significantly reduced for water level 1. This is expected because of the drier upper soil zone for this irrigation level. The average concentration of K in the irrigation water was 1.6 PPM.

3.3.2 Barley Soil Analyses

The feed and malt barley plots were fertilized with 123 kg/ha of N as ammonium nitrate at planting time each year. The residual NO_3 was determined at the end of the 1975 growing season (Table 3.4). The level of NO_3 in the upper 15 dm was relatively low for all treatments with water level 5--significantly less than the other four treatments. These results imply that a significant amount of leaching had taken place during the growing season. The soil NO_3 was sampled three times during the second growing season to evaluate the rate of N movement through the soil profile.

The two irrigations of water level 1 in 1976 both occurred between the first and second soil N sampling dates. The majority of the NO_3 for water level 1 was apparently used by the crop, with a small amount of movement to the 6-12 dm soil zone (Fig. 3.4). Water level 2 was irrigated once prior to the June 1 sampling date. Some movement of NO_3 from the 0-3 dm zone to the 3-6 dm zone apparently occurred. By the July 1 sampling date, 19.8 cm of water had been applied to treatment 2 and a small amount of NO_3 had accumulated

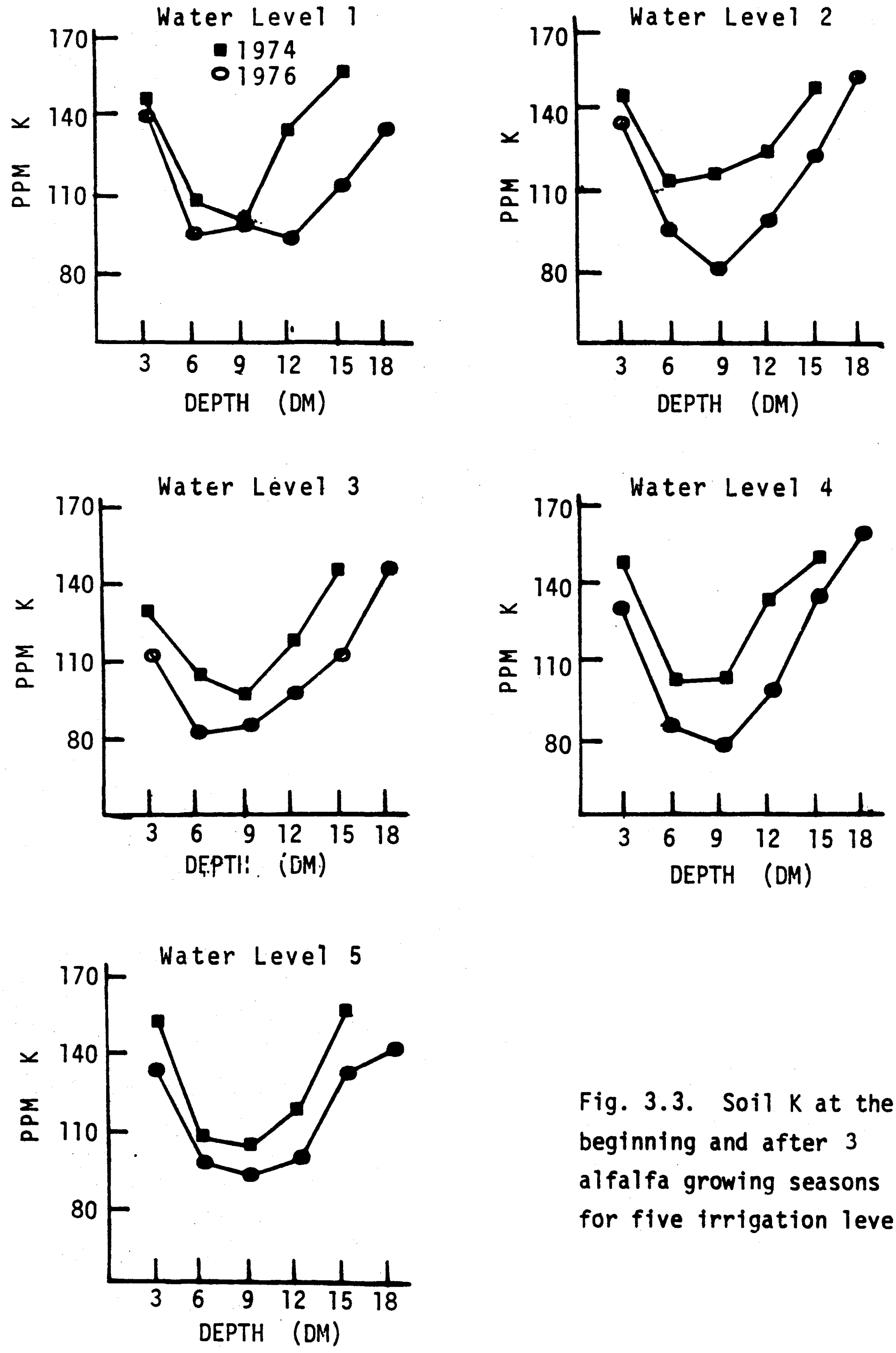


Fig. 3.3. Soil K at the beginning and after 3 alfalfa growing seasons for five irrigation levels.

Table 3.4. Average soil nitrate content at the end of the 1975 growing season for 'Steptoe' barley plots at five irrigation levels.

Water Level	Ave. Soil NO_3 in upper 15 dm (ppm)
1	10.8 a*
2	9.1 a
3	10.0 a
4	9.9 a
5	7.0 b

* Numbers within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

at the 9-12 dm zone. However, considerably more of the NO_3 associated with water levels 1 and 2, which were irrigated to FC, apparently was used by the plant rather than leached beyond the root zone.

Water level 3, which was irrigated at 90% AM, had been irrigated three times prior to the first soil sampling date. A very significant loss of NO_3 from the 0-3 dm soil zone was observed (Fig. 3.4). Accumulation of NO_3 in the lower soil profile was not obvious, indicating that the continued high moisture near the soil surface had resulted in a significant loss of N to volatilization. By the second soil sampling date and continuing through the rest of the growing season, water level 3 had the least total NO_3-N in the upper 15 dm root zone.

Water levels 2 and 4 were irrigated once prior to the June 1 sampling date. However, the additional water applied to level 4 caused approximately half of the NO_3-N in the upper 3 dm of soil to be leached into the 3-9 dm zone. As would be expected, the additional water applied during the first irrigation for water level 5 moved a large fraction of the NO_3-N beyond the 6 dm soil zone. It

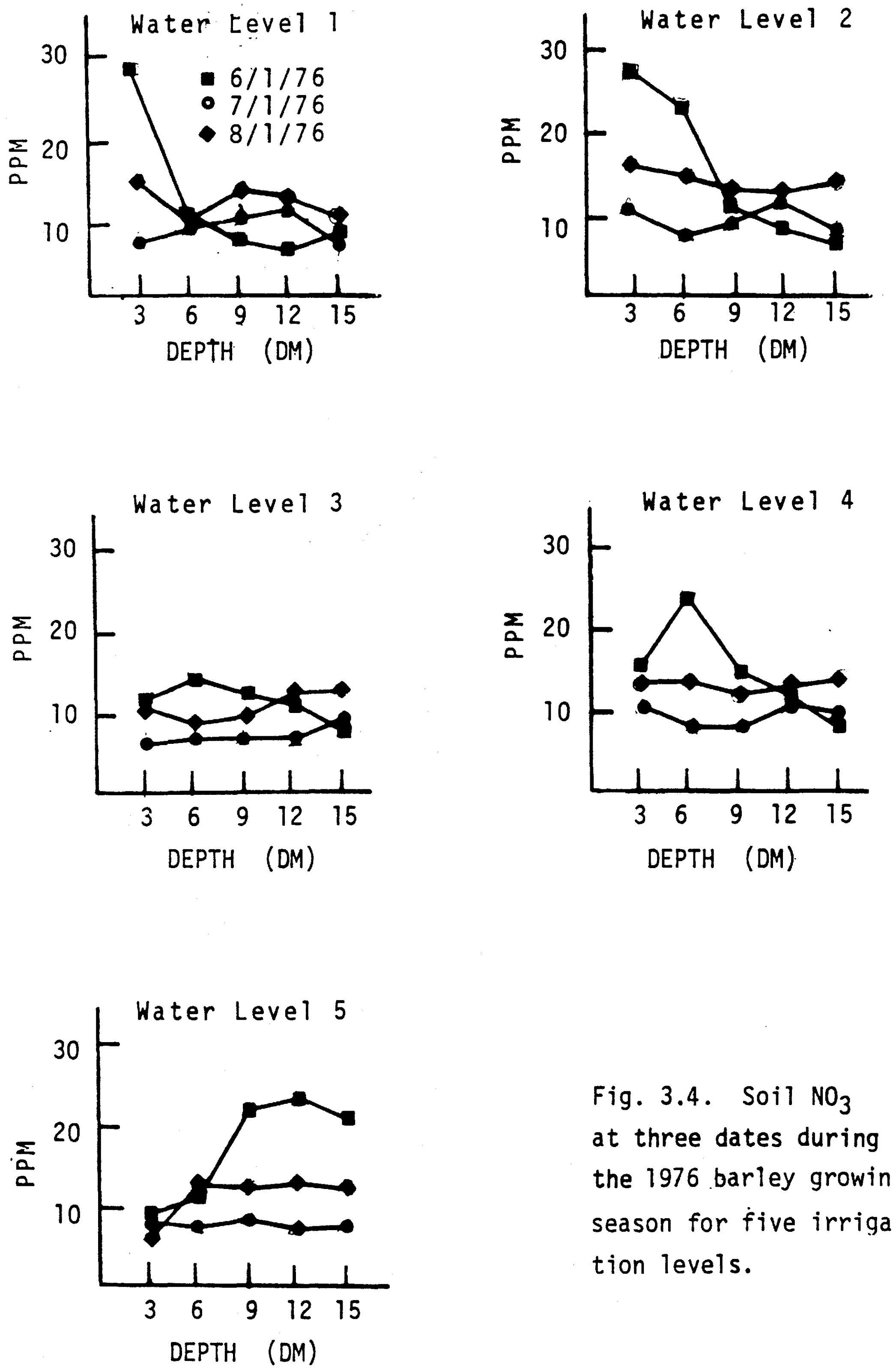


Fig. 3.4. Soil NO_3 at three dates during the 1976 barley growing season for five irrigation levels.

is obvious that an irrigation practice that applies much more water than is required to replenish the soil to FC will result in significant losses of N to soil depths beyond the root zone.

The soil NO_3-N content on August 1 was higher than on the July 1 sampling date for all water levels. Apparently, the reduced crop uptake as it reached maturity and the warmer soil temperatures during this period resulted in soil NO_3 release at a rate greater than plant uptake.

3.4 Results and Discussion of Alfalfa Plant Water Status

The pressure bomb and Campbell press were used on water levels 1 and 3 to evaluate these instruments for their potential use in irrigation scheduling. Initially a study was conducted at 45% available soil moisture with the Campbell press to evaluate the effect of leaf locations on water status. This was necessary to determine where to sample in the canopy for further studies. A continual decrease in bars of pressure was required to force exudate to surface from the petiole (press-petiole) or for the leaf to change color (press-leaf) moving from leaf positions at the top of the plant into the canopy (Table 3.5). The pressure required to obtain the petiole measurement

Table 3.5. Effect of leaf position on leaf water status measured with the Campbell press at 45% available soil moisture.

