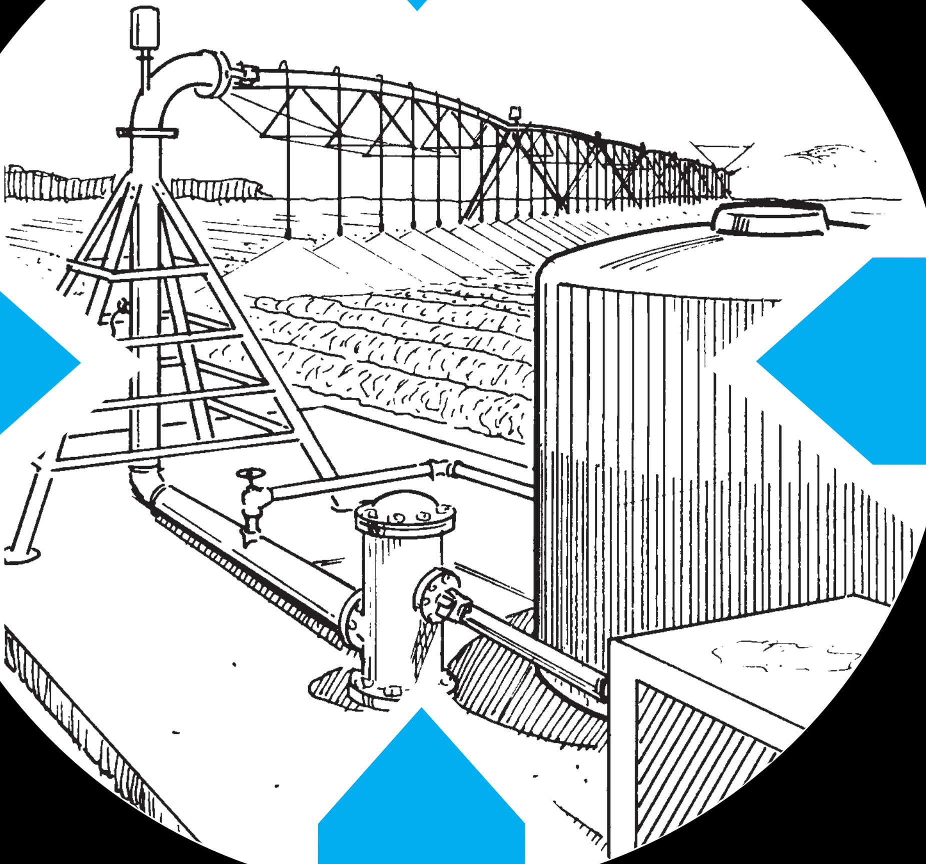
FERTIGATION / CHEMIGATION



Midwest Laboratories℠

MIDWEST LABORATORIES, INC. • 13611 B STREET • OMAHA, NE 68144 • 402-334-7770 • FAX 402-334-9121

TABLE OF CONTENTS

LIMITATION OF LIABILITY

The information in this publication is based on the best information available to the author at the time of publication. It is not intended to be used in place of instruction issued by the manufacturer of any product. All agricultural materials should be used in strict compliance with label directions, and the user assumes all liability for results of deviation from such directions.

ACKNOWLEDGEMENTS

The following people have lent considerable time and effort into making this resource handbook both understandable and credible. Their efforts and contributions are sincerely appreciated.

Steve Curley; C.P.Ag./S.S.
Midwest Laboratories Agronomist
Editor

Richard D. Curley; C.P.Ag. (contributing editor)
Fremont, Nebraska

Richard Goff; C.P.Ag. (contributing editor)
Midwest Laboratories Agronomist
New Ulm, Minnesota

Robert Hecht; C.P.Ag. (contributing editor)
Midwest Laboratories Agronomist
Seneca, Kansas

Jim Eiting
Valmont Irrigation
Valmont Industries
Valley, Nebraska

Don Johnson
Arcadian Corporation

Ed Krysl
Hickson Kerley, Inc.
Phoeniz, Arizona

John Menghini; C.P.Ag. (contributing editor)
Midwest Laboratories Agronomist
Omaha, Nebraska

Kennard Pohlman; C.P.Ag./S.S.
Managing Director and President
Midwest Laboratories, Inc.
Omaha, Nebraska

Richard H. Vande Walle
Martin Marietta Chemicals

R. J. Waller
Columbia Nitrogen Corporation

FERTILIZER AND CHEMICAL APPLICATIONS THROUGH IRRIGATION SYSTEMS

Applying fertilizer solutions through irrigation water is not a recent development; the first agricultural use of anhydrous ammonia was through application in irrigation water in the early 1930's (2). With the mechanization of irrigation, particularly with the development of center pivot sprinkler irrigation systems, new application techniques have opened up for fertilizer and chemical solutions. New words describing these application techniques include fertigation, chemigation, fungigation, herbigation, insectigation and pestigation (18).

Many considerations must be evaluated and properly managed to effectively apply fertilizer and chemical solutions through irrigation systems, such as soil types, when and how to apply fertilizer and chemicals according to crop requirements, and selection and types of materials suited for use.

AGRONOMIC CONSIDERATIONS FOR FERTIGATION:

Fertigation (hereafter referring to application of fertilizer into irrigation water) will generally show good crop response on all soil types if managed correctly. However, sandier, well-drained soils, will tend to reflect a greater degree of response due to a higher rate of water intake which lessens runoff and decreases the possibility of fertilizer and chemical loss. In the case of nitrogen fertigation on sandier soils, nitrate nitrogen losses can be decreased by permitting small more frequent applications (10) (13).

A comprehensive soil analysis is an essential guideline aiding in scheduling irrigation and additions of supplemental nutrient applications. Besides percent organic matter, soil pH and nutrient levels, soil analysis can supply guidelines in areas of particle size distribution (percent sand, salt and clay), bulk density, and available soil moisture determination as well. Soil survey maps can pinpoint locations of each soil type.

A more balanced, complete fertilizer program can be justified under irrigated conditions. Nebraska data shown in Table 1 shows a 100-bushel per acre response to required additions of N-P-K-S on irrigated corn.

Table 1.

Irrigated Corn Response to Balanced Fertility Inputs (NE)

Fluid Fertilizer	Corn Yield bu/A	Response to Fertilizer bu/A	Value of Extra Yield $/A
-	97	-	-
N	178	81	202.50
NP	187	9	22.50
NPS	192	5	12.50
NPKS	197	5	12.50

Fertigation of a 20-0-3-4S solution on corn grown on a sandy soil at Muscatine, Iowa, showed a 75-bushel per acre response over fertigation using only UAN 28 solution (Table 2).

Table 2.

Influence of N, K & S Fertigation on Corn Yield[1/]

20-0-3-4S			28-0-0		
G X L[2/]	:	Yield (bu/A)	G X L	:	Yield (bu/A)
16 X 45	:	180	14 X 30	:	105

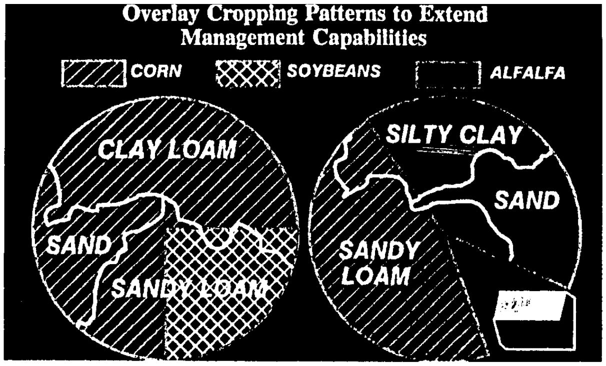
[1/] Curley, S. H. 1986. Fertigation field trial. Muscatine, IA

[2/] G X L = Girth (no. of kernels) X Ear Length (no. of kernels)

Irrigation response is not limited to crops grown on sandy soils and/or in limited rainfall areas. Studies have shown that the total amount of annual rainfall for a given crop isn't as important as the timing of the rain (4) (17). Properly managed irrigation can apply water in the right amount and at the correct time to economically justify irrigation even in areas where the annual rainfall exceeds 40 inches on medium and fine-textured soils.

Recent innovations in center pivot systems have allowed for variable rate application of water, fertilizer and chemicals (12) (19). Computer-aided devices allow for pivot control to stop at a particular point in the field, reverse directions, and/or run dry to another location in the field. Figure 1 illustrates the need for such control utilizing fertigation and/or chemigation across a field with varying soil types and crops (19).

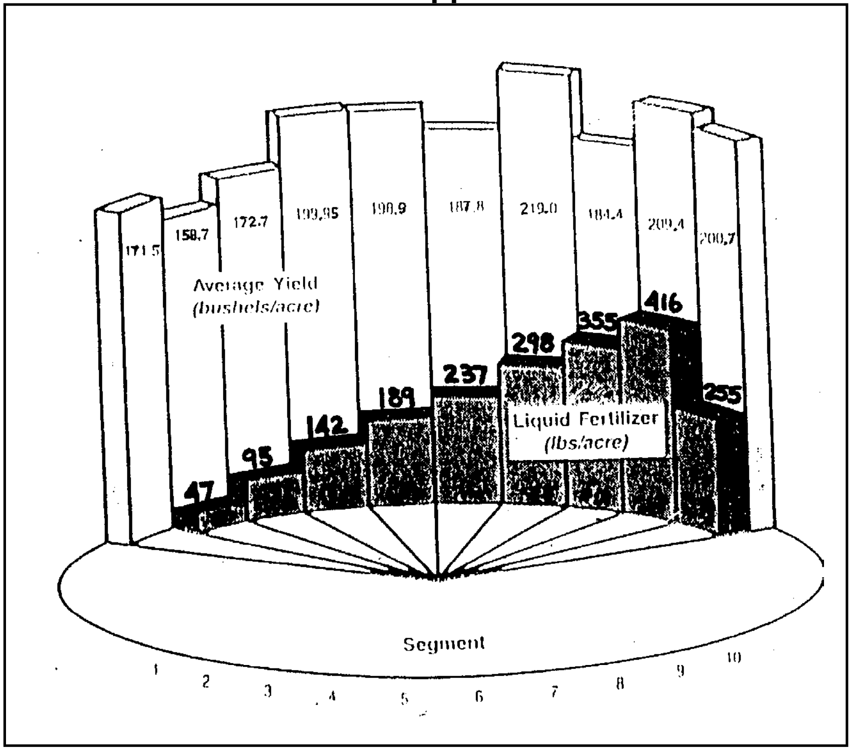
fig. 1. **The Future of Farm Mapping**



Research in eastern Colorado utilizing variable rate fertigation of liquid fertilizer via center pivot application is summarized in figure 2 (12).

fig. 2.

Effect of Variable Rate Fertigation of Liquid Fertilizer via Center Pivot Application on Corn Yields[1/]



[1/] The pivot was programmed to provide ten 12½ segments of a 130-acre cornfield with varying amounts of liquid fertilizer.