Node Number*	Press-petiole (bars)	Press-leaflet (bars)
1	-6.6 a**	-11.4 a
2	-5.7 ab	-10.3 ab
3	-5.4 bc	-10.1 ab
4	-5.5 abc	- 9.9 ab
5	-5.0 bc	- 9.4 b
6	-4.4 c	- 9.1 b

*Node 1 was the first expanded leaflet at the top of the plant.

**Numbers within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the .05 level.

was approximately double that required for the leaf to change color for all leaf positions.

The relationship between measurements by the pressure bomb and those by the Campbell press are shown in Table 3.6. When the soil was at FC, the press-leaf measurement was not correlated to the pressure bomb. The positive relationship of the bomb to the press-petiole values was significant but of a relatively low value. The correlations between the pressure bomb and the press measurements were positive and highly significant when the soil was at 45% AM. The press-petiole and press-leaf measurements were also significantly related.

Table 3.6. Relationships between the pressure bomb and the Campbell press methods of measuring alfalfa plant water status at the two soil moisture levels.

		Simple Correlation Coefficients	
	% Available soil moisture	Press-petiole	Press-leaf
Pressure Bomb	100	.46 *	.08
	45	.66 **	.64 **
Campbell Press-Petiole	100	NA	.69 **
	45	NA	.73 **

*, ** Simple correlation coefficients significant at the .05 and .01 levels, respectively.

Although the pressure bomb and press values were generally significantly correlated, the range of leaf values between the two soil moisture levels was much less for the press (Table 3.7). In fact,

Table 3.7. Plant water status of small and large alfalfa stems and leaves measured at two soil moisture levels with the pressure bomb and Campbell press.

Leaf size	Pressure bomb (bars)		Press-petiole (bars)		Press-leaf (bars)	
	45% AM	100% AM	45% AM	100% AM	45% AM	100% AM
Small	-9.5	-5.3	-5.7	-5.5	-10.1	-9.6
Large	-5.3	-4.2	-4.5	-5.1	- 9.2	-10.0
t-test	**	**	**	*	N.S.	N.S.

*, ** t-test for paired observations within a column significant at the .05 and .01 levels, respectively.

N.S. t-test nonsignificant at the .05 level.

the press values for plants with large leaves were actually slightly larger for the plants from water level 1 which was at FC.

Data in the current literature suggest that alfalfa plants with larger leaves may be superior in forage yield. In this study data were collected on relatively large and small alfalfa leaves to determine if large-leaved genotypes were more or less susceptible to moisture stress. The effect of plant genotype on the pressure bomb and press values was also of concern in evaluating the instruments for potential uses in irrigation scheduling.

The average size for the small and large leaflets was 1.73 and 3.59 cm^2, respectively. The most striking effect of leaflet size was the superior xylem pressure observed for the small leaves when the soil moisture in the upper 18 dm was at 45%. When the soil moisture was at FC, the small-leaved stems also had a better water status; however, the magnitude of the difference was not as great as for the lower soil moisture. The press-petiole values showed the same effect of leaf size as the pressure bomb; however, again the magnitude of the difference was much less with the press. No significant effect of leaf size was observed with the press-leaf technique. A portion of the superior water status of the small leaves may relate to the fact that they were significantly thicker. The mean SLW of the small leaves was 4.510 mg/cm^2 compared to the 3.948 mg/cm^2 for the large leaves.

In summary, the lack of magnitude between the pressure values for the two soil moisture levels for the Campbell press suggests that the potential use of the instrument for irrigation scheduling for alfalfa is limited. The effect of leaf size on the xylem pressure of alfalfa suggests that the development of alfalfa varities with small leaves may improve the ability of the plant to extract soil moisture under higher tensions.

Chapter 4

CROP GROWTH AND QUALITY ANALYSES

4.1 Background Studies on Alfalfa Irrigation

Several aspects of the influence of high irrigation levels on crop production and quality have been examined. However, the majority of the previous irrigation studies have dealt with the effects of limited rather than excess water. Also most studies have dealt only with the soil moisture in the upper 9 dm of soil. In terms of actual dry matter yield on an individual plant basis, one study reported that excess water caused a significant yield reduction in alfalfa (Mittra and Stickler, 1961). Follette et al. (1974) observed that yield and percent N were not adversely affected when irrigated at 1.5 times the predicted water requirement for the crop; however, as these data were taken from only 1 year, an adequate evaluation of long-term effects was not possible. An alfalfa irrigation study conducted at Logan, Utah, concluded that irrigation to FC when 90-65% available moisture (AM) remained, was the highest yielding (Peterson, 1972). They noted, however, that these results were dependent on total water-holding capacity of the soil. A soil and climate that produced rapid moisture tension changes in the soil might require 50% AM before irrigation for the highest possible production. Decreased alfalfa yields were obtained by applying water when 90% AM was depleted in the top 9 dm of soil, whereas irrigation at 50-30% AM did not affect yields (Joy and Dobrenz, 1971; Pogue et al., 1971).

Vough and Martin (1971) reported that alfalfa subjected to increased moisture stress increased the percent leaves in a field study and the percent digestibility in a greenhouse study. Bryant (1934) arrived at the same conclusion and additionally found a lower percent lignin in forages grown under moisture stress. Leaves and stems were consistently more digestible with low water levels. One group of workers found that the percent total N of alfalfa was not affected by either irrigation levels or depth of water table (Follette et al., 1974). Others reported that the nutritive value increased as soil moisture stress increased up to 50% AM (Brezeau and Sommor, 1964). They concluded that excess water was more damaging to hay quality than was limiting water. Jensen et al. (1967) found crude protein content of the plant to be unaffected by the moisture regime. But fiber and lignin percentages increased significantly with each increment of water, implying decreased forage quality.

Mittra and Stickler (1961) observed significant losses of alfalfa stands with waterlogging. Wahab and Chamblee (1972) demonstrated that irrigating alfalfa at 50% AM increased yield the first season, but decreased yield as much as 76% by the end of the second growing season. However, they maintained that this appreciable yield depression and loss of stand was a consequence of the frequent occurrence of rainfall closely following irrigation treatments, which produced excess soil moisture conditions. Other workers reported a significant increase in yield of alfalfa through six growing seasons when soil was allowed to dry to 50% AM and was then irrigated to FC, in comparison to nonirrigated plots (Jones et al., 1974). A 17% decrease in forage production was demonstrated for each of three (high, 70% AM; medium, 40% AM; and low, 10% AM) moisture levels from 1968 to 1969 (Joy et al., 1972). By the end of the 3-year study, twice as many plants per unit of area were observed in the low moisture regime in comparison to the high moisture regime. They concluded that stand persistence under Arizona conditions was substantially higher when crops were infrequently irrigated to FC.

4.2 Background Studies on Barley Irrigation

Barley is considered to be more tolerant of high irrigation levels than are many other crops, including alfalfa. This is thought to be due to barley's relative insensitivity to low oxygen supplies in the soil. Leyshon and Sheard (1974), however, observed a reduced mineral content along with a reduction in yield and growth of barley subjected to short-term flooding. They concluded that this was due to a decreased ion uptake resulting from a low oxygen availability in the soil.

Watson et al. (1976) reported a significant reduction in straw yield, number of tillers, and number of fertile heads of barley when subjected to intermittent and continual flood conditions in Australia. The same conditions seriously reduced grain yield and seed size of barley. Leyshon and Sheard (1974) in Canada observed a decrease in growth and grain yield of barley when subjected to a short-term flood state. High soil water stress was found to decrease yield, kernel weight, the number of fertile spikes, and the number of kernels per spike in barley (Wells and Dubetz, 1970).

Nutrient and mineral effects due to high water levels on barley have been reported. These changes in basic mineral composition can then result in further alterations to the growth, yield, and quality characteristics of the plant. Leyshon and Sheard (1974) found a decrease in nitrogen, phosphorus, and potassium in barley tops as a result of short-term flooding.

Malt barley is commonly grown in areas of high humidity and rainfall (Sosulski and Bendelow, 1964). In recent times, however, it has met with success as an irrigated crop in many western states. Irrigation treatment was found to significantly increase grain yield and decrease the saccharifying activity, although this remained within the range considered adequate for malting purposes. Irrigation also decreased the grain nitrogen content and increased the level of soluble nitrogen in the malt, which is a characteristic of good malting quality. Light irrigation increased the grain yield of malt barley, while heavy irrigation increased both yield and the proportion of large kernels.

4.3 Methodologies for Crop Yield and Quality Analyses of Alfalfa

Yield and quality data from all alfalfa plots were collected from a 1 x 15.2 m swath through the middle of each 9.1 x 15.2 m plot. Herbage subsamples were collected, weighed, and dried in a convection drying oven at 80° C for 48 hours and reweighed to determine moisture content. Quality samples were collected and dried at 60° C in a convection drying oven for 6 days. One-half gram of ground (.05 cm screen) tissue was used for forage digestibility determinations. The rumen fluid was obtained from a steer maintained on a mixed forage diet. The technique used was a modified Tilley and Terry "in vitro" dry matter digestibility (IVDMD) procedure (Goering and Van Soest, 1970). Percent protein was determined from 30 mg of tissue by the micro-Kjeldahl technique (Association of Official Agricultural

Chemists, 1955). Herbage P content was determined by the Agricultural Consultants Laboratory.

Specific leaf weight (SLW) in mg/cm^2, and leaf-to-stem ratio (L:S) were determined for each harvest. Stand counts were taken from the same location within each plot at the beginning and end of each growing season. The area counted was 0.28 m^2. A randomized complete block analysis of variance design was used to analyze all data.

4.4 Methodologies for Crop Yield and Quality Analyses of Barley

Barley plots were harvested on Aug. 13, 1975, and Aug. 2, 1976. Seeding rate was 112 kg/ha for both barley cultivars. Barley yield samples were taken from two swaths 1 x 3 m from each 4.5 x 9.2 m plot. Seed yield and test weights (kg/hl) were determined for both varieties. Percent digestibility and percent protein were determined on 'Steptoe' by the same techniques and methods of analysis as for the alfalfa. Rumen fluid, however, was obtained from a steer that had been maintained on a mixed grain diet.

'Moravian III' barley malt quality was determined by the USDA malting laboratory at Madison, Wisconsin. Barley kernel weight, plumpness, color, malt extract percent, extract fine-coarse difference, wort color, clarity of wort, percent nitrogen, wort percent nitrogen, ratio of wort nitrogen to malt nitrogen, diastic power, and α-amylase units were measured.

4.5 Results and Discussion of Alfalfa Yield and Quality

Individual harvest, total season forage yields, and 3-year average yields for alfalfa are shown in Table 4.1. The homogeneity between treatment yields for the first harvest of 1974 was probably a result of the application of uniform irrigation rates on all water levels prior to the first harvest. In 1974, treatments 4 and 5 responded adversely to the heavy irrigation rates by producing yields .56 and 1.59 mt/ha lower, respectively, than the check treatment (water level 2). A similar response was also observed the other 2 years. Over the 3-year period irrigation water level 2 yielded 4.5 mt/ha more than level 5 and 2.4 mt/ha more than level 4. Leaching of nutrients, when excess water was applied may also have contributed to the yield reduction of these treatments. The check treatment,

Table 4.1. Individual harvest and total season dry forage yield of alfalfa grown under five irrigation levels for 3 years (in metric tons/ha).

	Harvest Date			
Water Level	6/25/74	7/31/74	9/26/74	Total 1974
1	7.53 a*	5.20 a	4.57 a	17.27 a
2	7.10 a	4.77 a	4.41 a	16.28 ab
3	6.92 a	4.21 bc	4.48 a	15.61 b
4	7.08 a	4.55 bc	4.10 ab	15.72 ab
5	6.92 a	4.17 c	3.61 b	14.69 b
	7/07/75	8/11/75	9/25/75	Total 1975
1	7.35 bc	5.58 a	3.45 ab	16.37 b
2	7.91 b	5.15 b	3.38 ab	16.46 b
3	8.67 a	5.17 b	3.65 a	17.47 a
4	6.68 c	4.79 c	3.34 b	14.83 c
5	7.06 c	4.59 c	3.02 c	14.67 c
	6/11/76	7/22/76	8/31/76	Total 1976
1	5.82 a	3.09 a	3.74 ab	12.65 a
2	5.62 a	3.29 a	3.27 bc	12.18 a
3	5.78 a	3.29 a	3.67 a	12.74 a
4	5.64 a	3.25 a	3.11 bc	12.00 ab
5	4.93 b	3.14 a	2.98 c	11.05 b
	Three-Year Means			
	Harvest 1	Harvest 2	Harvest 3	Total
1	6.90 a	4.62 a	3.92 a	15.44 a
2	6.88 a	4.40 a	3.69 ab	14.97 a
3	7.12 a	4.22 b	3.93 a	15.27 a
4	6.47 b	4.20 b	3.52 b	14.18 b
5	6.30 b	3.97 c	3.20 c	13.47 c

* Numbers within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replications.

however, was not the highest yielding treatment. Water level 3 (90% AM and irrigation to FC) yielded the lowest of the treatments irrigated to FC in 1974 but the highest for the second and third growing seasons. The combined 3-year yield of the frequent irrigation treatment was nearly 1 mt/ha higher than the check treatment, which was irrigated at 50% AM. The low yield of level 3 for 1974, as compared to the other treatments, could be the result of a setback due to root location "conditioning" by irrigation with small frequent applications of water which would establish a large portion of the roots near the soil surface by the second growing season. The additional roots near the soil surface would be positioned for a greater utilization of soil oxygen.

Water level 1, which was the highest yielding treatment in 1974, declined in yield the second year. This decline could perhaps be explained by a water table depth of 18 dm in 1974. Treatment 1, with an infrequent irrigation schedule, probably developed a deep root system as the upper areas of the soil profile dried out. This treatment, then, utilized a larger percent of water from the water table. However, the depth of the water table increased beyond 24 dm in 1975 when an underground drainage system, which was not part of this study, was installed upslope from the irrigation plots. This could, in part, account for the reduction in treatment 1 yields for 1975. The water table rose again in 1976 to 18 dm, and as a result the relative yield of the driest irrigation treatment increased compared to the other treatments.

The mean soil moisture in the upper 18 dm for water level 1 never dried out to 10% AM in 1976, and as a result it was not irrigated. The soil moisture profile for water level 1 shown as a percent of FC on July 16, 1976 is shown on the following page.

The upper soil profile of water level 1 in 1976 contained significant amounts of moisture only following periods of substantial rainfall. Despite the lack of irrigation the yield of water level 1 was maintained. The three water levels which were irrigated only to FC yielded significantly more over the three seasons than levels 4 and 5 which were irrigated with water volumes of two and four times

Soil Depth (dm)	Available Soil Moisture (%)
1-3	5
3-6	0
6-9	3
9-12	53
12-15	100
15-18	100

the quantity required to reach FC, respectively. Water level 4 yielded 2.1 mt/ha more than level 5 over the 3-year period.

Specific leaf weight (SLW) is often used as an indicator of carbon exchange in alfalfa and implies an increased photosynthetic capacity per unit leaf area with a potential increase in dry matter production. Differences in SLW between irrigation treatments for the 3 years were not statistically significant (Table 4.2). A trend of decreased SLW with increased water supply was observed all 3 years. These results are probably not significant due to the use of only two replications per treatment. A significant harvest date by SLW interaction was observed each year. SLW was significantly higher for the third harvest each year. These harvest date differences are probably due to climatic effects on alfalfa growth.

Leaf-to-stem ratio (L:S) can be interpreted as a quality indicator for alfalfa. A higher ratio would indicate a supposedly high degree of palatability and digestibility. A trend of increased L:S with increased water was found; however, no significant differences were observed (Table 4.3). The continuous increase in L:S with later cutting dates would suggest an effect due to seasonal climatic factors.

Stand persistance over the 3-year period was not significantly affected by irrigation levels. Plant numbers for all water levels were reduced 45-55% over the 3 growing seasons. The high water levels did not result in long term surface flooding which may explain why water levels did not affect stand persistence in this study. The

Table 4.2. Mean specific leaf weight of alfalfa grown under five irrigation levels for 3 years (in mg/cm^2).

Water level	Harvest 1	Harvest 2	Harvest 3	3 year mean SLW
1	3.57*	3.4	3.87	3.61
2	3.33	3.77	3.87	3.66
3	3.40	3.10	3.47	3.24
4	3.37	3.33	3.73	3.48
5	3.33	3.33	3.50	3.39
Mean	3.40b**	3.39b	3.69a	

* There were no significant differences at the .05 level within a harvest.

** Harvest means followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

soil type also allowed adequate soil drainage of excess water into the water table. Additional years of data would be necessary to fully evaluate the effect of irrigation practice on stand persistance.

Percent digestibility (IVDMD) for harvest 1 of 1974, cut at one-tenth bloom, was significantly lower for water level 2 (the check) when compared to the two high water levels (Table 4.4). The highest water level treatments, 4 and 5, resulted in the least digestible alfalfa for harvest 2, which was cut at full bloom. The IVDMD of water level 3 was the highest the second harvest and lowest the third harvest in 1974. Due to a water level by harvest interaction, no significant differences were detected in mean percent IVDMD between water levels for the 1974 season. Harvest 1 of the 1975 season was cut at one-half bloom and produced the least digestible matter under treatments 1, 2, and 4. The total season mean percent IVDMD of the

Table 4.3. Mean leaf-to-stem ratio of alfalfa grown under five irrigation levels for 3 years.

Water level	3 Year Means Harvest 1	Harvest 2	Harvest 3	Mean
1	.38*	.51	.76	.55
2	.41	.52	.73	.55
3	.36	.57	.74	.56
4	.41	.54	.80	.58
5	.37	.57	.82	.59
Mean	.39**c	.54b	.77a	

* There were no significant differences at the .05 level within a harvest.

** Harvest means followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

driest irrigation level was significantly lower than the heaviest water application treatment.

In 1976 no effect of irrigation level on IVDMD was observed. The 3-year mean IVDMD for harvest 1 was reduced by the two lowest water levels. However, the 3-year mean IVDMD for all nine harvests was not affected by irrigation level. This was in opposition to Vough and Martin (1971) and Bryant (1934), who found increased percent digestibility with increasing moisture stress. The lack of significant difference in the three mean IVDMD of the study resulted from a significant harvest date by water level interaction.

The 3-year mean percent protein by harvest is shown in Table 4.5. Water level 1 was significantly lower than level 5 in protein content the first harvest. Irrigation treatment did not affect the alfalfa 3-year mean protein content for the second and third harvests. The significant differences in harvest 1 were overshadowed by the other two harvests. There was no effect of irrigation on protein

Table 4.4. Individual harvest and average season digestibility (IVDMD) of alfalfa at five irrigation levels for 3 years (in percent).

	Harvest Date			
Water Level	6/25/74	7/31/74	9/26/74	1974 Mean
1	60.3 ab*	58.6 ab	64.8 ab	61.2 a
2	60.0 b	58.1 ab	66.4 a	61.5 a
3	62.3 ab	59.9 a	62.7 b	61.6 a
4	62.8 a	56.9 b	66.0 a	61.9 a
5	62.9 a	57.5 b	65.1 ab	61.8 a
	7/07/75	8/11/75	9/25/75	1975 Mean
1	57.0 b	63.2 a	71.5 a	63.9 b
2	57.4 b	65.2 a	73.1 a	65.2 ab
3	61.2 a	65.6 a	69.7 a	65.5 ab
4	59.0 b	64.6 a	70.9 a	64.8 ab
5	61.7 a	65.6 a	71.9 a	66.4 a
	6/11/76	7/22/76	8/31/76	1976 Mean
1	65.5 a	65.1 a	67.4 a	66.0 a
2	64.7 a	61.8 a	69.9 a	65.5 a
3	64.8 a	62.1 a	68.6 a	65.2 a
4	65.4 a	62.1 a	68.1 a	65.2 a
5	65.0 a	62.6 a	68.9 a	65.5 a
	3 Year Means			
	Harvest 1	Harvest 2	Harvest 3	Mean
1	60.9 b	62.3 a	68.0 a	63.7 a
2	60.7 b	61.6 a	69.8 a	64.1 a
3	62.8 a	62.6 a	67.0 a	64.1 a
4	62.4 a	61.2 a	68.3 a	64.0 a
5	63.2 a	61.9 a	68.6 a	63.1 a
Mean	62.0 b	61.9 b	68.3 a	

* Numbers within a column and harvest means followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replicates.

content when the three harvests were combined. The mean percent protein of a given harvest increased as the growing season progressed.

Table 4.5. Mean percent protein of alfalfa forage grown under five irrigation levels for 3 years.

Water level	Harvest 1	Harvest 2	Harvest 3	3 Year Mean percent protein
1	16.2b*	17.9a	18.2a	17.4a
2	16.8ab	17.6a	18.9a	17.8a
3	16.5ab	17.3a	18.4a	17.4a
4	16.7ab	17.9a	18.7a	17.8a
5	17.0a	17.9a	18.5a	17.8a
Mean	16.6c	17.7b	18.5a	

* Numbers within a column and harvest means followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

The forage quality factor P was highly affected by irrigation level. The dry treatment (water level 1) had the lowest mean percent P for each of the 3 years (Table 4.6). For the 3-year combined mean the forage from the three levels with the highest rates of water application had the highest P content with the check treatment midway between the wet and dry treatments. The relatively dry upper zone of soil for water level 1 obviously limited the uptake of P by the plant. This is indicated by the lower level of P in the plant tissue and by the soil P data (Fig. 3.2). Water levels 4 and 5, which received the same number of irrigations as level 2 but higher quantities of water, apparently had significant amounts of P uptake from the lower soil profiles which accumulated P moved from the upper soil zone.

Table 4.6. Individual harvest and total season percent phosphorous of alfalfa grown under five irrigation levels for 3 years.

	Harvest date			
Water level	6/25/74	7/31/74	9/26/74	1974 Mean
1	.23c*	.27a	.22a	.24b
2	.25b	.27a	.23a	.25ab
3	.26ab	.27a	.24a	.25ab
4	.26ab	.28a	.24a	.26a
5	.27a	.28a	.24a	.26a
	7/07/75	8/11/75	9/25/75	1975 Mean
1	.21a	.26b	.27a	.25b
2	.23a	.27ab	.26a	.26ab
3	.24a	.29a	.28a	.27a
4	.23a	.28ab	.27a	.26ab
5	.24a	.28ab	.28a	.27a
	6/11/76	7/22/76	8/31/76	1976 Mean
1	.18bc	.18b	.20b	.19c
2	.17c	.19b	.20b	.19c
3	.19ab	.21ab	.22a	.21a
4	.20a	.21ab	.22a	.21a
5	.18bc	.22a	.22a	.20b
	Three-Year Means			
	Harvest 1	Harvest 2	Harvest 3	Mean
1	.21b	.24c	.23b	.22c
2	.22ab	.24c	.23b	.23b
3	.23a	.25b	.25a	.24a
4	.23a	.26a	.24ab	.24a
5	.23a	.26a	.24ab	.24a

* Numbers within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replicates.