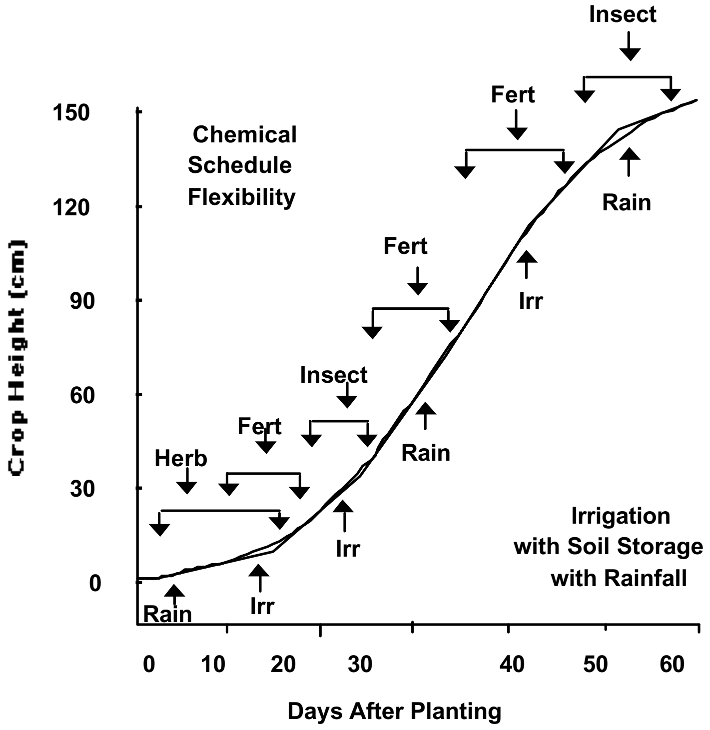
More precise control of water, fertilizer and/or pesticide applications via center pivot systems is a must regarding current and future concerns over water-use-rates, fertilizer economics and pesticide efficacy and safety. As quoted in the Omaha World Herald, these automated, variable control irrigation systems will "save farmers time; conserve energy and water.....and open the farm field to a new world of closely controlled automatically regulated farming." (19)

WHEN AND HOW TO APPLY/FERTIGATION CROP REQUIREMENTS:

CHEMIGATION STRATEGIES:

Chemigation scheduling is relatively simple and easily managed in areas where complete crop growth is dependent on irrigation and where the soil has very little moisure-holding capacity. However, the soil moisture conditions in most corn and grain sorghum production areas include both rainfall and irrigation. Under these conditions, chemigation strategies must include some flexibility to take advantage of the environment (water and soil) as well as to make the most efficient use of the irrigation system.

fig. 3.



The chart above represents such a strategy. It depicts a flexible chemigation schedule that can be used on soils with some moisture storage capacity and in areas when both rainfall and irrigation water are available during the growing season.

APPLICATION FLEXIBILITY:

Chemigation strategies for corn and sorghum will generally include herbicide, plant nutrients and insecticides. Herbicide approaches for corn and grain sorghum could include either preemergence treatment before the crop emerges, or early postemergence applications shortly after the crop is established. Plant nutrients can also be applied in a flexible schedule with proper management.

Insecticides applied with irrigation water have been successful in controlling a number of insects in corn and grain sorghum, including fall armyworm, corn earworm and European corn borer. Thus, herbigation, fertigation and insectigation, when combined with good crop and soil monitoring and recommended irrigation management techniques, can be successfully applied over a wide range of environmental conditions. And that success can result in reduced production costs and maximum crop yields.

NITROGEN FERTIGATION:

The amount of nitrogen to apply depends on the crop to be grown and the yield goal. Once nitrogen has converted to the nitrate-nitrogen form in the soil, potential nitrogen losses due to leaching are possible with accompanying irrigation. With large amounts of water being applied, especially on sandy soils, nitrate-nitrogen losses can be very high (13). Therefore, split-applications of nitrogen during the growing season become essential under irrigation. Where equal rates of broadcast and periodic split-applications of nitrogen were compared, the split-application technique showed less nitrogen leaching loss and higher yields in corn (10) (13). Additional research on corn has further supported the benefits of split applications of nitrogen by combining early side-dressed applications and later season sprinkler-applied nitrogen (9) (10). No matter which split application method is utilized, efficient nitrogen applications should be based on leaf analysis in an attempt to maintain adequate tissue nitrogen. During the later stages of periodic split-nitrogen applications, accompanying applications of small amounts of potassium, sulfur and boron have been shown to be beneficial also, especially on coarse and sandy, low organic matter soils (10, 21, 22).

Nitrogen applications before or at planting time should be two-thirds to one-half the total nitrogen need for corn or grain sorghum. The remaining one-third to one-half of the total nitrogen should be applied beginning at the 5 to 8-leaf stage of corn and the 5-leaf stage of grain sorghum (10).

Table 3.

Suggested Spit-Nitrogen Application Schedule
For Corn and Grain Sorghum (10)

			Weeks After Planting									
Method	**Preplant**	**Planting**[1]	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
							Lbs.N/A					
Corn												
Sprinkler	155	10			25		25	15	10	10		
Sprinkler	165				30		20	15	10	10		
Combination[2]	35	10		46Sd.		31Sd.		58Sp.		45Sp.	25Sp.	
Grain Sorghum												
Sprinkler	115	10			20		20	15			10	
Sprinkler	125				20		20	15			10	
Combination	20	10		35Sd.		25Sd.		45Sp.		35Sp.	20Sp.	

PHOSPHORUS FERTIGATION:

Phosphorus fertilizer in the form of ammonium polyphosphate solutions (APP) have been successfully applied in sprinkler irrigation water. However, due to relative phosphate immobility in soil, coupled with phosphate's importance for early season growth, sprinkler-applied phosphorus may not be meeting crop's needs during the critical early stages of growth (especially corn and grain sorghum). Research in Nebraska has been done to determine soil distribution of phosphorus

[1] Nitrogen applied at planting in a starter band application.

[2] Combination is both sidedress and sprinkler applied nitrogen, where Sd = sidedress and Sp = sprinkler.

from sprinkler-applied APP for a clay loam and sandy loam soil (13). The Nunn clay loam extractable P was restricted to the upper one inch of soil (fig. 4). The Haxtun loamy sand allowed movement of extractable P to a depth of seven inches. Even with phosphate movement to this depth, in order to benefit root supply and crop response, movement would have to have been very early in the growing season via sprinkler-applied APP. Lesser benefits from later season phosphate movement after the entire season's irrigation water would be expected (13). The same research also indicated a more favorable plant uptake of phosphorus and increased early season growth where broadcast incorporated or row-applied phosphorus was utilized in comparison to sprinkler-applied phosphorus. Sprinkler-applied phosphorus can be used as a viable saving treatment, or as a supplement on sandy soils. Generally crop response to phosphorus is through root uptake early in the growing season, so phosphate must be worked into the tillage layer first.

fig. 4.

Soil Profile Distribution of NaHCO-Extractable P

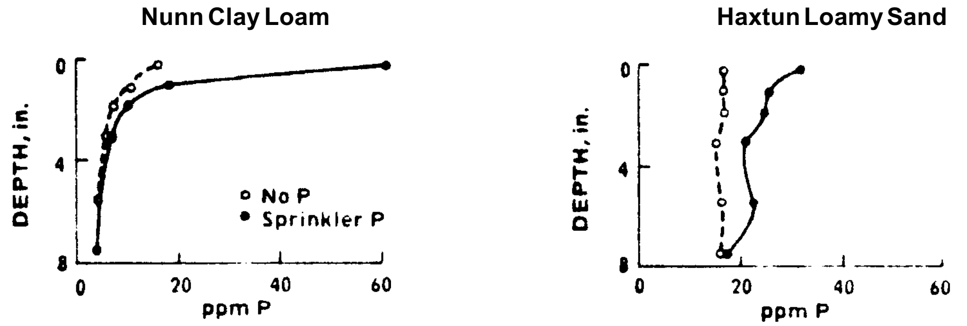


Fig. 1. Soil profile distribution of NaHCO.-extractable P.

POTASSIUM AND MAGNESIUM FERTIGATION:

For the same reasons just discussed for phosphorus, potassium and magnesium application in irrigation water is generally not recommended except on sandy soils. Research data from Nebraska (10) has shown that potassium can be the limiting factor in corn yields on irrigated sandy soils where high rates of nitrogen have been applied. Keeping both tissue nitrogen and potassium at high levels during the later injection applications is critical on sandy soils to aid in ear fill and higher yields. Light applications of both potassium and magnesium have been shown to be beneficial on corn, where one hundred pounds of a 20-0-4-5 Mg solution worked very well in western Nebraska and Kansas just prior to tasseling-silking time in corn (16).

SULFUR FERTIGATION:

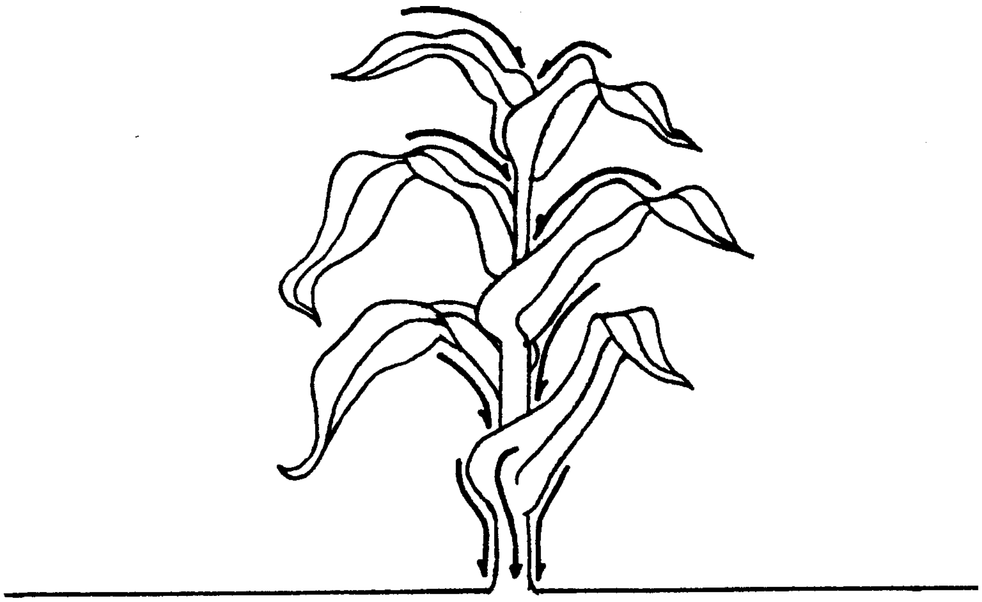
When sandier, lower organic matter soils are under irrigation, the need for sulfur becomes more pronounced. Just as nitrate nitrogen is highly leachable, so is sulfate sulfur, the form of sulfur taken up by plants. Periodic, split-applications of sulfur are recommended, along the same schedule as for nitrogen applications with approximately a 1:10 sulfur to nitrogen ratio being adhered to at each application. Total sulfur applications of ten to twenty pounds per season, depending on the amount of sulfur already contained in the water, are usually sufficient. Sulfur deficiencies are not uncommon on sandy soils, especially during cold, wet springs where irrigation may not occur before the 10 to 12-leaf stage in corn or grain sorghum. Correcting for these conditions requires supplementing sulfur before irrigation begins, applying sulfur in a starter (five to eight pounds of S per acre) or in preplant applications combined with nitrogen and/or phosphorus (preferably in a surface, dribble band) is highly recommended.

ZINC AND OTHER MICRONUTRIENT FERTIGATION:

The benefits of sprinkler system foliar applications of micronutrient are not always evident. Nutrient concentrations in irrigation water are generally at such a low level that foliar feeding through sprinkler systems is not effective. Generally, irrigation supplies one-half to one inch of water per application, while lower limits can be as low as one-fourth to one-third inch of water equalling an application of 7,000 to 9,000 gallons per acre (13). A 30-pounds per acre nitrogen application of urea ammonium nitrate (UAN28) in one-third inch of water equals a concentration of 200 ppm urea N, 100 ppm ammonium-N, and 100 ppm nitrate N. Normally, foliar feeding rates of 10 to 20 gallons per acre of concentrated fertilizer solution are applied, making the concentration of nutrients in irrigation water quite low in comparison, especially considering proportional amounts of micronutrients.