The growth and quality responses of alfalfa for the three growing seasons suggest a number of disadvantages resulting from an irrigation schedule requiring water application in excess of FC. Treatments 4 and 5 produced significantly less forage than the drier treatments. These high water level treatments produced herbage of adequate quality with a sufficient percent protein and a high percent digestibility when compared to the other treatments; however, both had drastically reduced irrigation efficiency. The high volumes of water associated with the low irrigation efficiency resulted in excessive deep percolation. The surplus water lost to deep percolation provides an opportunity for nutrient leaching and a saline seep phenomenon when the water resurfaces. Intermittent flooding produced by the high water regimes lowered spring growth and apparently weakened plant vigor as forage yield was decreased (Fig. 4.1). Even though Fig. 4.1 appears to show a reduced stand for the high water levels, this was not the case as only early spring growth was reduced.

An irrigation schedule of small frequent applications of water, as in treatment 3, has not formerly been considered a practical approach to irrigation scheduling management. Previously, constraints imposed by the economics of frequent application served to limit this practice and promoted instead the practice of minimizing the number of irrigations by increasing the time between them and attempting to store water in the profile for subsequent crop use. These constraints, however, may have been reduced with the development of irrigation systems capable of delivering water to the soil in small quantities.

The small and frequent irrigation applications of level 3 produced some unexpected results, in view of the poor stand persistence generally attributed to alfalfa grown in soil maintained near FC. The alfalfa under level 3 maintained an adequate stand, which is surprising as the root zone was never allowed to "dry out" during the growing season to any appreciable extent. This treatment produced forage of adequate percent protein and digestibility. It also produced dry matter forage yield over the 3-year period equal to the

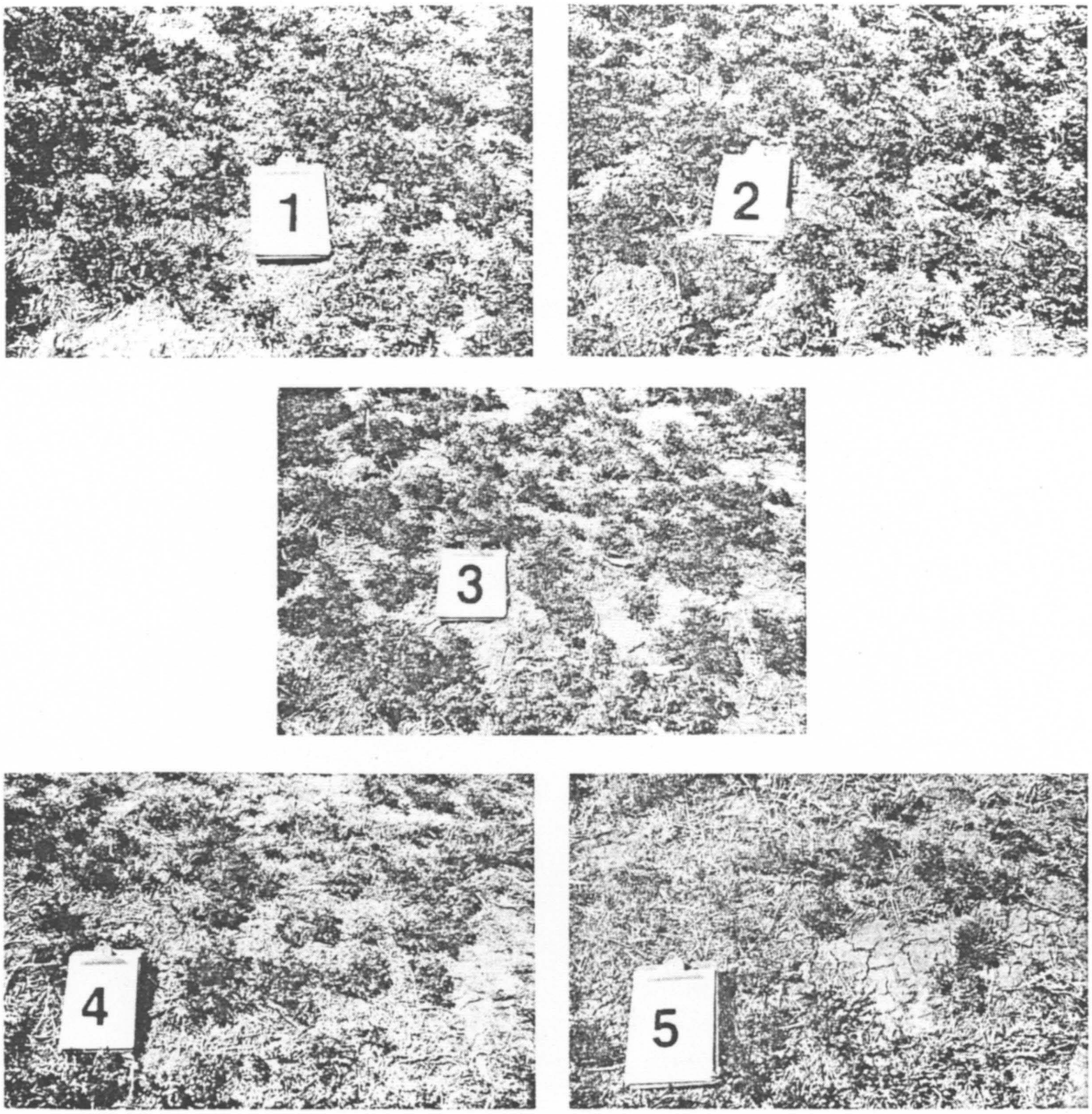


Fig. 4.1. Plant populations and spring growth of alfalfa grown under five irrigation levels taken in the spring of the third growing season.

control. The high yields and early spring growth indicate this irrigation schedule could be effective with the appropriate irrigation system.

Treatment 2 was relatively efficient in water use and maintained a good stand over the 3-year study. It produced herbage of average quality and yield. This scheduling is similar to that currently suggested by the IMS program, yet despite the overall adequacy of the system, its actual advantages over treatments 1 and 3 are limited.

Treatment 1 was the most efficient in terms of water use, maintained a vigorous stand, and produced the greatest total amount of herbage for the 3 years combined. The high yield for 1974 was possibly the result of a high water table of 18 dm, which was utilized by the crop. Alfalfa grown under this regime could potentially reduce rather than increase the water table and aid in alleviating potential saline seeps. Forage quality was adequate with the exception of P, which could be limiting for some classes of livestock. Treatment 1 also had the distinct advantage of requiring the fewest irrigation applications.

4.6 Results and Discussion of Barley Yield and Quality

The yield and test weight of the feed barley, 'Steptoe', were significantly affected by the water level. Water level 5 yielded significantly less than level 1 over the two growing seasons (Table 4.7). No other irrigation levels significantly decreased grain yield. Although treatment 1 yielded the most, the low irrigation rate for this treatment resulted in a significantly lower seed test weight. These data suggest that grain yield is reduced under very high water levels and the test weight is reduced when the barley is subjected to moisture stress.

The 'Steptoe' grain IVDMD for the 2 years was highest for irrigation level 5, resulting in a digestibility 5% higher than water level 1 (Table 4.8). This was expected as water stress conditions at the time of seed filling can starve the grain of photosynthate and reduce the amount of nonstructural carbohydrates stored. The barley seed digestibility generally increased with increased levels of irrigation. Even though the percent IVDMD was lower for the dry irrigation regime, the additional yield from this treatment

Table 4.7. The test weight and yield of feed barley grown under five irrigation levels for 2 years.

	1975		1976		2 year means	
Water Level	Kg/hl	Kg/ha	Kg/hl	Kg/ha	Kg/hl	Kg/ha
1	59.7 c*	5994 a	62.8 b	3818 a	61.2 a	4906 a
2	63.5 ab	6155 a	63.0 ab	2963 a	63.2 b	4559 ab
3	64.0 a	6238 a	63.6 a	3395 a	63.8 b	4816 ab
4	63.1 ab	5909 a	63.6 a	3228 a	63.4 b	4568 ab
5	62.4 b	5182 b	63.2 ab	2885 a	62.8 b	4033 b

*Numbers within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replicates.

Table 4.8. The percent digestibility (IVDMD) of barley grain grown under five irrigation levels for 2 years.

Water Level	1975	1976	2 year mean
1	69.6 c*	85.0 a	77.3 b
2	72.8 abc	85.9 a	79.4 ab
3	72.3 bc	88.5 a	80.4 a
4	74.5 ab	85.8 a	80.2 a
5	76.2 a	85.3 a	80.7 a

* Numbers followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replicates.

resulted in a superior IVDMD yield/ha of 14% for water level 1 when compared to level 5.

The mean percent protein of the seed for the 2-year feed barley study was the highest for water level 2 and significantly lower for levels 4 and 5 (Table 4.9). The reduced protein under the high

Table 4.9. The percent protein content of barley grain grown under five irrigation levels for 2 years.

Water Level	1975	1976	2 Year mean
1	9.5 a*	9.4 a	9.4 ab
2	9.4 a	10.1 a	9.8 a
3	8.9 ab	9.2 a	9.1 ab
4	8.4 bc	9.6 a	9.0 b
5	7.7 c	8.1 b	7.9 c

* Numbers followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replicates.

water level regimes could be attributed to the increased soil nitrate leaching which occurred.

In summary 'Steptoe' was variously affected by irrigation treatments 4 and 5. Treatment 5 reduced grain yield by 906 kg/ha from the driest treatment. The quality of the grain in percent protein was also adversely affected. The heavy irrigation application, however, produced a grain of high digestibility and of medium seed weight. Irrigation at level 4 was not as detrimental to grain production as was irrigation at level 5. Seed weight, digestibility, and grain yield were adequate for treatment 4. Percent protein was low in comparison to the drier regimes.

The irrigation efficiency, percent digestibility, and yield were high for treatment 3. Frequent small irrigation applications produced a grain of average percent protein with the heaviest seed weight in comparison to all other treatments. Maintenance of soil moisture at near FC did not adversely affect grain yield and percent protein, as was seen with the treatments irrigated to an excess of FC. It would appear that the surplus water applied or the intermittent flood conditions encountered with treatments 4 and 5--and not a high moisture content as was found with treatment 3--was responsible for the reduction in yield and percent protein.

Treatment 2 had high irrigation efficiency and yield, and a grain of average percent digestibility and kernel weight. The percent protein was high with treatment 2 in comparison to other schedules, but low for a feed barley protein content. The regime of 50% AM and irrigated to FC was not high enough to increase the grain digestibility nor low enough to starve the grain during seed filling.

The dry regime of treatment 1 adversely affected the barley by producing a grain of low kernel weight and of low percent digestability. However, the seed yield of level 1 was the highest and the grain possessed a comparatively high percent protein.

Mean grain yield of 'Moravian III' malt barley for the 2 years was reduced 14 and 22% as a result of the excess application of water in treatments 4 and 5, respectively, when compared to treatment 1, which was irrigated when AM reached 10% (Table 4.10). The 2-rowed

Table 4.10. The test weight and yield of malt barley grown under five irrigation levels for 2 years.