Responses to micronutrient fertigation cannot be entirely written off, however; quick-fix or rescue treatments in severe cases utilizing fertigated micronutrients may show favorable results. Figure 5 lends a possible explanation. Sprinkler application will thoroughly wet the entire plant, increasing the probability of foliar absorption nutrients. Additionally, water flowing off the leaf surface would tend to be directed downward and concentrate at the base of the stem, concentrating nutrients for root uptake. The positive interaction of moist soil, concentrated nutrients, as well as nitrogen present in the solution would contribute to the possibility of response to fertigated micronutrients.

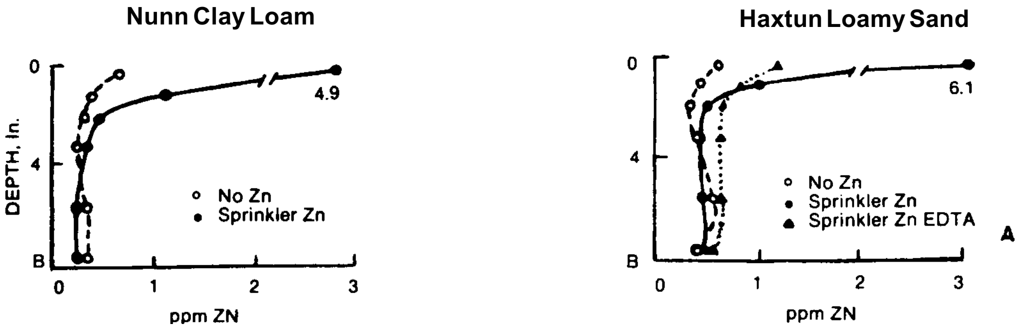
fig. 5.



Due to the importance of micronutrients at early stages of growth, in-row applications (zinc, iron, manganese, or copper) or broadcast incorporated (boron) are recommended. A notable exception might be zinc, as in-season zinc deficiencies in corn have been corrected with ZnEDTA on sandier soils (10). Research done on a sandy loam soil shows ZnEDTA movement to the four-inch depth, sufficient enough to correct in-season zinc deficiencies if applied early in the growing season (figure 6).

fig. 6.

Soil Profile Distribution of DTPA-Extractable Zn



Another exception might be boron, especially considering that the form of boron plants take up is a neutral (non-charged) molecule (boric acid: $B(OH)_3$). Boron soil movement in continuously irrigated, coarse, sandy textured, low organic matter soils can be likened to nitrate-nitrogen movement (21, 22). In order to accurately determine how much boron needs to be added during later irrigation applications (9-10 weeks after planting), a tissue test is highly recommended. Generally, one-quarter to one-half pound of boron per acre meets the later growth stage requirements in corn under continuous irrigation on sandier soils.

Table 4.

Suggested Fertigation Schedule For Corn and Grain Sorghum

WEEKS AFTER EMERGENCE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N			x		x		x		x			x		x	
P			●	●											
K			x		x		x		x			x		x	
Mg			▲		▲		▲								
Ca**															
S			x		x		x		x			x		x	
Zn*			■		■										
Mn*															
Fe*															
Cu*															
B									○			○			

x : N-K-S solution as 20-0-3-4S: first two applications may be sidedressed.
● : Phosphate materials (10-34-0 or 11-55-0) as rescue in sandy soils only.
▲ : Magnesim materal (chelate or FloMag®) applied with N-K-S solution above.
■ : Zinc material (chelate formulations) applied as rescue in sandy soils only.
○ : Boron material (Solubor®) applied along with N-K-S solution above.
* : Best applied in a starter.
** : Calcium needs are best met through liming material applied prior to planting. However, supplemental Ca needs during weeks 5-9 can be met by using Promesol®, or calcium nitrate. Check for fertilizer formulation compatibility anytime calcium products are added to the fertilizer formulation. Calcium is <u>not</u> compatible with phosphorous or sulfur products.

SELECTION OF MATERIALS:

NITROGEN MATERIALS; ANHYDROUS AMMONIA:

Anhydrous ammonia can be injected into the irrigation ditch, gated pipe or even sprinkler irrigation systems **only if** a water softening agent is injected ahead of the ammonia. Scalings from accumulations of calcium carbonate on the inside of siphon tubes, walls of pipes, and sprinkler nozzles will readily form without additions of a sodium polyphosphate softening agent (i.e., Calgon) into the irrigation stream ahead of the ammonia.

The ratio of ammonia to water should not exceed 110 ppm ammonia for most water supplies and should not exceed 50 ppm ammonia in some highly alkaline water (2) (15). For example, a well producing 1,000 gpm could be capable of carrying 55 pounds of ammonia per hour; highly alkaline water could carry a maximum of 25 to 30 pounds per hour. To accurately determine how much ammonia and inhibitor to apply, the water quality (hardness) must be analyzed. See appendix for relative rates of ammonia and inhibitor injection.

UREA AMMONIUM NITRATE SOLUTIONS (UAN 28, 30, 32):

These are non-pressure nitrogen solutions and are readily adaptable to fertigation with all types of irrigation systems: ditch, gated pipe, and sprinklers (solid set, movable and center pivot). See appendix for examples of field calculations for UAN solution applications.

Other fertilizer materials available for nitrogen fertigation include calcium nitrate (15% N), ammonium nitrate solution (21% N), urea solution (19% N), combinations of ammonium nitrate and urea solutions, aqua ammonia (which is subject to the same restrictions as injection of anhydrous ammonia), ammonium thiosulfate (12-0-0-26S), and ammonium sulfate solutions (base grade: 8-0-0-9S).

PHOSPHATE MATERIALS:

Ammonium polyphosphates (APP) (10-34-0; 10-37-0, 7-21-7 etc.) and suspensions utilizing mono-ammonium phosphate (MAP) (11-55-0) can be applied through irrigation systems, but the quality of the irrigation water must be known beforehand. APP solutions may react in hard water (high calcium, magnesium and bicarbonate content) forming a precipitant (calcium ammonium pyrophosphate) (7) which collects on the walls of the pipes and nozzles and eventually causes plugging. A simple test for APP compatibility with the irrigation water follows (11):

(1) Measure an amount of irrigation water in milliliters (ml.) equal to the gpm pumping rate, i.e., 950 gpm = 950 ml.

(2) Add the number of ml. of APP equal to the desired APP pumping rate to the measured amount of irrigation water.

(3) If a cloudy precipitate forms, the addition of APP to this irrigation water is not advisable.[1/]

Urea-phosphate solutions (UP) are acid-based phosphate fertilizer formulations that have shown promise for use in irrigation systems with hard water. These formulations will sequester calcium and

---

[1/] The Tennessee Valley Authority (TVA) has conducted studies showing that formation of insoluble calcium and magnesium pyrophosphates upon additions of APP into hard irrigation water could be avoided by adding phosphoric acid to decrease the pH of the APP base solution to 4 or lower (1).

magnesium preventing formation of precipitate in the irrigation water (1). Base solutions made from UP and water resulting in an 8-20-0 grade have a pH of 1.5, made by dissolving crystalline UP in water with added head (125½ F: dissolution time of five minutes; heat of 150½ F allows dissolution in one minute). Studies conducted by TVA with two relatively hard irrigation waters (the Republican River near Culbertson, Nebraska, and the Colorado River in Colorado) using a UP 8-20-0 solution showed no precipitation difficulties (1). Resulting pH of the applied irrigation water was 7.0 and 6.8, respectively. For practical use in irrigation systems, about 800 gallons of water per pound of P_2O_5 per acre should be applied. This rate of application in hard water is possible using UP 8-20-0 base solution, while in the same waters only 25 gallons of water per pound of P_2O_5 can be applied without precipitation problems using APP 10-34-0 (1).

See appendix for information on fertigation worksheets for application of N, P and K solutions and suspensions through center pivot systems.

POTASSIUM AND MAGNESIUM MATERIALS:

Potassium is available in some clear solutions (i.e., 3-18-18, 9-18-9, 7-21-7, etc.). However, when potassium is generally applied through irrigation systems (center pivot units), it is needed without accompanying phosphorus. So applying potassium, as KCl (0-0-62) through irrigation water generally requires premixing solutions or suspensions of potassium fertilizer materials. Development of potassium thiosulfate (KTS: 0-0-25-17S), a clear solution, has lent considerable flexibility in formulating solutions of soluble potassium with a variety of fertilizer materials with minimal mixing. Potassium nitrate is also another highly soluble, flexible-use potassium material available for fertigation purposes.

Additions of KCl, water and UAN 28/32 solution can be easily made with a minimum of mixing time required. A typical analysis of this solution would be a 20-0-3. Where higher analysis potash mixes are needed, suspensions requiring clay must be made. A 60 percent KCl suspension made from water, clay, UAN 32 and KCL making a final analysis of 12-0-25 is possible. See appendix on suspension formulations and conditions.

Magnesium applications through irrigation water have been generally restricted due to mixing and solubility problems of magnesium, either as a sulfate of potash magnesia or as magnesium oxide. One of the problems is that successfully suspending magnesium materials requires a strict mixing order to first get a good gel strength with clay, or using a special liquid clay for gelling strength, in addition to properly adding the magnesium and other fertilizer materials in the correct order. Improper suspension formulation utilizing magnesium fertilizer materials such as sulfate of potash magnesia or magnesium oxide can turn extremely viscous and, in effect, nonflowable, due to magnesium hydration of the suspension (loss of water in the mix) (6, 20). Higher quality MgO materials are currently available which enable flowable suspension formulations of magnesium without associated hydration problems in the mix (16), **only if** proper procedures are followed in the suspension formulation process. See appendix **(Table A-20)** for example suspension formulations involving MgO. $MgSO_4$ can also be utilized as a magnesium source, but because of its hygroscopic properties (takes on water from the air) and high cost, use on a wide basis is restricted. Magnesium has been applied through sprinkler systems as a chelate solution containing 2 1/2 percent Mg (23). However, meeting total magnesium requirements via sprinkler irrigation using magnesium chelate solutions may not be economically feasible, especially on sandy soils.

SULFUR MATERIALS:

Suitable sulfur sources include ammonium thiosulfate (12-0-0-26S: fluid), potassium thiosulfate (0-0-25-17S: fluid) ammonium sulfate (21-0-0-24S: dry), ammonium sulfate solution (8-0-0-9S), and finely divided elemental sulfur (92% S).

Ammonium thiosulfate (ATS: 12-0-0-26S) and potassium thiosulfate (KTS: 0-0-25-17S) are highly compatible fluid nitrogen-sulfur, potassium-sulfur materials having both elemental and sulfate sulfur in the formulation. ATS-UAN and KTS-UAN combinations will do better yield-wise than UAN alone, due to the ATS/KTS effect of reducing free ammonia loss from the UAN (10). As little as 2 percent ATS/KTS in UAN (by volume) gives the effect; however, through irrigation water 10 percent ATS/KTS in UAN (by volume) would be recommended as a minimum.

Ammonium sulfate (21-0-0-24S) is a dry, granular material, but will readily dissolve in water or UAN mixtures to yield an 8-0-0-9S solution. UAN-ammonium sulfate combinations are highly compatible and premixing and storage have proven to be an effective method of handling ammonium sulfate for fluid applications. Ammonium sulfate is also available in solution form as an 8-0-0-9S. See appendix table A-25 for liquid nitrogen: sulfur grades utilizing both dry and fluid forms of ammonium sulfate.