	1975		1976		Two year means	
Water Level	Kg/hl	Kg/ha	Kg/hl	Kg/ha	Kg/hl	Kg/ha
1	66.8 a*	5134 a	68.9 b	3401 a	67.8 a	4268 a
2	68.0 a	5153 a	70.1 ab	2697 a	69.0 a	3925 ab
3	66.7 a	5142 a	71.0 a	2903 a	68.8 a	4022 ab
4	67.2 a	4575 ab	70.3 ab	2784 a	68.8 a	3680 bc
5	67.3 a	4040 b	69.9 ab	2614 a	68.6 a	3327 c

* Numbers within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test. Numbers are the mean of four replicates.

malt barley grain weight was not affected by water level as it was in the 6-rowed feed barley. All malt quality characteristics with the exception of α-amylase in 1975 were unaffected by water levels (Table 4.11). The α-amylase level was reduced, which is detrimental to malt quality, under the heavy irrigation treatments. In general, irrigation treatments supplying water in excess of FC reduced overall grain yield in comparison to the other treatments. The driest treatment, however, was high in yield and equal to the other treatments in percent protein.

Severe lodging occurred with both barley cultivars under the heavy irrigation levels. Lodging was noted with treatments 2 and 3 but not to the extent of 4 and 5. Only treatment 1 remained free of lodging for the duration of the growing seasons.

Table 4.11. 'Moravian III' malt barley quality characteristics at five irrigation levels for 2 years.

Water Level	Kernel Weight (mg)	Plump Barley (%)	Color (Agtron)	Malt Extract (%)	Extract Fine-Coarse Diff.(%)	Wort Color	Clarity of Wort	Barley N (%)	Wort N (%)	Ratio Wort N / Malt N (%)	Diastatic Power (Deg)	α-amylase (20° Units)
1975												
1	38.3*	90.6	73	78.5	2.2	1.4	sl hazy	2.08	.60	28.6	134	32.4 a**
2	37.0	85.9	75	78.4	2.7	1.4	"	2.07	.53	25.5	138	30.9 ab
3	37.6	89.5	77	79.0	2.5	1.4	"	1.98	.57	28.3	139	31.3 ab
4	37.6	87.9	81	79.6	3.0	1.4	"	1.99	.58	28.1	136	27.6 c
5	38.0	91.5	75	79.8	2.6	1.4	"	1.90	.59	30.4	127	28.7 bc
1976												
1	39.8*	96.0	70	78.6	1.6	1.5	hazy	2.03	.57	29.1	183	32.9
2	39.1	93.4	72	78.3	1.6	1.6	"	2.03	.58	28.8	166	32.4
3	39.7	96.2	66	79.0	1.4	1.5	"	1.98	.58	29.7	166	32.8
4	39.9	96.2	72	79.3	1.4	1.6	"	1.88	.56	30.7	162	32.1
5	40.6	97.1	68	79.0	1.3	1.8	"	2.03	.59	30.0	176	34.4

* In 1975 significant differences were found between treatments only for α-amylase. In 1976 there were no significant differences. Numbers are the mean of four replicates.

** Numbers within a column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Chapter 5

ECONOMIC ANALYSIS OF ALTERNATIVE IRRIGATION PRACTICES

5.1 Introduction

In Wyoming, as in most of the arid western states, irrigation is the largest consumptive use of water. As of 1973, irrigation was responsible for about 81% of the water consumptively used in the state (Wyoming State Engineer's Office, 1973).

For most irrigation districts, water management has meant meeting the water demands of their users. The increased demand for irrigation water has been met through the construction of large reservoirs and delivery systems, providing additional water supplies, improving delivery systems, and developing water allocation policies.

Typically, water allocation policies consist of a flat charge per acre, which entitles each irrigator to a specified quantity of water, usually specified in acre-feet. While the quantity of water received will vary from year to year depending on supply, the water allocation policy means that irrigators will pay the same per acre-foot of water regardless of the quantity used within the allotted amount. Furthermore, the per acre charge is usually set at a level to cover capital, operation, and maintenance costs of the supply facilities. Generally, this water allocation policy has resulted in a relatively low price per acre-foot of water received. For example, the water charge for the Midvale Irrigation District near Riverton, Wyo., has averaged around $16.20/ha-m ($2.00 per acre-foot of water).[1]

It has been argued that the relatively low price for water has resulted in the substitution of water for labor in irrigated agriculture. A strong argument could also be made that such a pricing policy helps to explain some of the low water use efficiencies found in irrigated agriculture. Both of these arguments can be supported by information obtained from the water records of the Midvale Irrigation District. The quantity of water used for irrigation began increasing in 1963 (USBR, 1976). The increased water usage appears

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[1] Personal communication with Pete Stevens, Midvale Irrigation District, Pavillion, Wyoming, June, 1977.

to be related to the larger farm sizes since irrigated hectares in the district have remained fairly constant. With the increase in farm size, the popular practice was to substitute water for labor by doubling the length of run and set times. These irrigation practices tended to increase surface runoff, deep percolation losses, and caused plant stress in that the length of time between irrigations was increased. These changes in irrigation practices not only affected yields, but increased water losses, which in turn increased the potential for degrading water quality.

This study is primarily concerned with on-farm irrigation management. Irrigation management at the farm level consists of timing of irrigation, applying correct amount of water, distribution of water in the field, and drainage. This chapter concentrates on the cost and returns to irrigators under alternative irrigation practices. As indicated in Chapter 3, five alternative irrigation practices were considered in this study. The primary objective of this chapter is to estimate the per hectare costs and returns to irrigators under each of the five alternative irrigation practices for alfalfa, malt barley and feed barley. Using the above estimates, the net return per hectare for each of the three crops for each of the five irrigation alternatives can be calculated.

A second objective is to estimate the costs and returns to irrigators of the IMS offered by the USBR in the Midvale Irrigation District. The IMS program is aimed primarily at assisting irrigators with the decision of when to irrigate and how much water to apply - the argument being that improved timing and quantity of water applications would increase crop yields. It should also improve water use efficiency and reduce the potential for degrading water quality. The results from this analysis should be useful to irrigators in deciding how often to irrigate and how much water to apply in attempting to bolster net returns.

5.1.1 Method of Analysis

To estimate the costs and returns of alternative irrigation practices, the effects of the alternative irrigation practices on crop yield must be determined first. The yield impacts of the five alternative levels of water application were estimated by field trials over a 3—year period. Each treatment was replicated four times in a randomized complete block design. Those data were used to estimate continuous response functions using regression analysis. The response of crops to irrigation scheduling were estimated from yields obtained from the Midvale Irrigation District for irrigators who participated in the IMS program at least 1 year during the 1972 to 1976 period. Once these yield impacts were determined, budgeting was used to determine the costs and returns of individual crops for each of the alternative irrigation practices considered.

5.2 Analysis of Experimental Data

As explained in Chapter 3, the study focused on three crops (alfalfa, feed barley, and malt barley). Each of these crops were grown under five different irrigation treatments and each treatment had four replicates. The yield data from these replicates was used in estimating the relationship between yield and the alternative irrigation treatment, i.e., levels of water application.

5.2.1 Estimating Production Functions

In estimating the production functions for alfalfa and malt and feed barley, the primary objective was to determine the impact of alternative levels of water application upon yields. The model for estimating the impact on yields was complicated by the fact that data were obtained over 3 years. This means the data could be influenced by the weather for the different years, and this in turn affects the coefficients obtained by regression analysis. The objective was to determine the effects of the level of water applications on yield net of any yearly effects.

There are two general alternatives in using regression analysis to estimate production functions where class differences, such as year and level of water application effects, are found in the data. One alternative is to estimate separate equations for each group of data. The other alternative is to use dummy variables to allow for differences among groups of data while using all of the observations.[2]

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[2] For a review of the use of dummy variables see Ben-David and Tomek (1965).

The model used for analyzing year and level of water application effects from the Riverton data is given below:

$$Yld_j = A_0 + A_1 + A_2 + b_j X_j + c_j X_j^2 + e_j$$

Where:

Yld_j = yield for water application j

A_0 = intercept parameter

A_1 = dummy variable for 1975

A_2 = dummy variable for 1976

b_j, c_j = parameters of water application

X_j = water applications

e_j = error term

and where j = 1, 2, 3: and (1) represents cm of water applied;
(2) cm of water per application; and
(3) number of applications.

The above equation can be interpreted as a regression of yield on water application with the intercept varying from year to year. Under this model, the intercept for all 3 years of data on alfalfa is: $A_0 + 1/3\ (A_1 + A_2)$. In the regression analysis, six different regressions of yield on water application were run. The water application variables considered in these regressions were the cm of water applied, the cm of water per application and the number of applications.[3] The coefficients for the six alternative regressions for alfalfa are presented in Table 5.1. The first regression equation, where yield is a function of cm of water applied, taken from Table 5.1, is: Metric tons/hectare/cutting = 5.16 - .00316 X.

The same approach was used in estimating equations for malt and feed barley for the alternative water applications. However, there were only 2 years of data on barley and an additional dummy variable was introduced to allow for the difference between malt and feed barley. A summary of the estimated regression coefficients for the six alternative regressions for malt and feed barley are presented in Table 5.2.

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[3] The cm of water applied and number of applications for the five different applications on alfalfa are summarized in Table 3.2.

Table 5.1. Estimated regression coefficients for alternative irrigation treatments on alfalfa.

Parameters	Regression coefficients for alternative equations[1]					
A_0	5.74	5.88	5.59	5.66	5.64	5.65
A_1	-.16 (1.44)[2]	-.15 (1.38)	-.14 (1.29)	.02 (.23)	.02 (.24)	.02 (.23)
A_2	-1.58 (12.75)	-1.63 (12.46)	-1.50 (12.24)	-1.44 (14.13)	-1.44 (13.84)	-1.44 (12.58)
b_1[3]	-.00316 (4.44)	-.00575 (2.56)	-.00314 (4.60)			
b_2				-.01513 (5.40)	-.01334 (1.45)	-.01506 (4.74)
b_3			.02144 (2.40)			.00045 (.06)
c_1[4]		.0000081 (1.22)				
c_2					.000033 (.20)	
R^2	.80	.81	.82	.82	.82	.82
S_yx[5]	.33	.32	.31	.31	.31	.31

[1] Results are in metric units

[2] The numbers in parentheses are t-values.

[3] The b's are slope coefficients for quantity of water applied, quantity of water per application and number of applications, respectively.

[4] The c's are slope coefficients for the squared value of quantity of water applied and quantity of water per application, respectively.

[5] Number of observations is 60.

It is interesting to note from Tables 5.1 and 5.2 that the signs of the regression coefficients for alternative levels of water application are negative, which means that for this set of data yield is decreasing with increased levels of water applications. Furthermore, the squared term for cm of water applied is insignificant, which means that yields decreased in a linear fashion with increased water applications. This suggests that the quantity of water applied might be reduced even further. It also suggests that farmers using the

Table 5.2 Estimated regression coefficients for alternative irrigation treatments on feed and malt barley.

Parameters	Regression coefficients for alternative equations[1]					
A_0	6411	6262	6310	6207	5589	6601
A_2	-2627	-2601	-2588	-2394	-2403	-2527
	(17.49)[2]	(16.55)	(16.10)	(17.24)	(17.91)	(15.36)
M_1[3]	-746	-745	-743	-741	-746	-746
	(5.78)	(5.75)	(5.74)	(5.49)	(5.72)	(5.57)
b_1[4]	-9.5010	-4.9110	-9.5648			
	(4.52)	(.59)	(4.53)			
b_2				-31.7852	67.2184	-39.7160
				(3.48)	(1.67)	(3.78)
b_3			18.5112			-47.3509
			(.70)			(1.49)
c_1[5]		.02713				
		(.57)				
c_2					-2.9893	
					(2.53)	
R^2	.83	.83	.83	.82	.83	.82
S_{yx}[6]	573	576	575	600	579	595

[1] Results are in metric units.