Finely divided elemental sulfur (92 percent S) can be utilized in fluid suspension mixtures. However, a very fine sulfur material must be utilized (-200 mesh or 2 or 44 micron size). As with any suspension, correct formulation is critical in attaining a good, flowable material. Refer to page 80 in the appendix: suspension formulation considerations, and specifically table A-22 page 81 of the appendix for guidelines in using elemental sulfur in suspension formulations.

ZINC AND OTHER MICRONUTRIENT MATERIALS:

If these nutrient are to be applied through a sprinkler-type system, formulations should be applied so that the element can move through the soil (anion form) (10). Chelated micronutrients would serve this purpose: ZnEDTA, FeEDHA, CuEDTA. Zinc ammonia complex can be used also, as well as lignosulfonates and amino acid chelates. Urea-sulfuric and/or urea-phosphoric solutions have shown effective sequestering capabilities for micronutrient materials. The acidic properties of these solutions combined with micronutrients allow less expensive micronutrient materials to be used as well as enhancing micronutrient availability once applied. Again, other than for zinc applications, little documented work citing crop responses to micronutrients applied via sprinkler-type irrigation systems has been done (13).

CHEMIGATION:

Herbicides, insecticides, fungicides, and a variety of other pesticides used in control of weeds, insects and disease in crop management are being utilized in sprinkler irrigation systems. Considerations as to EPA approved labels on specific products and State Department of Agriculture rulings on sprinkler-applied chemicals must be assessed before use is legal. Where use is approved, prime consideration must be given to soil type, the amount of active ingredient per gallon of liquid product, time of day and even time of growing season.

Advantages of applying herbicides and pesticides through center pivot or well-designed solid set irrigation systems include uniformity of a prescription application, timeliness, and chemical incorporation and activation. Research has proven that herbicides and fertilizers can be applied together without sacrificing efficacy or utilization of materials (7). Combining materials in this manner in one application results in considerable reduction in application cost (Table 5).

Table 5.[1]

Costs of Conventional and Chemigation Application of Chemicals

Type of Chemical	Conventional[a] ($/A)	Chemigate[b] ($/A)	Water Applied (in.)
Fertilizer	2.25	2.25	0.5
Herbicide	5.60[c]	1.80	0.4
Insecticide	2.25	0.70	0.15
Fungicide	2.25	0.70	0.15
Nematicide	5.60[c]	2.25	0.5

[a] Cost of aircraft or tractor sprayer assumed to be equal.
[b] Based upon operating costs of a 150-acre center pivot (fixed costs charged against irrigation).
[c] Includes cost of mechanical incorporation.

HERBIGATION (14):

Many herbicides have been demonstrated to selectively control weeds in crops when applied through a well designed and properly functioning sprinkler irrigation system. These include preemergence agents like alachlor, atrazine, benefin, bensulide, butylate, chloramben, cyanazine, dimethazone, diphenamid, trifluralin, and vernolate. Postemergence herbicides used successfully via herbigation include acifloren, bromoxynil, chloramben, fluazifop, halaxyfop, lactofin, naptalam+dinoseb, tridiphane, and xylafop. Trifluralin has also been used successfully as a postemergence treatment in corn for suppression of shattercane and control fo sandbur (applied prior to 4-leaf stage of corn) (3). Bentazon, glyphosate, imazaquin, MSMA, paraquat, and sethoxydim have also been used, but have shown poor or variable activity.

Crop tolerance to preemergence herbigation has been good to excellent, and crop tolerance to postemergence herbigation has been good also.

Postemergence herbigation results have been encouraging but somewhat variable, most likely due to herbicide runoff from plant foliage. Currently, postemergence application of herbicides through sprinkler irrigation is not feasible in less than 0.1 inch or 2,715 gallons/acre of water, exceeding the volume of water necessary to cause foliage runoff by approximately 28 times. All water soluble or water-miscible herbicide formulations have generally shown poor activity when applied postemergence via herbigation, with the exception of sethoxydim. However, additions of nonemulsifiable vegetable or petroleum-based oil have been shown to aid in the improvement of more consistent postemergence efficacy via herbigation (tridifane activity was not positively influenced by an oil carrier).

INSECTIGATION (14):

Insectigation was first done in the mid-1970's using methomyl, a water soluble compound, but control was highly variable. Water soluble oil formulations have since proved to be the most effective for use in sprinkler irrigation systems, however, dimethoate, methomyl, and monocrotophos have proven unsuccessful.

Successful compounds, used as either oil additives or as technical plus oil formulations have included Orthene 75S, Sevin 4-Oil 80S, Furadan 4F, Lorsban 4E technical, cypermethrin technical, diazinon 4E, Kelthane 1.6 EC, Disyston 8E, Thiodan 2E, Pydrin 2.4 EC technical, malathion 4E technical, permithrin technical, Comite 6EC, Bolstar 6EC, Larvin 4F oil, and toxaphene 8EC

[1] Co-chemigation Showing Promise. Dowler, C.C. Solutions Magazine, January, 1985 pp. 36-43.

technical. EPA, state, and local regulations will ultimately determine insecticide use through sprinkler irrigation systems. Table 6 lists the crops treated and insects controlled by insectigation using oil formulations.

Table 6.

Crops Treated and Insects Controlled by Chemigation

Crop	Insects Controlled
Broccoli, cabbage, cauliflower, collards	Cabbage looper, imported cabbage worm
Corn, field and sweet	Corn earworm, fall armyworm, stink bugs, spider mites, aphids
Cotton	Boll weevil, caterpillar group
Cucumbers, squash	Spotted cucumber beetle, pickleworm
Lima beams	Stink bugs, corn earworm
Peanuts	Thrips, leafhoppers, corn earworm, fall armyworm
Snap beans	Thrips
Sorghum	Corn earworm, fall armyworm, stink bugs
Southern peas	Pea weevil, lesser cornstalk borer
Soybeans	Corn earworm, soybean looper, velvetbean caterpillar, stink bugs
Spinach	Vegetable weevil, leafminer, tarnished plant bug
Tobacco	Caterpillar, aphids
Tomatoes	Tomato fruitworm, corn earworm, Colorado potato beetle
Turnips	Diamondback moth, aphids

FUNGIGATION (14):

Fungicides have been applied through overhead sprinkler systems for more than ten years. Successful control of foliar diseases via fungigation include early blight, late blight, and *Botrytis* vine rot of Irish potato; *Cercospora* leaf spot and *Rhizoctonia* crown rot of sugar beet; early and late leaf spots of peanut; and white mold of dry beans. However, no studies to date have been conducted using water-insoluble formulations for foliar disease control.

Several soilborne pathogens have successfully been controlled with metam-sodium applied through overhead irrigation systems. These pathogens include *Verticillium* wilt of Irish potato; *Pythium* and *Rhizoctonia* root rot of collard, spinach and cucumber; pod rot and *Verticillium* wilt of peanut; white rot of onion; and lettuce drop. *Fusarium* sp. are not controlled by metam-sodium. PCNB and carboxin have been applied through sprinkler irrigation and provided good control of southern stem rot of peanut in Alabama. However, other broad spectrum fungicides, such as methyl bromide, have not been applied through sprinkler irrigation.

Fungigation can be an effective means of application especially if treatment on a broadcast basis is called for. However, soil fungicides are usually applied in-furrow or banded over the row and obtaining equivalent concentrations via irrigation water would require three to six times as much chemical. Therefore, fungigation of soil fungicides on crops in rows of 3 feet or more apart may not be economically or environmentally advantageous. Fungigation is effective, however, when rows are close, or if the entire soil surface requires treatment, allowing more uniform distribution and efficacy when applied through overhead irrigation water.

CONSIDERATIONS IN REVIEWING AGENTS PRIOR TO CHEMIGATION (18):

Effective and economically sound benefits from use of some chemicals via chemigation have been demonstrated for quite some time. However, some crop protection mixtures are not appropriate for chemigation: use of caution and common sense is a foremost consideration. Chemigation can only be an acceptable application alternative if it is performed in strict adherence to requirements applied to other types of crop protection applications. Recommendations follow regarding chemical agent toxicity ratings and corresponding suitability of their use for chemigation purposes. Economics of use or efficacy of application is not the issue in these recommendations but rather safety for human considerations.

No member of Toxicity Class I (oral LD_{50} less than 50 mg/kg or dermal LD_{50} less than 200 mg/kg) is recommended to be applied by chemigation. Class I agents can be more safely applied by means other than chemigation, lessening potential human exposure from in-field crop monitoring and setup and disassembly of irrigation equipment. Table 5 lists agents within the Class I toxicity rating.

Use of Class II toxicity agents (oral LD_{50} 50-500 mg/kg or dermal LD_{50} 200-2000 mg/kg or producing severe skin reactions) via chemigation should be exercised with caution. If application of those agents in the Class II toxicity rating are intended, careful precautions by the applicator are warranted. Table 8 lists the Class II toxicity agents.

Table 7.

Class I Toxicity Agents—*Chemigation Not Recommended*

Acti-dione PM
(cycloheximide) f[1]
Aldrin i
Aldicarb i, n
Bidrin i
Carbofuran i, n
Co-Ral i
Dasanit i, n
DDVP i
Delnay (dioxathion) i
Dinoseb h
Di-systox i
Dithio i

DNOC f, i, h
Dyfonate i
Endrin i
EPN i
Famphur i
Guthion i
Lannate (methomyl) i
Methyl parathion i
Monitor i
Nemacur (phenamiphos) n
Paraquat[2] h
Parathion i

Phosdrin i
Phosphamidon i
Picfume (chloropicrin) f
Sulfotepp i
Systox (demeton) i
TEPP i
(phorate) i
Thiodan (endosulfan) i
Trithion (carbophenothion) i
Vydate (oxamul) i, n
Warbex i
Zectran i

1. f = fungicide, i - insecticide, n = nematicide, h = herbicide
2. Paraquat is not strictly a Class I agent on the basis of LD_{50}, but is included here because of its effects and its usual handling procedures.

Table 8.

Class II Toxicity Agents—*Chemigation with Strict Precautions*

Alanap (naptalam) h[1]
Arasan (thiram)[2] f
Basagran (bentazon) h
Baygon i
Baytex (fenthion) i
Bendiocarb i
Bordeaux mixture f
Bromoxynil h
Bux i
Ciodrin i
Cygon (dimethoate) i
D-D n
Dexon f

Diazinon i, n
Dibrom (naled) i
Dithane D-14 (nabam) f
Dursban (Lorsban) i
Duter f
Entex (fenthion) i
Ethion i
Fenvalerate i
Fundal i
Galecron i
Imidan i
Lindane i

Mesurol i
Meta-Systox R i
Nicofume i
Nicotine sulfate i
Pydrin (fenvalerate) i
Randox (CDAA)[2] h
Rotenone i
Ruelene i
Telone[2] n
Vapona i
Vorlex f, n
Zolone (phosalone) i

1. f = fungicide, i =insecticide, n = nematicide, h = herbicide
2. May be listed for severe skin reaction effect as well as for LD_{50}.

FERTIGATION/CHEMIGATION PRECAUTIONS OF USE:

WATER QUALITY CONSIDERATIONS:[1/]

A water analysis should be obtained before system design so that problem elements can be assessed and water treatment strategies outlined. The pH should also be known since higher pH's

[1/] Bisconer, Inge. 1986. Chemigation with micro-irrigation systems: An overview with design considerations. In: Proceeding of Winter Meeting American Society of Agricultural Engineers. Chicago, IL Dec. 16-19, 1986.

will often cause precipitation of elements in solution, and decrease the effectiveness of chlorine as a water treatment remedy. Table 9 serves as a guide in the interpretation of a water analysis:

Table 9.

	Clogging Hazard		
Water Quality Parameter	**Slight**	**Moderate**	**Severe**
pH	< 7.0	7.0 - 8.0	> 8.0
Dissolved Solids (max. ppm)	< 500	500 - 2000	> 2000
Manganese (ppm)	< 0.2	0.2 - 0.4	> 0.4
Iron (ppm)	< 0.1	0.1 - 0.4	> 0.4
Sulfides (ppm)	< 0.1	0.1- 0.2	> 0.2
Calcium Carbonates (ppm)		No levels established	

WATER TREATMENT:

Routine system maintenance may include treating the water with chlorine to control organic growth. Chlorine is an effective biocide which will prevent microorganic growth in a micro-irrigation system and prevent emitter clogging. Since chlorine is most effective at lower pH's, it is important that the pH of the water be monitored and, if necessary, controlled during chlorination.

At times, chlorine is used to precipitate iron, manganese and sulfur out of solution prior to filtration. Care should be exercised in determining the rate of precipitation of each of these chemicals, particularly if they occur together, so that precipitation of one or several does not occur downstsream of the filter. Since chlorine will react with ammonia to form chloramines, nitrogen and chlorine should be injected at separate times.

Routine system maintenance may also include treating the water with acid to prevent the precipitation of dissolved solids such as iron and carbonate, and to increase the efficacy of chlorination. Commonly applied acids include phosphoric acid (which may also add phosphate to the root zone), hydrochloric acid (muriatic acid), and sulfuric acid (sulphur dioxide).

Once the water has been treated, the system must be thoroughly flushed to expel resultant particulate matter from the system. Organic matter which has been killed by chlorine or decomposed by acid could clog the emission devices if not flushed.

FILTRATION:

Irrigation filtration selection is dependent on the type and quantity of contaminants in the source water initially, and the effluent quality required for the type and size of emission devices to be used. Physical contaminants in irrigation water consist of both organic and inorganic matter. The organic contaminants include algae, weed seeds, aquatic plants and animals, and generally anything that is or was alive. The inorganic contaminants include the range of soil (sand, silt, and clay) particles, scale from rusted pipes, and chemical precipitates, such as iron ochre, calcium carbonates, sulfur and manganese. A successful rule of thumb is to provide filtration one-seventh to one-tenth the aperture size of the emission device to be used.

SAFETY PRECAUTIONS:

The following use precautions will result in a safe and successful application of fertilizer and chemicals plus oil mixtures:

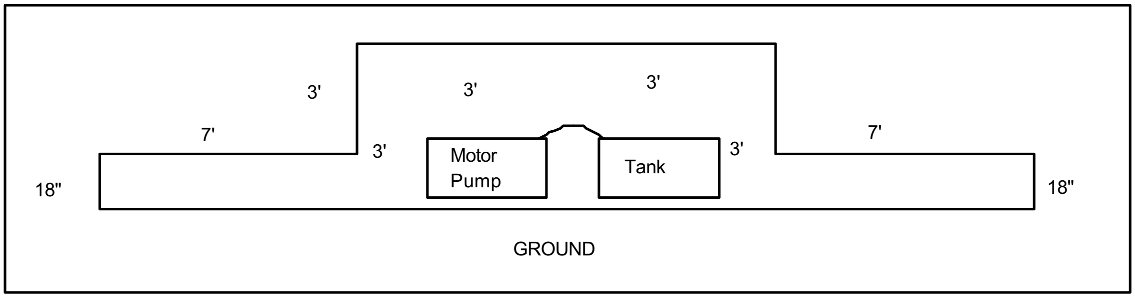
1. Check label for Class IC Flammable Liquid. Class IC Flammable Liquid Use (including petroleum-based oil additives) through overhead sprinkler irrigation systems should comply with all fire regulations that apply to Class IC flammable liquids.

2. **Minimum distances** between injection equipment, tanks and electrical ignition sources, **proper electrical construction** are essential to safely handle any pesticide formulation containing petroleum-based oil (non-emulsifiable) through center pivots. Electrical installations must meet Class I, Group D, Division 1 or 2 requirements as specified in the National Electrical Code 70 (NEC 70). This type of wiring is generally referred to as explosion proof. Consult with a certified electrician to correctly wire the injection system as defined by NEC 70 for hazardous area applications.

If insecticide is diluted with at least 2 parts water, the chemical injector motor and wiring need not be explosion proof. Non-explosion proof electrical equipment must either be outside the hazard zone or disconnected from the power source while making the dilution.

3. The injector unit and steel drums (or steel tank) of insecticide are surrounded by a hazardous zone. Any electrical motors or electrical writing **within the hazardous zone** must conform to Class I, Group D, Division 1 or 2 wiring standards. The hazardous zone will look like the following drawing, which is taken from the National Fire Protection Association, Inc. (NFPA 497):

fig. 7.



The minimum distances describing the hazardous zone illustrated by the shaded area (figure 7) are three feet in all directions from the equipment plus an additional seven feet away by 18 inches above grade. Any wiring outside of this hazardous area need not be explosion-proof.

4. Use only **steel** mix tanks which are large enough to allow the system to complete a revolution with one filling. It should be free of rust, fertilizer, sediment and foreign material and equipped with an in-line strainer placed between the tanks and the injector pump.

5. The irrigation pumping plant and the chemical injection pump must be interlocked so that if the irrigation pumping plant stops, the chemical pump will also stop. This procedure will help prevent the possibility of accidentally filling the entire irrigation pipeline with the chemical mixture from the supply tank if the irrigation unit stops running.

6. Properly functioning check and vacuum relief valves (anti-siphon devices) are required in the irrigation pipeline to keep water and/or a mixture of water and chemical from draining or siphoning back into the irrigation well and polluting the groundwater. Both of these valves are located **between** the irrigation pump discharge and the place of chemical injection into the irrigation pipeline[1/]. Make sure they are present and functioning properly.

7. A properly functioning check valve in the chemical injection line is required to stop the flow of water from the irrigation system back into the chemical supply tank.

8. Safety shut-off provided independently of the system for the injector pump (if electric motor is used).

[1/] Local and state laws normally specify proper location and construction of check and vacuum relief valves. Consult your State Department of Agriculture for details.

9. A positive displacement pump is required to provide uniform injection into the water line. The injection pump must provide a greater pressure than that of the irrigation system at the point of injection. The pump must contain Viton seals and all electrical service must meet National Fire Protection Association 30 (NFPA 30) and NEC 70.

10. To ensure uniform mixing of the pesticide into the water line, inject the mixture into the fertilizer injection port of just ahead of an elbow or tee in the irrigation line so that the turbulence created at those points will assist in mixing. It is suggested that the injection port be higher than the pesticide tank to prevent siphoning.

11. Do not apply a pesticide solution when wind speed or direction results in unacceptable drift from the application area.

12. Do not allow irrigation runoff to collect or runoff and pose a hazard to livestock, wells, or adjoining crops.

13. Allow foliage to dry before reentering fields.

14. When transferring pesticide formulations from the container to the steel tank, be sure to disconnect the pump and injector from the electrical source and be sure that the electrical source is at least ten feet away and 18 inches off the ground in any direction from the injection unit and tank.

15. Use nylon or xylene resistant hoses.

16. Apply through systems with uniform water distribution.

CHEMIGATION SYSTEM DESIGN:[1/]

Chemigation systems must incorporate proper safety and injection equipment. The following presents some guidelines in equipment selection and system design.

SAFETY EQUIPMENT:

The importance of incorporating proper safety equipment in a chemigation system design cannot be over-stressed. Two specific hazards are: (1) the irrigation pumping plant may shut down from mechanical or electrical failure while the injection equipment continues to operate, causing a mixture of water and chemicals to backflow into the irrigation well or other water source, or possibly causing chemicals to empty unnecessarily into the irrigation system, and (2) the chemical injection system may stop while the irrigation pump continues to operate, causing water to backflow through the chemical supply tank and overflow onto the ground. Two strategies used to prevent these hazards are backflow prevention devices and interlock injection devices. Figures 8 and 9 illustrate safe chemigation system design.

Although chemigation poses some inherent dangers, it should be noted that proper chemigation in a micro-irrigation system has the potential of enhancing safety conditions. First, the risk of groundwater pollution and environmental contamination are reduced by virtue of its precision. Second, lesser amounts of less toxic chemicals are often applied through a system which decreases the exposure and number of individuals involved with conventional pesticide application.

[1/] Bisconer, Inge. 1986. Chemigation with micro-irrigation systems: An overview with design considerations. In: Proceedings of Winter Meeting American Society of Agricultural Engineers. Chicago, IL Dec 16-19, 1986.

Four different types of backflow prevention devices are used to protect the water source from chemical contamination. Two of these are double check valves and reduced pressure principle devices which are used to prevent both back siphonage and back pressure, but the double check valve is not recommended for use with toxic chemicals. Atmospheric vacuum breakers and pressure vacuum breakers are two other types of devices which are used to prevent backsiphonage only.

fig. 8.

Micro-Irrigation Control Station

LEGEND:

AV = ANTISIPHON VALVE
BPD = BACKFLOW PREVENTION DEVICE
CST = CHEMICAL STORAGE TANK
FV = FOOT VALVE
INJ = ELECTRICAL CHEMICAL INJECTOR
P = PUMP
PG = PRESSURE GAUGE

PR = PRESSURE REGULATOR
S = SOLENOID VALVE
ST = STRAINER
TC/SR = TIMER CONTROLLER & SAFETY RELAY
WM = WATER METER
WF = WATER FIILTER OR FILTERS
VB = VACUUM BREAKER

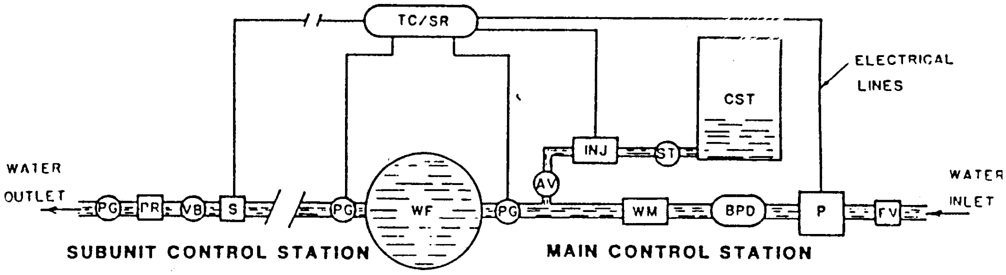
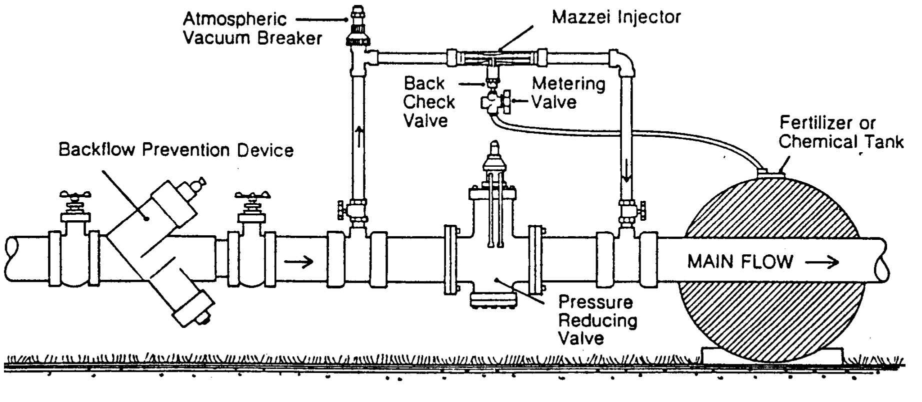


fig. 9.

Use of Safety Equipment with Mazzei Injectors



Backflow prevention devices should be installed between the water supply or pump and the chemical injection line.