[2] The numbers in parentheses are t-values.

[3] Intercept coefficients for malt barley.

[4] The b's are slope coefficients for quantity of water applied, quantity of water per application and number of applications, respectively.

[5] The c's are slope coefficients for the squared value of quantity of water applied and quantity of water per application, respectively.

[6] Number of observations is 80.

higher levels of water might well be able to increase yields by decreasing the quantity of water applied. This will be discussed further after the costs and returns are computed for each of the five alternative levels of water application.

It is also interesting to note that the variation in yield explained by the variables cm of water and cm of water per application is for all practicable purposes the same.

5.2.2 Economic Analysis

This section examines the effect which different levels of irrigation applications have on returns to management and other fixed factors. Partial budgeting was used to investigate this question.

To estimate the effect on returns, the production costs and yield associated with each of the five alternative levels of application must be determined. Crop production costs in the Riverton Area, Fremont County, Wyo., have been reported elsewhere (Agee, 1977). These production costs were adjusted to reflect the costs associated with each of the five levels of water application on alfalfa, malt barley, and feed barley. The cost categories adjusted due to change in irrigation practices and the associated change in yield were: (1) labor costs associated with the number of irrigations, (2) a water charge related to the quantity of water used, and (3) harvest costs associated with different yields.

Since production costs were adjusted in the same manner for both alfalfa and barley, an example using alfalfa indicates how irrigation and harvest costs were adjusted for all five irrigation practices for each crop. The first adjustment of irrigation costs was the labor cost associated with the number of irrigations. It was assumed that labor costs for irrigation vary in direct proportion to the number of irrigations. For example, Agee's report indicated that .62 hours/hectare/irrigation are required to irrigate alfalfa after the initial irrigation in the spring. Using this information, the labor cost associated with each alternative irrigation practice can be obtained by multiplying .62 times the number or irrigations (less one for the initial irrigation) times the hourly wage rate ($3.50/hr.).

The first adjustment of harvest costs was the labor cost associated with baling due to a change in yield. From Agee's report, the labor cost per metric ton for baling was calculated to be $.86; thus multiplying $.86 by the mt/ha for each of the five irrigation practices gives the labor cost of baling for each alternative. All variable harvest costs (e.g., labor, fuel, repairs, twine) for both alfalfa and barley were adjusted from the base budget for each of the five irrigation practices using the procedure just described. This analysis considers only variable costs of production, the implicit assumption being that fixed costs per hectare will change insignificantly with small changes in yield.

A summary of the returns and fixed and variable costs for alfalfa, malt barley, and feed barley are presented in Tables 5.3, 5.4, and 5.5, respectively. Returns for each irrigation practice for each crop were obtained by multiplying the yield by the price for the crop. The prices used in this analysis were $55.10 per metric ton for alfalfa, $.12 per kg for malt barley and $.08 per kg for feed barley. These figures reflect current prices received by farmers in Wyoming.

5.2.3 Results and Conclusions

A quick review of Tables 5.3, 5.4, and 5.5 indicates that water application alternative 1 has the greatest return to management and real estate for the three crops considered. Water application alternative 1 was where available moisture was depleted to 10% and then irrigated to FC. The average water applied per year under this application was 35 cm for alfalfa and 23 cm for malt and feed barley. For water application alternative 2, where available moisture was depleted to 50% and then irrigated to FC (which was to represent a check), the average water applied was 51 cm for alfalfa and 27 cm for malt and feed barley. For water application alternatives 1 and 2, there was no deep percolation.

Water use studies conducted by the U.S. Bureau of Reclamation (USBR) (1976) within the Midvale Irrigation District in 1971, 1972 and 1973 indicated an average irrigation efficiency of 33% with an average farm delivery of 1.4 ha-m (4½ acre-feet). If irrigation efficiency was only 33% this would mean an average of 45 cm of water added to the soil and deep percolation and surface runoff of 92 cm. Six alfalfa fields included in the USBR study had an average irrigation efficiency of 39% with an average farm delivery of 165 cm of water. This would mean an average of 65 cm of water added to the soil and deep percolation and surface runoff of 100 cm. The three barley fields included in the USBR study had an average irrigation efficiency of 29% with an average farm delivery of 104 cm of water. This computes to be 30 cm of water added to the soil and deep percolation and surface runoff of 74 cm.

Table 5.3 Estimated return to management and real estate for alfalfa grown under alternative irrigation treatments near Riverton, Wyo.

Item	Application #1	Application #2	Application #3	Application #4	Application #5
Yield (metric tons/ha)	15.44	14.97	15.27	14.18	13.47
	$/ha	$/ha	$/ha	$/ha	$/ha
Gross Return @ $55.10/metric ton	850.74	824.85	841.38	781.32	742.20
Variable Production Costs					
Plant	22.93	22.93	22.93	22.93	22.93
Grow (includes irrigation labor)	90.23	94.57	116.27	94.57	94.57
Harvest	106.67	103.42	105.52	97.96	93.07
Miscellaneous[1]	15.69	15.75	16.94	15.47	15.23
Interest[2]	11.78	11.83	13.08	11.55	11.29
Total Variable Costs	247.30	248.50	274.74	242.48	237.09
Water charge[3]	19.77	19.77	19.77	19.77	19.77
Fixed Costs (power units and implements)					
Grow	21.35	21.35	21.35	21.35	21.35
Harvest	72.67	72.67	72.67	72.67	72.67
Total Production Cost[4]	361.09	362.29	388.53	356.35	356.66
Return to Management and Real Estate (per hectare)	489.65	462.56	452.85	424.97	385.54

[1] Miscellaneous cost is 5% of the plant, grow, harvest and power and implement costs.

[2] Interest is 10% of the variable plant, grow, harvest and miscellaneous costs for 6 months.

[3] Water charge is based on $19.77/ha, which during an average year would provide farmers with about 1.5 ha-m. Any additional water would cost $16.20/ha-m.

[4] The total production cost does not include the real estate or management expenses.

Table 5.4. Estimated return to management and real estate for malt barley grown under alternative irrigation treatments near Riverton, Wyo.

Item	Application #1	Application #2	Application #3	Application #4	Application #5
Yield (kg/ha)	4268	3925	4022	3680	3327
	$/ha	$/ha	$/ha	$/ha	$/ha
Gross Return @ $.12/kg	512.16	471.00	482.64	441.60	399.24
Variable Production Costs					
Preplant	108.15	108.15	108.15	108.15	108.15
Plant	34.31	34.31	34.31	34.31	34.31
Grow (includes irrigation labor)	59.83	65.57	79.92	65.57	65.57
Harvest[1]	57.94	55.06	55.88	53.00	50.19
Miscellaneous[2]	17.37	17.51	18.27	17.41	17.27
Interest[3]	13.88	14.03	14.83	13.92	13.77
Total Variable Costs	291.48	294.63	311.36	292.36	289.26
Water charge[4]	19.77	19.77	19.77	19.77	19.77
Fixed Costs (power units and implements)					
Preplant	25.57	25.57	25.57	25.57	25.57
Plant	11.15	11.15	11.15	11.15	11.15
Grow	17.89	17.89	17.89	17.89	17.89
Harvest	32.59	32.59	32.59	32.59	32.59
Total Production Cost[5]	398.45	401.60	418.33	399.33	396.23
Return to Management and Real Estate	113.71	69.40	64.31	42.27	3.01

[1] Harvest cost is based on 29.65 per hectare plus $.0044/kg for yield over 3228 kg/ha.

[2] Miscellaneous cost is 5% of preplant, plant, grow, harvest and power units and implements cost.

[3] Interest is 10% of the variable preplant, plant, grow, harvest and miscellaneous cost for 6 months.

[4] Water charge is based on $19.77/ha, which during an average year would provide farmers with about 1.5 ha-m. Any additional water would cost $16.20/ha-m.

[5] The total production cost does not include the real estate or management expenses.

Table 5.5. Estimated return to management and real estate for feed barley grown under alternative irrigation treatments near Riverton, Wyo.

Item	Application #1	Application #2	Application #3	Application #4	Application #5
Yield (kg/ha)	4906	4559	4816	4568	4033
	$/ha	$/ha	$/ha	$/ha	$/ha
Gross Return @ .08/kg	392.48	364.72	385.28	365.44	322.64
Variable Production Costs					
Preplant	108.15	108.15	108.15	108.15	108.15
Plant	29.31	29.31	29.31	29.31	29.31
Grow (includes irrigation labor)	59.83	65.57	79.92	65.57	65.57
Harvest [1]	63.89	60.98	63.15	61.06	56.56
Miscellaneous[2]	17.42	17.56	18.39	17.56	17.34
Interest[3]	13.93	14.08	14.96	14.08	13.85
Total Variable Costs	292.53	295.65	313.88	295.73	290.78
Water charge[4]	19.77	19.77	19.77	19.77	19.77
Fixed Costs (power units and implements)					
Preplant	25.57	25.57	25.57	25.57	25.57
Plant	11.15	11.15	11.15	11.15	11.15
Grow	17.89	17.89	17.89	17.89	17.89
Harvest	32.59	32.59	32.59	32.59	32.59
Total Production Costs[5]	399.50	402.62	420.85	402.70	397.75
Return to Management and Real Estate	-7.02	-34.90	-35.57	-37.26	-75.11

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[1] Harvest cost is based on 29.65 per hectare plus $.0044/kg for yield over 3228 kg/ha.

[2] Miscellaneous cost is 5% of preplant, plant, grow, harvest and power units and implements cost.

[3] Interest is 10% of the variable preplant, plant, grow, harvest and miscellaneous costs for 6 months.

[4] Water charge is based on $19.77/ha, which during an average year would provide farmers with about 1.5 ha-m. Any additional water would cost $16.20/ha-m.

[5] The total production cost does not include the real estate or management expenses.

These water use data indicate that the quantity of water added to the soil is close to the water added to the soil for applications 3, 4, and 5 for alfalfa and barley. These data suggest that even at the present low irrigation efficiencies farmers in the Midvale Irrigation District might be able to reduce water application and increase yields at the same time. But perhaps even more important is the improvement in irrigation efficiency which could reduce water applications substantially.

In summary, all indications are that water application alternative 1 or 2 would allow farmers to decrease the quantity of water applied and at the same time increase yield and returns to management and real estate. Furthermore, these results would be even more pronounced if the added fertilizer and drainage costs that are likely to occur under the higher water application levels are taken into consideration.

5.3 Analysis of Irrigation Scheduling Data

Results from the experimental data and water use studies on the Midvale Irrigation District indicate the need for improved water use efficiencies and that the quantity of water applied could be reduced without decreasing yields. In attempting to improve irrigation efficiency and at the same time increase yield, the USBR has been using a program called Irrigation Management Service. The overall objectives of the program are to demonstrate that (1) information on when to irrigate and how much to apply can be economically provided on a district-wide scale; and (2) participants will benefit through increased crop yields, improved crop quality, reduced water uses and lower production costs (USBR, 1974).

The IMS program was initiated on the Midvale Irrigation District in 1971. There were nine irrigators in the program in 1971 and seven more were added in 1972. Beginning in 1973, all interested farmers were allowed to participate in the IMS program.

The objective of this section is to analyze the scheduling data from 1972 through 1976 to determine the economic feasibility of scheduling. The first step in this process is to estimate the response of crops to irrigation scheduling.