Interlock injection devices insure that if the irrigation pumping plant stops, the chemical injection pump will also stop. If the irrigation pump and chemical injection pump are both electric, the electric controls for the two electric motors should be interlocked. The chemical injection pump may also be interlocked with the irrigation pumping plant with sensing devices such as flow or pressure switches, or conductivity meters if fertilizer is being injected.

Simultaneously, a safety device is needed to prevent water from flowing back through the injection pump and overflowing the chemical supply tank whenever the injection pump is turned off and the irrigation pump is still operating. A check valve, vacuum breaker or normally-closed solenoid valve can be placed in the injection line after the injection pump. A solenoid valve will provide a positive shutoff on the chemical injection line so that neither the chemical nor the water can flow in either direction if the chemical injection pump stops. An electric solenoid valve must be electrically connected with the motor driving the electrical injection pump and electrically interlocked with the irrigation pump.

INJECTION EQUIPMENT:

Several types of chemical injectors are available (figure 10), each varying in price, power source, degree of accuracy and longevity. Although each injector will pump varying concentrations of chemical over time (figure 12), all are suitable for use in micro-irrigation systems providing each valve zone obtains the same amount of chemical. Regardless of type, any components coming into contact with chemical must be of plastic or stainless steel to prevent corrosion.

Positive displacement pumps inject chemicals precisely and are operated by electricity, gasoline engines or water power using the pressure of water in the irrigation system. Although more costly, they are easily controlled and provide for complete command of injection rate and duration of application. Pumps may be either of the proportional rate type, where the injection rate changes with the water flow in the system so that a constant dilution ratio is maintained, or of the constant rate type, where the injection rate is independent of the mainline flow and dilution ratio is variable.

Venturi suction devices are simple and are of low cost, operating by means of a pressure differential inducted by a constriction within the mainline at the site of injection. Should energy costs prohibit implementation of a constriction, a venturi may be installed in series with a small centrifugal pump in a parallel circuit. This may be engineered to operate more than one venturi, allowing injection of more than one chemical simultaneously.

Differential pressure tanks, or batch tanks, have their inlet and outlet connected to the main line at two points having different water pressures, causing water to flow through the tank and displace the chemical it contains. Although no power source is necessary, it is important to note that the chemical concentration decreases with time, limiting each batch injection to one valve zone to maintain distribution uniformity.

Controllers are available which allow complete automation and monitoring of the chemigation operation. For instance, several are capable of initiating injections, monitoring their activity, and deactivating injections according to external sensors such as flow and pressure switches, EC and pH monitors, and weather data.

The chemical injection point should be located upstream of the filter. This will prevent microorganic growth in the filter, and filter out any precipitates that may occur due to the injection of chlorine. Chlorine may precipitate iron, manganese and sulfur out of solution, and many fertilizers will react with one another, and with chlorine, to form insoluble compounds.

The chemical injection and suction ports should be carefully placed. In order to maximize chemical and water mixing, it is best to extend the injection nozzle into the center of the pipeline where velocity is at its highest. Although the degree of chemical mixing will largely depend on the viscosity and solubility of the chemical, one test found that proper mixing of UAN-32 (specific gravity 1.33 vs. specific gravity of water 1.0) occurred within 60 pipe diameters (50 ft) of the injection site. It may be wise to equip the chemical tank with an agitator if mixing is anticipated to be a problem. The chemical suction port should be placed above the bottom of the chemical supply tank to prevent the suction of impurities.

fig. 10

Chemical Injection Devices

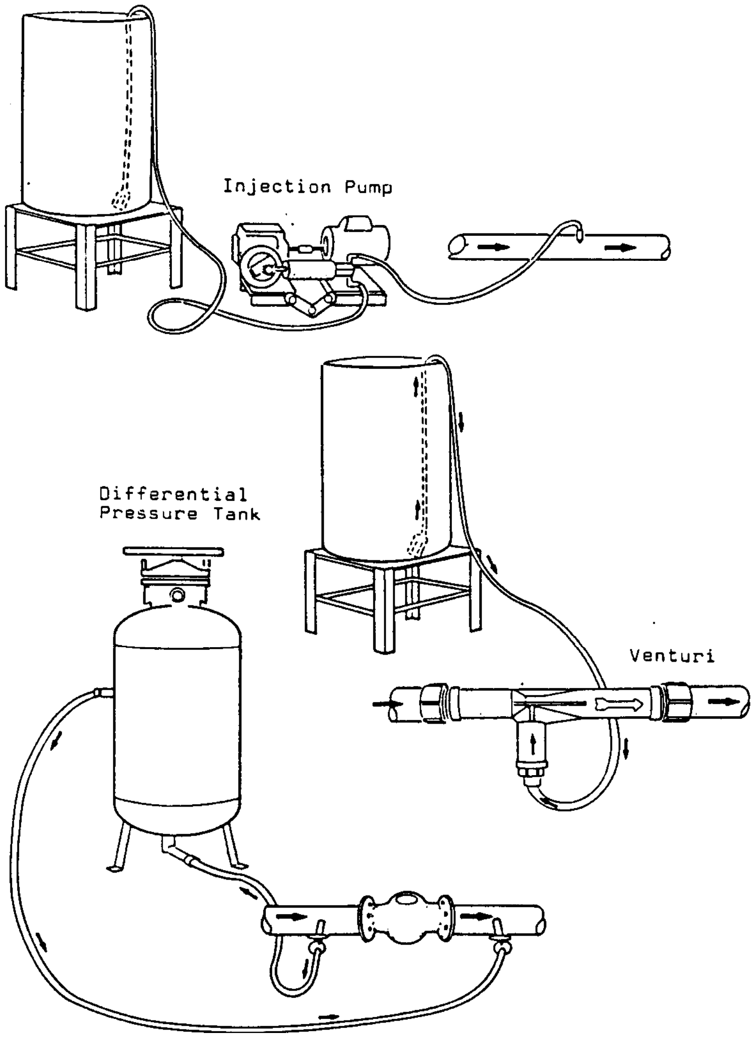


fig. 11.

Diagram of Metering and Injection Equipment for Applying Fertilizer in Irrigation Water (4)

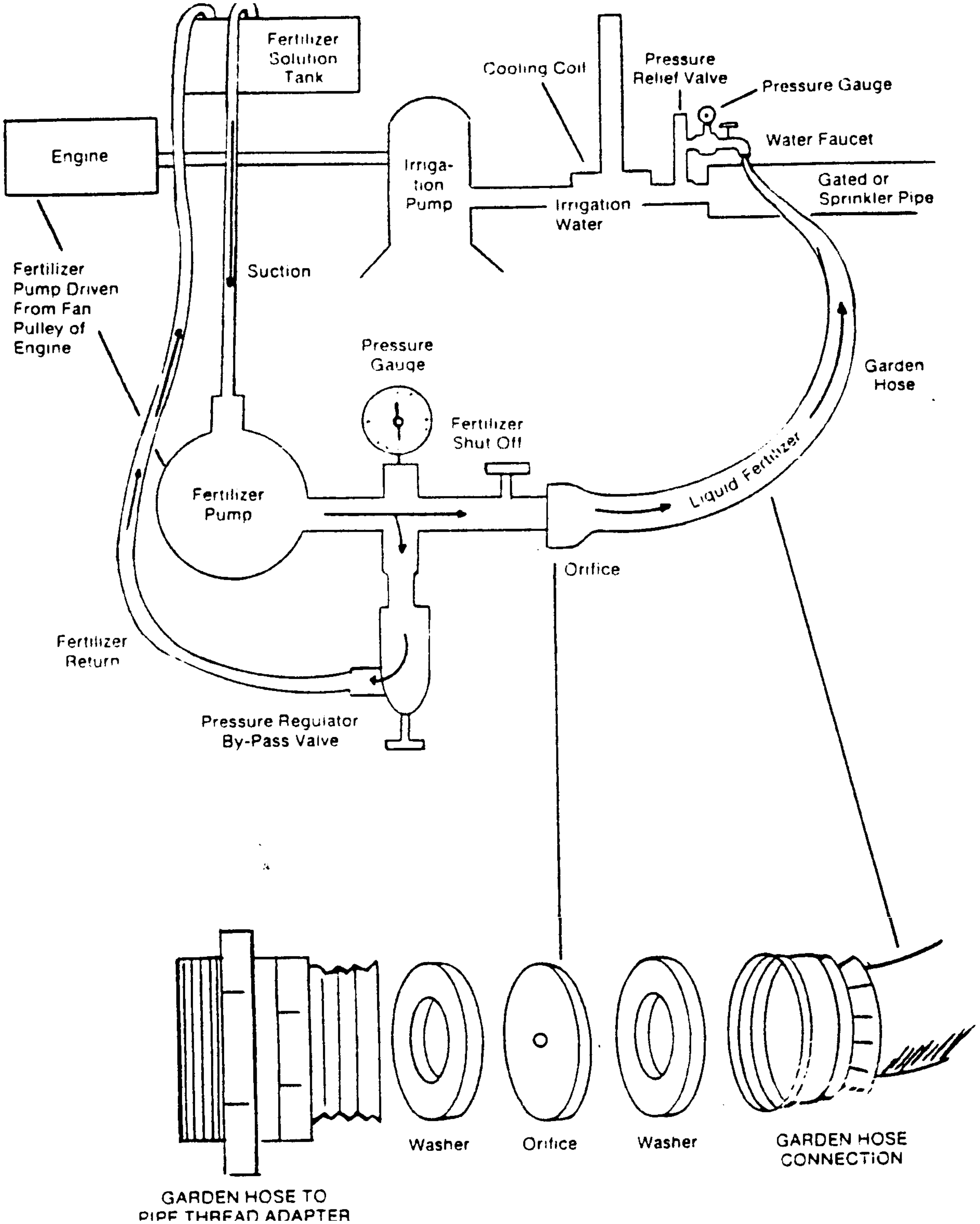
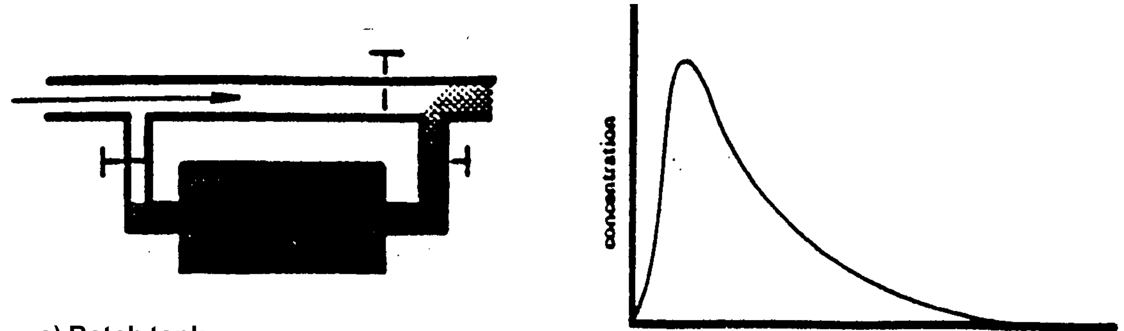
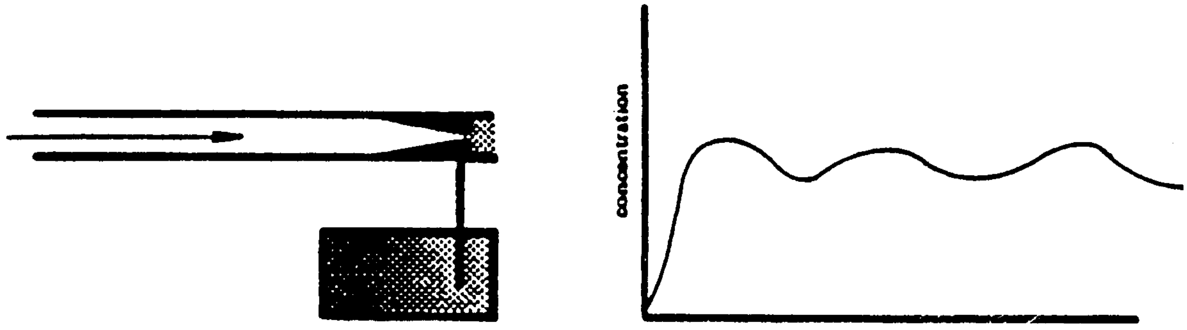


fig.12.