5.3.1 Estimation of Crop Responses to Irrigation Scheduling

A list of irrigators who participated in the IMS program for at least 1 year during the 1972 to 1976 period was compiled. Yearly crop yields reported to the Midvale Irrigation District by the above irrigators were used. The model used for estimating the response of various crops to irrigation scheduling is given below:

$$Yld_j = A_0 + A_1 + A_2 + A_3 + A_4 + S_1$$

Where:

Yld_j = yield for crop j

A_0 = intercept parameter

A_1 = dummy variable for 1973

A_2 = dummy variable for 1974

A_3 = dummy variable for 1975

A_4 = dummy variable for 1976

S_1 = dummy variable for scheduling

The primary purpose of the above model was to estimate the impact of irrigation scheduling on crop yields net of yearly effects. Since the irrigation managers were the same for the crops on scheduling as for the crops not on scheduling, it was assumed that management and other variable inputs were constant for this set of data. Crop response to irrigation scheduling was estimated for alfalfa, barley, hay, pasture, corn silage, corn grain, and oats. All showed a positive response to scheduling except for corn grain and oats. Of the crops showing a positive response to irrigation scheduling, alfalfa, barley, and pasture responses were statistically significant at the 10% level. Results of the estimated response to irrigation scheduling for the various crops are shown in Table 5.6.

The two major crops in the Midvale Irrigation District are alfalfa and barley. Alfalfa accounts for about 38% of the irrigated acreage and barley accounts for approximately 17%, for a total of 55% of the irrigated acres. The average yield for the irrigators studied for the 1972-1976 period was 7.8 mt/ha for alfalfa and 3554 kg/ha for barley. The average yield for the district was the same for alfalfa and 40 kg/ha less for barley. This suggests that the management level of the irrigators studied was approximately equal to the management level for the entire district. The influence of management was minimized because the same group of irrigators was used to estimate crop yields for both IMS scheduled and nonscheduled fields.

For alfalfa and barley, the increase in yield under irrigation scheduling was 1.03 mt/ha and 314 kg/ha, respectively. These increased yields represent a 13% and a 9% increase in yield, respectively. Since alfalfa and barley are the two major crops, the above increase in yields will be used in the next section to estimate the additional costs and returns to irrigators in the Midvale Irrigation District.

Table 5.6 Estimated coefficients of the response of certain crops to irrigation scheduling.

	Estimated Coefficients for Alternative Crops						
Parameters	Alfalfa	Barley	Corn silage	Corn grain	Oats	Other hay	Pasture
	MT/Ha	Kg/Ha	MT/Ha	Kg/Ha	Kg/Ha	MT/Ha	Aum
A_0	7.47	4092	33.0	5053	3498	6.66	4.9
A_1	-.11 (.54)*	-863 (2.72)	-6.3 (1.75)	-942 (1.35)	-1004 (2.18)	-2.47 (1.23)	-.3 (.42)
A_2	.16 (.36)	-992 (3.16)	-9.9 (2.68)	-665 (.95)	-682 (1.75)	-2.29 (1.25)	-2.5 (1.58)
A_3	1.01 (1.93)	-499 (1.58)	1.8 (.23)	-1827 (2.14)	-731 (1.49)	-2.71 (1.17)	-1.3 (.69)
A_4	.67 (1.57)	-342 (1.11)	-2.9 (.79)	50 (.07)	-704 (1.47)	-2.06 (.98)	-1.9 (1.07)
S_1	1.03 (3.13)	314 (1.48)	1.3 (.55)	-383 (.71)	-368 (1.11)	1.70 (1.00)	2.3 (1.86)

* Values in parentheses are t-values

5.3.2 Economic Analysis of Irrigation Scheduling

To estimate the increased cost and returns under irrigation scheduling, the 130 ha case farm reported in a previous study will be used (Agee, 1977). The case farm consists of 40.5 ha of malting barley, 50.6 ha of alfalfa, 26.3 ha of corn silage and 12.2 ha of dry beans. It was assumed that alfalfa and barley yields will increase by 1.03 mt/ha and 314 kg/ha, respectively. Since the increased yield for corn silage was not significant and the increased yield for dry beans was not estimated, it was assumed that the yield for these crops under scheduling would equal the district average of 28.5 metric tons and 2018 kg/ha, respectively.

The first step was to estimate the average gross return per ha for the 130 ha case farm where irrigation scheduling was not practiced. The average yields used for alfalfa, barley, corn silage and dry beans were 7.8 metric tons, 3554 kg/ha, 28.5 metric tons and 2018 kg/ha, respectively. With prices of $55.10/metric ton, $.12/kg, $15.40/metric ton and $.26/kg, respectively, the average gross return per ha would be about $438.

Following the above procedure, an estimate of the average gross return per hectare was made for the 130 ha case farm when irrigation scheduling was practiced. The average yields for alfalfa and barley would now be 8.8 mt/ha and 3868 kg/ha, respectively. The yields for corn silage and dry beans were assumed to remain the same and the same prices were used. With the above yields and prices, the average gross return per hectare under scheduling would be approximately $471.

A comparison of the gross return under nonscheduling versus scheduling indicates an increase in gross returns of approximately $33 per hectare when irrigation scheduling was practiced. This represents part of the benefits from irrigation scheduling. Other benefits to the irrigator might be reduced fertilizer applications and improved crop quality. An estimate of these benefits was not made because the appropriate data were not readily available. An additional benefit to society might well be a reduction in the loss of salts and nitrates to surface and ground water because of a reduction in percolation and surface runoff of water with irrigation scheduling. No attempt was made to estimate this benefit due to the lack of data. Thus the comparison of benefits and costs was based solely on the increased yield and the estimated cost of the irrigation scheduling service.

A USBR publication (1974) indicates that the IMS program cost about $11 to $12 per hectare in 1972. Using $12 per hectare, irrigation scheduling would increase returns to the 130 ha farm by about

$21/ha. This suggests that irrigation scheduling would pay for itself from the increased yield alone without consideration of the other possible benefits mentioned earlier.

Chapter 6

ESTIMATION OF INCREASED DRAINAGE REQUIREMENT

Drainage is not a prerequisite for irrigated agriculture but it is required in many cases. The necessity to leach water through the soil profile and the problem of water distribution efficiency causes excess water to pass below the root zone. If the soil and geological characteristics of the area are not conducive to transporting water away from the fields, a water table builds up, and in turn, saturated conditions may occur in the root zone. Overirrigation, no matter what the reason, accelerates the rate at which water tables build up and drainage problems begin. Also, overirrigation is unfortunately the norm rather than the exception on most irrigation projects in the West and the reason for most drainage problems in the area.

6.1 Sources of Excess Water

Irrigation water that becomes part of the ground water can come from several different sources. The sources include transportation losses, storage losses, overirrigation, field distribution losses, and water purposely passed through the soil for leaching of excess salts. All of these losses are inherent to irrigated agriculture except those associated with overirrigation.

6.1.1 Transportation Losses

It is not uncommon in the main canals to lose up to 50% of the water diverted (Houk, 1951). A recent study by Walker et al. (1977) found that the Grand Valley, Colo., irrigation project lost approximately 6% of its water in the major canals and an additional 9% in lateral ditches. Another way of looking at the transportation losses in the Grand Valley is to realize that they are equivalent to 50% of the cropland's consumptive use in the system.

Lining of canals is not a total solution to transportation losses; Worstel (1976) reported that concrete-lined canals had an average seepage rate of 7.3 cm/day or approximately one-fourth the seepage rate for unlined canals. Some irrigation projects are replacing canals with pipe systems to reduce seepage.

Farm ditches can also lose from 5 to 50% of their water (Houk, 1951). However, in the western U.S. a modern system may be expected to lose only 10 to 15% of its water (Richey et al., 1961).

6.1.2 Storage Losses

Farm storage reservoir losses are highly variable and such reservoirs are not universally used. As evidenced by surface salt accumulations and marshes, seepage from many of these reservoirs do cause problems immediately downstream from the reservoirs. Most federally built irrigation systems do not utilize on-farm storage.

6.1.3 Overirrigation

Overirrigation is generally said to occur when low application efficiencies are measured. Application efficiency is defined as the ratio of the net volume of useful water applied to the soil in a field to the gross volume of water delivered to the field times 100 (Hall, 1960). Useful water is taken to be water required to meet the consumptive use of the field plus the necessary leaching fraction. However, no one has stated how low the application efficiency may become before overirrigation occurs. One must be careful because all irrigation systems will have application efficiencies less than 100% if they try to meet the maximum consumptive use of a field. Shown in Table 6.1 are potential application efficiencies where the systems are operated to supply a predetermined value of soil moisture deficit and where the systems are reasonably suited and well designed for the various site conditions (Keller, 1976). The inability of an irrigation system to distribute water in a uniform manner must be taken into consideration. A general rule of thumb often applied is that overirrigation occurs, be it the system's fault or the irrigator's fault, if the application efficiency is less than 70%. Nevertheless, the excess water must be carried away by the drainage system.

6.1.4 Field Distribution Losses

The main factors in low field application efficiencies are the surface runoff and deep percolation for surface irrigation systems, and water lost to evaporation and deep percolation for sprinkler and trickle irrigation systems. Because of the spatial water distribution there will always be some deep percolation if the average depth of application approaches the water necessary to bring the soil to FC within the root zone. All systems will overirrigate in some portion of the field. Factors which affect the distribution of infiltrated water are soil infiltration characteristics, slope, desired depth of application, length of run, volume of inflow, total time of application, and geometric configuration of channel or width of border (Karmeli, 1977).

Table 6.1 - System application efficiency ranges

Irrigation System	Probable Range
Surface	
Furrow	40 to 75%
Border	50 to 80%
Basin	60 to 75%
Hose Basin	- to 90%
Sprinkler	
Hand move	60 to 75%
Center pivot	75 to 80%
Full coverage	60 to 85%
Giant	50 to 70%
Trickle	
Point source	65 to 90%
Line source	60 to 85%

6.1.5 Leaching Requirement

The leaching requirement is defined as the fraction of the irrigation water that must be leached through the root zone of the plants in order to prevent the soil salinity from exceeding a specified level (Luthin, 1973). For many situations the deep percolation losses due to the spatial distribution of water, excessive or untimely precipitation, overirrigation or both are sufficient to meet most leaching requirements. For example, as shown in Table 6.2, the irrigation water used on this study's field plots was relatively low in salts. Assuming that there will be no yield reduction for barley and alfalfa until the electrical conductivity of the water at the bottom of the root zone reaches 6,000 µmhos, the leaching requirement would be 2% of the required irrigation water. No special effort would be required to meet this leaching requirement.

If the water table is allowed to approach the surface of the field, salt problems can develop even where the irrigation water is relatively free of salts. For example, the conductance of the ground water below the field plots was 770 µmhos (≈ 500 mg/1). Even with this amount of salt in the ground water, an upward flow from the ground water table would soon concentrate salts in the soil at levels capable of retarding plant growth. Several areas adjacent to the field plots had salt accumulations as a result of high water tables (Fig. 3.1).

Table 6.2 - Average water quality data for field plots at Riverton, Wyo. - 1974-1976.