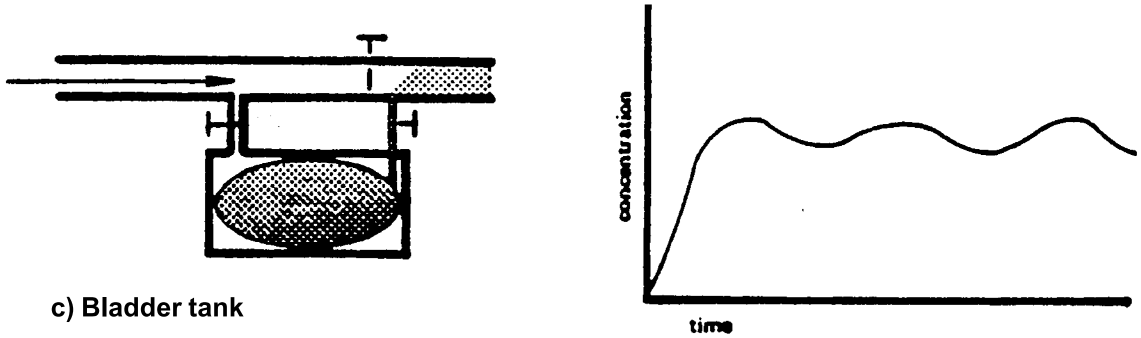
Chemical Injection Equipment Performance



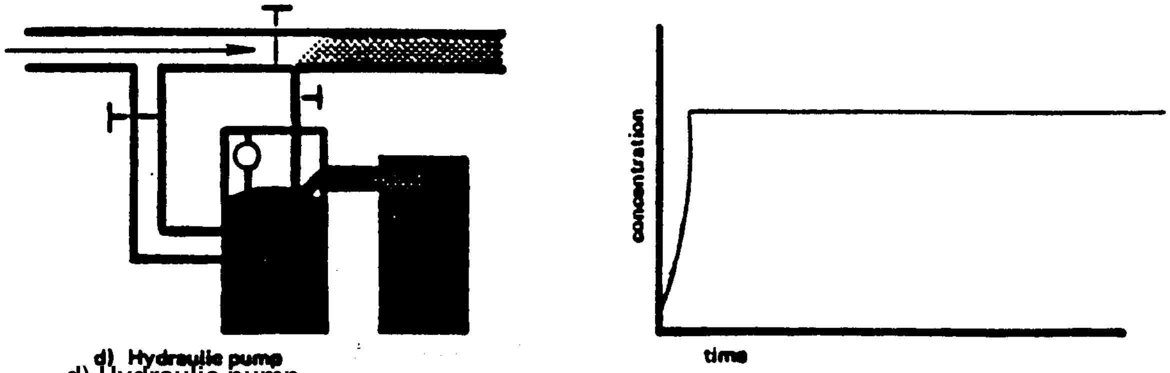
a) Batch tank



b) Venturi



c) Bladder tank



d) Hydraulic pump

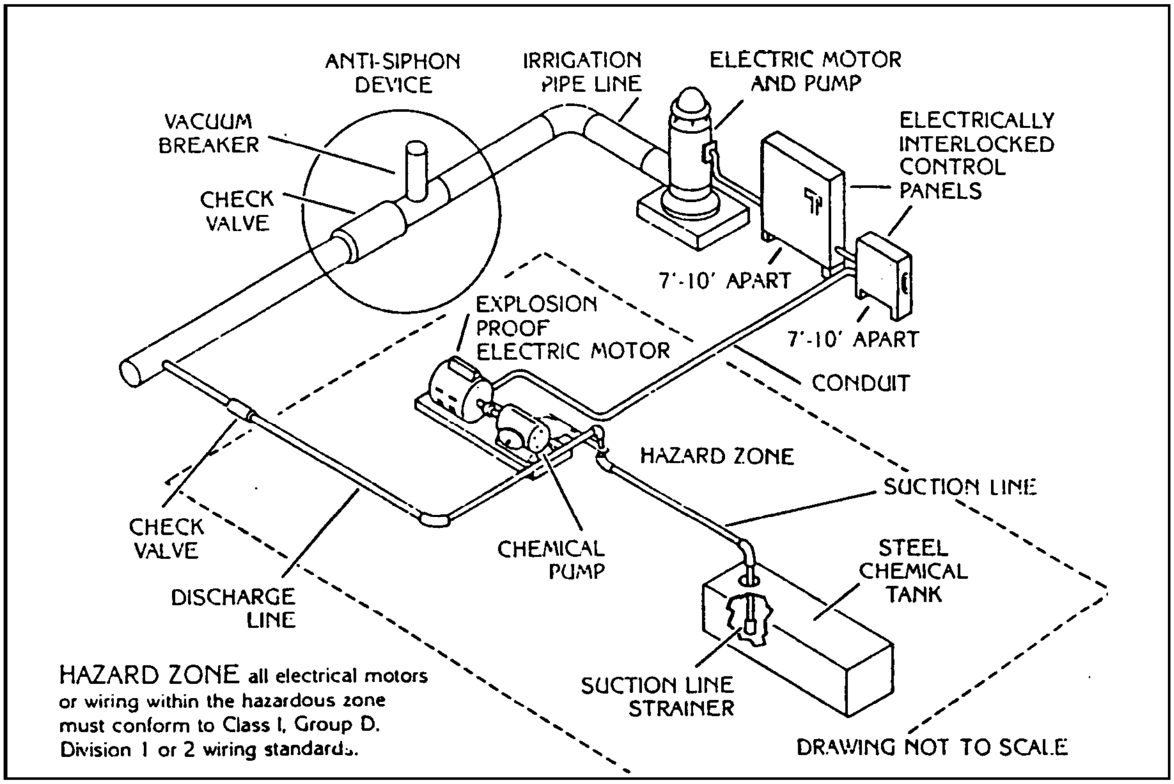
d) Hydraulic pump

If acid is being injected to increase the efficacy of chlorine, note that acid and chlorine should never be mixed together in the same tank. Individual tanks and injection heads should be provided for each chemical, the acid injection site normally being placed upstream of the chlorine.

One possible physical layout for fertigation/chemigation via pivot injection could look like figures 13, 14 or 15.

fig. 13.

Anti-Pollution Devices and Arrangement of Valves (Motor Drive)[1] [2]



HAZARD ZONE all electrical motors or wiring within the hazardous zone must conform to Class I, Group D. Division 1 or 2 wiring standards.

DRAWING NOT TO SCALE

---

[1] Center-pivot irrigation guidelines. Dow Chemical Company. 134-1048-84.

[2] Fertigation and the Importance of Anti-Pollution Devices (Part 1). Fischbach, F.E. *Solutions Magazine*, March-April, 1977, pp 8-12.

fig. 14. Anti-Pollution Devices and Arrangement of Valves (Engine Drive)[1]

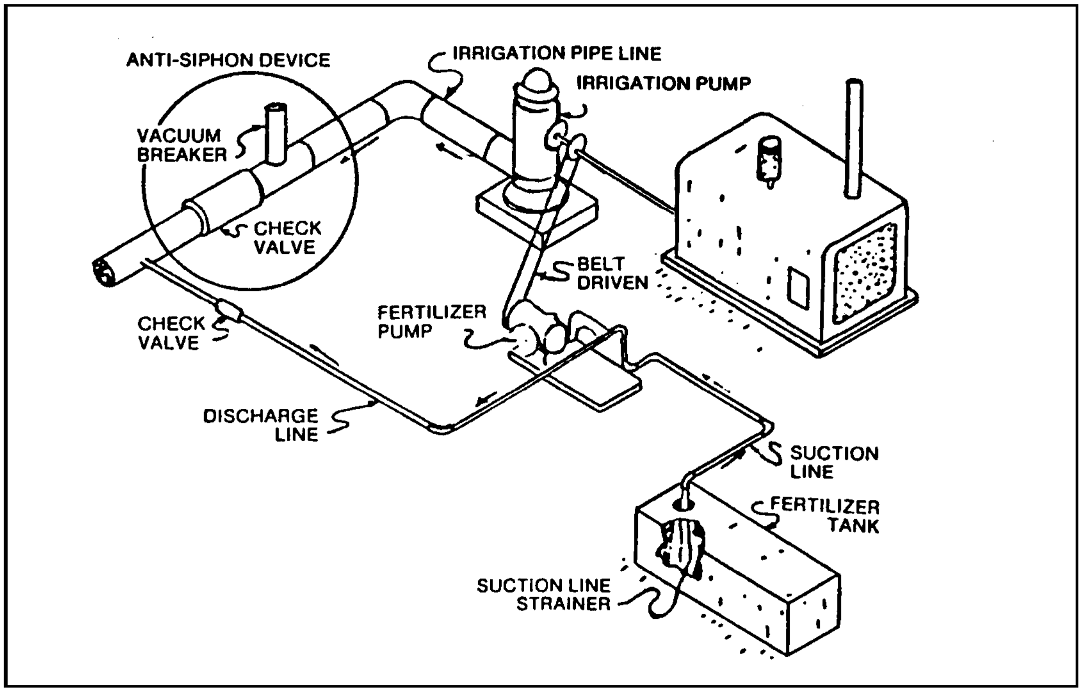
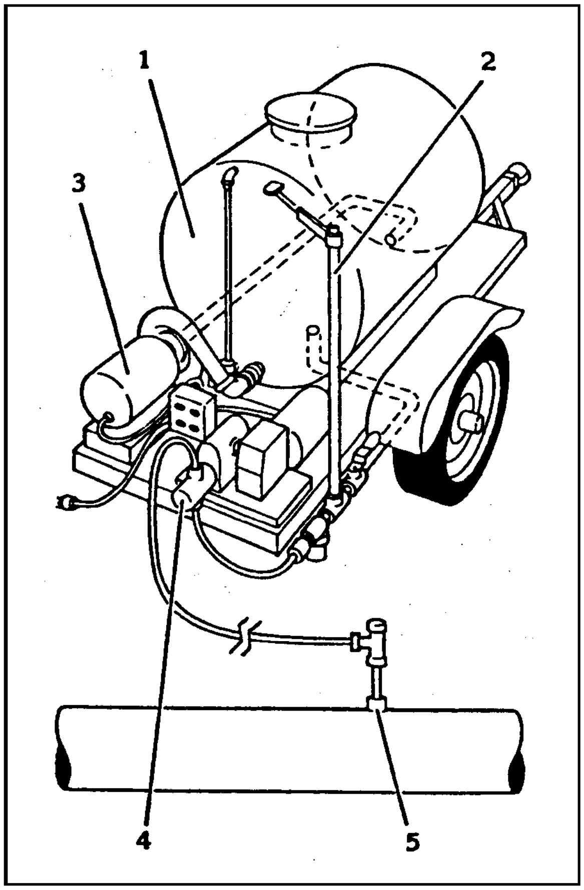


fig. 15. Basic Equipment Requirements for Insecticide Injection[2]



1. **Nurse Tank**

   The nurse, or holding, tank containing the insecticide solution should be constructed of a corrosion-resistant steel. Adequate agitation must be provided by either a mechanical or hydraulic pump to keep the solution suspended during the entire period of application.