Parameter	Irrigation Water	Ground Water
Calcium	18 mg/1	127 mg/1
Magnesium	7.6 mg/1	12 mg/1
Sodium	4.8 mg/1	46 mg/1
Potassium	1.6 mg/1	4.4 mg/1
Carbonate	0 mg/1	0 mg/1
Bicarbonate	76 mg/1	499 mg/1
Sulfate	20 mg/1	52 mg/1
Nitrate	0 mg/1	1.5 mg/1
Flouride	--	1.3 mg/1
Boron	0.2 mg/1	2.1 mg/1
Silica	--	13 mg/1
CO_3 (Total)	--	270 mg/1
T.D.S.	96 mg/1	493 mg/1
Hardness	75 mg/1	370 mg/1
pH	7.7 mg/1	
Conductance	150 µmhos/cm@25°C	770 µmhos/cm@25°C
Sodium %	12 %	20.7 %

6.2 Determination of Drainage Costs

There are several different procedures for determining drain spacings and several different sets of costs for drains. Depending on ones' selection the relative costs for any given physical situations will be different. However, it is not necessary to test each alternative. What is necessary is to determine the drainage costs for each physical situation using a procedure for calculating drain spacings and cost data that are equivalent, all things considered. In this study the procedures and costs recommended by the USBR were used.

6.2.1 Bureau of Reclamation Drain Spacing Procedure

The USBR procedure for calculating drain spacings takes into consideration the transient regimen of the groundwater recharge and discharge. According to Dumm (1962) it gives a spacing with which dynamic equilibrium is reached at a specified water table height under the specific soil, irrigation, crop, and climatic characteristics of the area. The fundamental assumption implicit in the concept of dynamic equilibrium is that the temporal distribution of recharge is a periodic function (McWhorter, 1977). The USBR procedure as put forth by Dumm (1962) (1967) was used for calculating drain spacings in this study.

6.2.1.1 Recharge Interval and Amount

Presented in Tables 3.2 and 3.3 are the seasonal deep percolation losses and the irrigation dates respectively for the various water levels and crops. It was assumed that the irrigation for each water level for each year represented the design distribution of recharge. It was further assumed that the only recharge occurring was due to irrigation and that the depth of recharge was the same for each irrigation. The deep percolation was estimated using a seasonal water balance for the crop. Some error may have been introduced for the alfalfa since it appeared that it was obtaining some of its water directly from the capillary fringe above the water table.

6.2.1.2 Soil Parameters

Field tests were made in the vicinity of the field plots to ascertain the soil permeability. An average permeability of 61 cm/day was measured. The soil material between maximum allowable water table and the impermeable barrier was assumed to be homogeneous and isotropic. Specific yield in the zone in which the water table would fluctuate was estimated to be 0.10. The depth to the impermeable barrier was determined to be 9.14 m. It should be understood that there is considerable spatial variability in all the above soil parameters within a given field (Biggar et al., 1977).

6.2.1.3 Drain Depth and Aerated Zone

There is no criterion for selecting the depth of drain other than that it must provide a properly aerated zone between the water table and the soil surface. It is possible to optimize the depth with an economic analysis for a single crop but it is very difficult to do it for a multiple crop rotation. A recent in-house study at the University of Wyoming indicated that deep parallel drains may be the most economical. Following these findings, it was decided to assume the drains to be 3.1 m in depth. The minimum depth of an aerated zone was selected to be 1.2 m. This would allow barley to produce at the maximum yield without any adverse effect from a high water table (Luthin, 1957). Presented in Figure 6.1 is a diagram showing the aerated zone for parallel drains.

6.2.1.4 Results of Drain Spacing Calculations

Presented in Table 6.3 are the drain spacings that were calculated for the above physical conditions. In general for the given physical conditions and for a barley-alfalfa rotation, irrigation practices similar to that used in water level 3 would require a maximum drain spacing of 305 m, for water level 4 a maximum drain spacing of 61 m, and for water level 5 a maximum drain spacing of 9 m. It is unlikely that anyone would recommend 9 m drain spacing. A good engineer would recommend a wider spacing with a corresponding improvement in irrigation practices. It is also understood that changing the physical parameters which go into the USBR procedure will change the drain spacings.

6.2.2 Cost Relationships for Underground Drains

Good cost relationships for underground drainage systems are difficult to find in published form. To obtain reasonable cost for the condition in the Riverton area, the local USBR office was contacted and cost data were obtained from Richard Brohl. All cost data were for a base time of July 1976. The interest rate used was 5.5%, which was the cost to a farmer for borrowing money during July 1976 from the State of Wyoming.

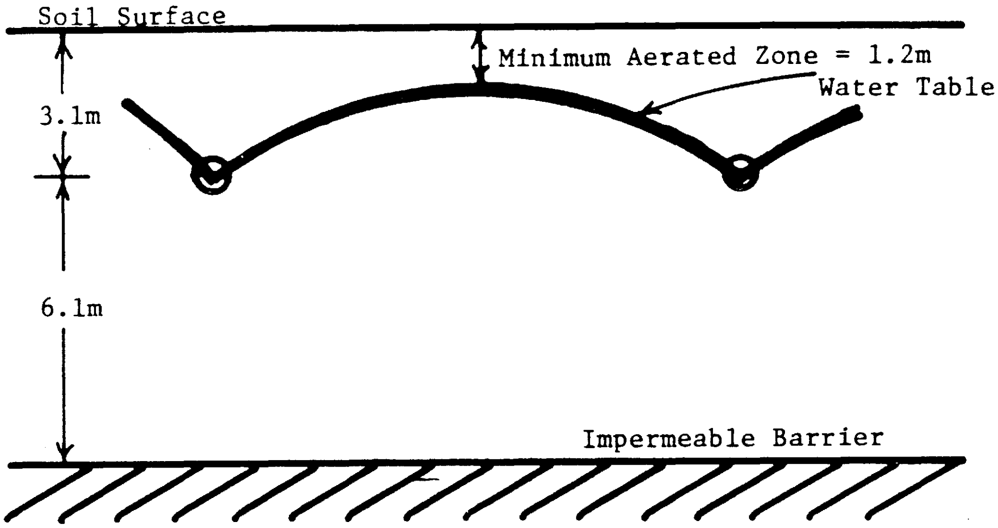

Figure 6.1 - Example of water table between parallel drains

6.2.2.1 Gravel Cost

The gravel cost per cubic meter was $14.13. It was assumed that a 15 cm thickness of gravel (the envelope) was laid all the way around the drain plus extra gravel for the bottom corners of the trench. It was further assumed that collector pipes were also encased by a gravel envelope. All the drainage systems in this study were assumed to have square grids with two collector pipes similar to that shown in Figure 6.2.

6.2.2.2 Excavation and Backfill Cost

The cost for excavation and backfill of the trenches was $3.27 per cubic meter. For calculation purposes, it was assumed that the width of the drain was equal to the pipe diameter plus twice the envelope (gravel) thickness.

6.2.2.3 Manhole Cost

Manhole costs for drains up to 2.1 m deep were $770 per manhole. For drains over 2.1 m in depth the cost per manhole was $910. A cost of $910 per manhole was used in this study. A survey of typical

Table 6.3 Drain spacings and drainage system costs for the different water treatments.

Water Treatment	Crop	Year	Drain Spacing (m)	Average Annual Cost ($/ha)
4	Alfalfa	1974	62	260
5	"	1974	9	1198
3	"	1975	335	79
4	"	1975	324	82
5	"	1975	12	1000
3	"	1976	310	77
4	"	1976	398	74
5	"	1976	12	1000
3	Barley	1975	327	82
4	"	1975	72	222
5	"	1975	15	823
4	"	1976	455	74
5	"	1976	60	260

systems in the Riverton area indicated that 3.5 manholes per kilometer of drains were needed. Manholes were assumed to be needed for both lateral and collector drains.

6.2.2.4 Outlet Pipe Cost

In many areas natural outlets for the drainage water are not available. Such is the case at Riverton, Wyo. To gather the water from the various farms, a collector system was built. The cost per connection was $350. From an examination of several systems, the average number of outlets was one outlet per 2.12 kilometers of drains. Again, in calculating the number of outlets the outlets were considered the same as the lateral drains (see Figure 6.2).

6.2.2.5 Tile Pipe Cost

The drain pipe used for this study was assumed to be clay tile. Corrugated plastic pipe costs approximately 40% less than for clay tile but is unavailable in the study area. For all water levels 10 cm pipe could be used for the laterals and 20 cm for the collectors. The 10 cm pipe cost $5.74 per meter and the 20 cm pipe cost $8.20 per meter.

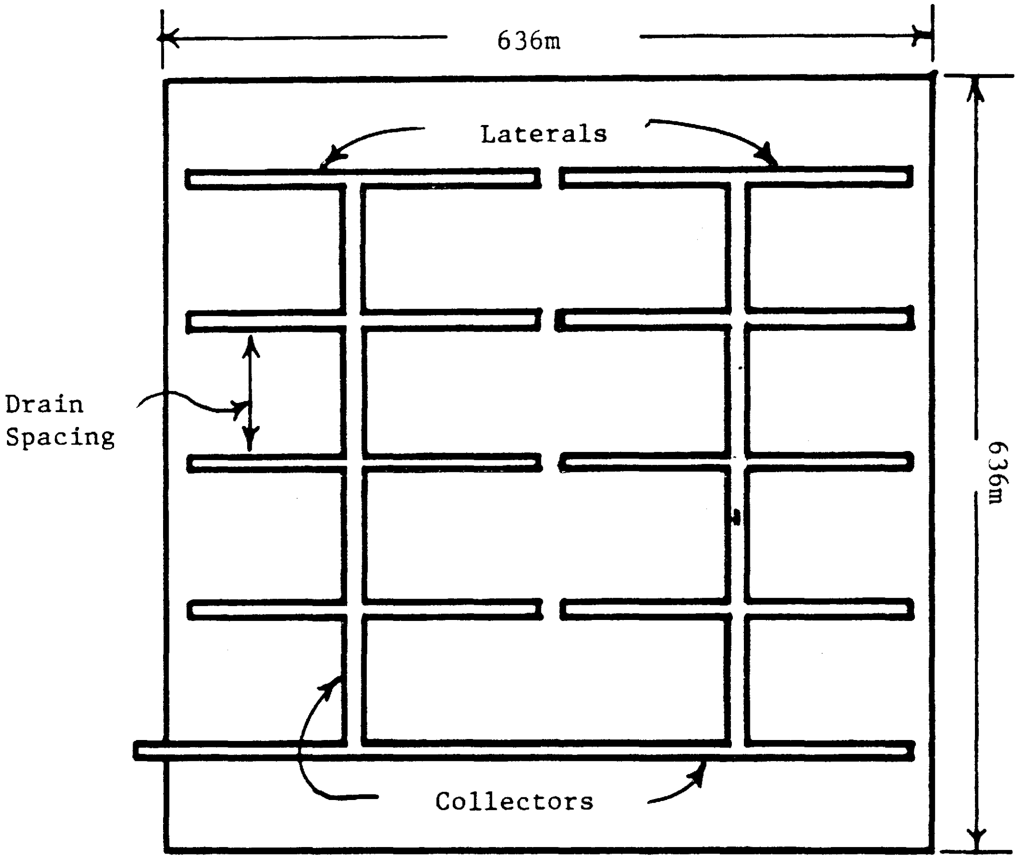

Figure 6.2 - Drainage system for hypothetical field

6.2.2.6 Operation and Maintenance Cost

From present systems in use, the operation and maintenance cost for the drainage system was estimated to be $31 per kilometer per year.

6.2.2.7 Results of Cost Analysis

All costs were calculated as average annual costs. The capital construction costs were computed as average annual costs by using a life expectancy of 25 years for all components and by using an interest rate of 5.5%. The results are shown in Table 6.3. For the given physical situation and irrigation practices similar to those used in water level 3, the drainage system would cost $86/ha/yr, for water level 4, $272/ha/yr, and for water level 5, $1038/ha/yr.

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