2. **Calibration Tube**

   Calibration is vital in order to adjust injection flow rates to conform with recommended pesticide application rates. The calibration tube should be installed in-line midway between a quarter-turn ball valve and a 50-mesh strainer.

3. **Explosion-Proof Motor and Wiring**

   When insecticide and non-emulsifiable oil are used, all wiring and motors must conform to Class I, Group D, Division 1 or 2 (NEC 70) electrical wiring codes. The equipment unit must also be at least 10 feet away in any direction and 18 inches above grade from an electrical source.

---

[1] Fertigation and the Importance of Anti-Pollution devices (Part 1). Fischbach, F. E. *Solutions Magazine*, March-April, 1977, pp 8-12.

[2] Center-pivot irrigation guidelines. Dow Chemical Company. 134-1048-84.

When insecticide, oil, and **at least 2 parts of water per part of insecticide are "premixed,"** the motor and wiring need not be explosion proof, if the unit is outside the hazardous zone or proper disconnect and lock out provisions are made during pesticide concentrate transfer.

4. **Injection Pump**

   A positive-displacement injection pump must be located between the nurse tank and the irrigation pipe. This is necessary to inject the pesticide solution into the pressurized mainline leading to a center-pivot sprinkler system.

5. **Injector Assembly**

   This assembly is placed at the junction of the pesticide injection line and the water mainline. It is comprised of a ball check valve and a vacuum relief valve. The vacuum brake will prevent back-flow contamination of the water source in the event of a system breakdown or a power failure. It is suggested that the injection port be higher than the nurse tank to prevent siphoning.

CHEMICAL EFFECTS ON IRRIGATION SYSTEM COMPONENTS

Chemical effects on system components from field experience has indicated that the commonly used materials such as 28-32 percent UAN solutions, APP and UP solutions and most approved herbicides, insecticides and fungicides generally do not adversely affect system components. Recommended concentrations of fertilizer materials, although salty, will not damage galvanized surfaces, although painted surfaces are more susceptible to fertilizer corrosiveness. Caution should be used in adding solutions that will cause reduction of water pH to 6.5 or lower, as some component damage may occur due to increased reactivity/corrosivity of some solutions. Care should be taken to flush irrigation systems after chemical applications, and clean out injection pumps and solution tanks with clean water.

IRRIGATION SYSTEMS FOR DAIRY MANURE[1/]

The fluid consistency of a particular waste determines the best combination of equipment, energy and labor required for transporting and applying that waste to the land. As dairy manure becomes more liquid, manure pumps and tank wagons become more effective than bucket loaders and box spreaders. In many situations, through the addition of process water and runoff or the removal of solids, the tanker contains mostly water on its trip to the field. Perhaps it is time to consider a change from tanks and tractors to pumps and pipes.

The use of irrigation equipment can save operating time, energy and related costs when moving highly liquid wastes. For example, the removal of 2 feet of water from a half acre manure storage basin would require 60 hours and about 250 gallons of fuel utilizing a 30 horsepower manure pump and 100 horsepower tractor on a 3,000 gallon tank spreader with field trips completed every 30 minutes. The same task could be accomplished in 23 hours with 7 man hours and 75 gallons of fuel utilizing traveling gun irrigation equipment with about 30 horsepower on the pump and 14 horsepower on the traveler.

Irrigation equipment can provide additional advantages. Soil compacting produced by traveling over the fields with heavy manure spreading equipment is lessened. Irrigation can occur on growing crops and when soils are wet allowing more available days for waste application which can result

[1/] Herbert Brodie, P.E., Extension Agricultural Engineer, Department of Agricultural Engineering, University of Maryland. In: Proceedings of the Dairy Manure Management Symposium. Syracuse, New York. February 22-24, 1988. pp. 195-203.

in a reduced waste storage requirement than with tank spreaders. Irrigation can be managed to provide a uniform application of manure nutrients across a field. Soluble nutrients applied through irrigation are carried into the upper soil layer with the water which reduces the soil surface loss of ammonium nitrogen and lessens the need for covering the waste with soil after spreading. In addition to spreading wastes, irrigation equipment can be used to supply water to crops during drought.

Irrigation has some disadvantages that must be considered. Spraying liquid manure from storage into the air may cause considerable odor release. Although the ammonium nitrogen that reaches the soil infiltrates with little loss, 20 to 30 percent of the ammonium nitrogen can be lost to the air in the spray before it reaches the soil surface. The field is connected to the waste source with a mainline pipe which must be moved or duplicated if other fields are to receive irrigated waste. Irrigation cannot occur during freezing weather and equipment must be cleaned, winterized and properly stored to be ready for the next season. Irrigation must be managed to prevent runoff from excessive application rates and to prevent excessive nutrient application. Irrigation equipment can cost as much or more than conventional liquid manure equipment.

WHAT TYPES OF WASTE CAN BE APPLIED THROUGH IRRIGATION EQUIPMENT?

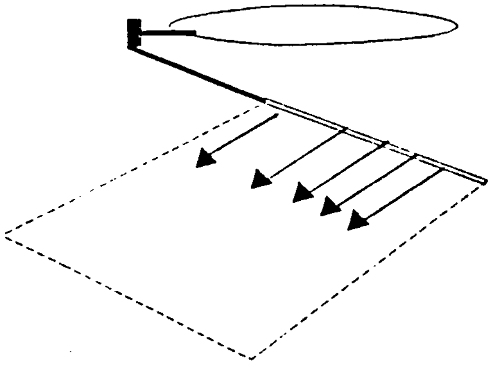
The solids content is the major factor in determining if irrigation can be used to apply the waste. Solids content varies with the animal housing and manure collection system. Waste water from milking parlors, flushing waste systems, treatment lagoons, runoff holding ponds and unmixed surface water on open manure storage tanks or pits can be easily pumped through irrigation equipment. Liquid manure less than 15 percent solids content can be pumped through irrigation equipment using special pumps and gun type nozzles. Wastes containing trash, abrasive and stringy material are not suitable for pumping unless preconditioned by separation and/or grinding.

WHAT TYPES OF IRRIGATION EQUIPMENT CAN BE USED?

The type of irrigation equipment to use is dependent on the solids content of the waste, the quantity of waste to move and the size of the area to which the waste is to be applied. The irrigation equipment must be matched with the topography of the farm, the infiltration and water storage capacity of the soils and the cropping patterns.

SURFACE IRRIGATION

Surface irrigation or flood irrigation can be used on dairies for small frequent flows from milking parlors and runoff collection basins. The system consists of an automatically or manually controlled submersible pump in a protected sump, underground plastic pipe and a gated pipe across the surface of a grassland filter area. The gated pipe is 4 to 6-inch diameter plastic pipe with openings or gates every 30 to 80 inches to assure water distribution across the width of the soil-plant filter. Pumps can be eliminated on some farms where land slopes are advantageously used to develop gravity flow.

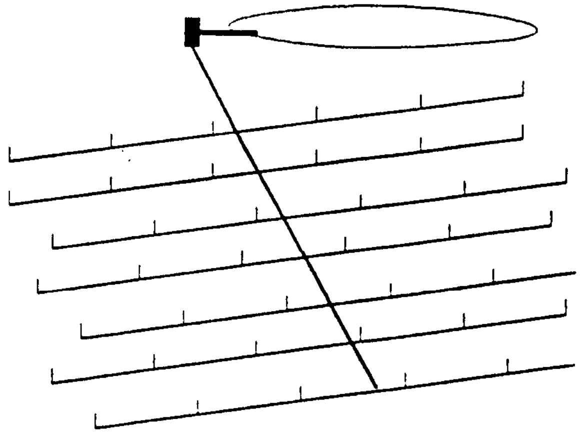


GATED -PIPE SURFACE FLOW

In regions where surface irrigation is a normal cropland practice large volumes of waste can be included with the irrigation water. However, waste with high nutrient or solids content will not be uniformly applied to the field, which will prevent optimum nutrient management.

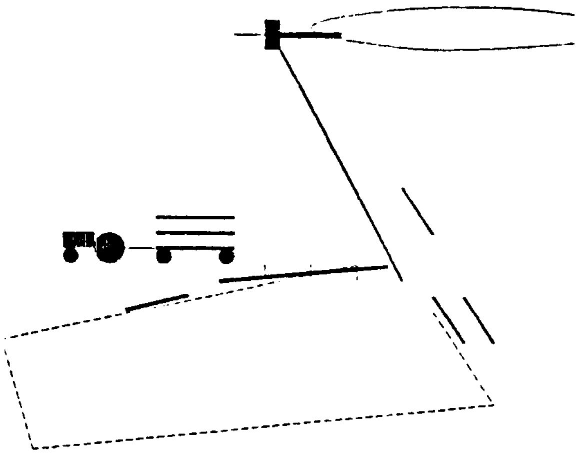
SOLID-SET SPRINKLER IRRIGATION

Solid-set sprinkler irrigation consists of a pumping system, a mainline to the application site and a series of lateral pipes fitted with sprinkler risers and nozzles. The piping system covers the entire disposal area and once in place the pipes are not moved. Buried solid-set systems can be permanently established for the life of the system. Portable aluminum pipe systems may be set up and taken down as needed but usually remain in place for the entire season. Solid-set systems can be used where topography and other restrictions prevent the use of surface irrigation. Once installed, solid-set systems require little labor to operate and can be designed for any quantity of flow, type of waste, application uniformity and size of application area but the capital cost increases very rapidly with size.

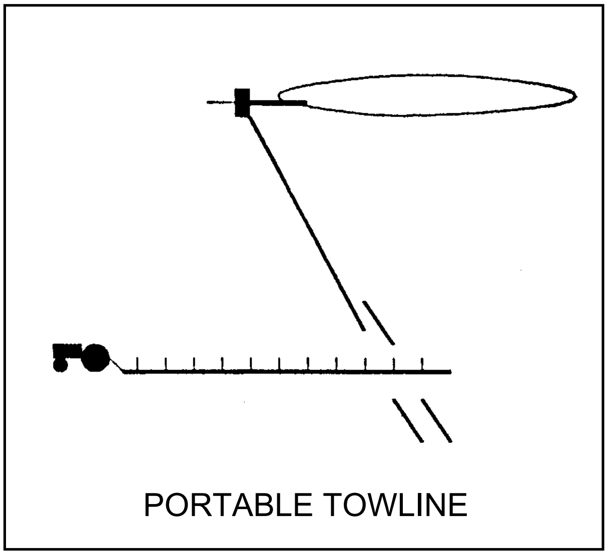

SOLID-SET

HAND-MOVE PORTABLE SPRINKLER IRRIGATION

Hand-move portable systems consist of a pumping unit, aluminum main line pipe and lateral pipe fitted with risers and nozzles. These systems are portable, adaptable to diverse topography, can achieve good application uniformity and have relatively low initial cost. Sprinkler capacities between 1 and 20 gallons per minute each are common with the pump capacity being the sum of the total sprinkler capacities. The operating procedure is to lay out the pipe and sprinklers (a setting) and irrigate an area then move the pipe to a new location (or set) and irrigate more. The labor requirement becomes excessive for large areas and large quantities of waste. Moving pipe becomes an undesirable task if manures or highly dirty waters are irrigated. The system is best used for moderate flows from waste water collection tanks, small lagoons or runoff holding ponds.


PORTABLE HAND-MOVE

TOWLINE SPRINKLER IRRIGATION

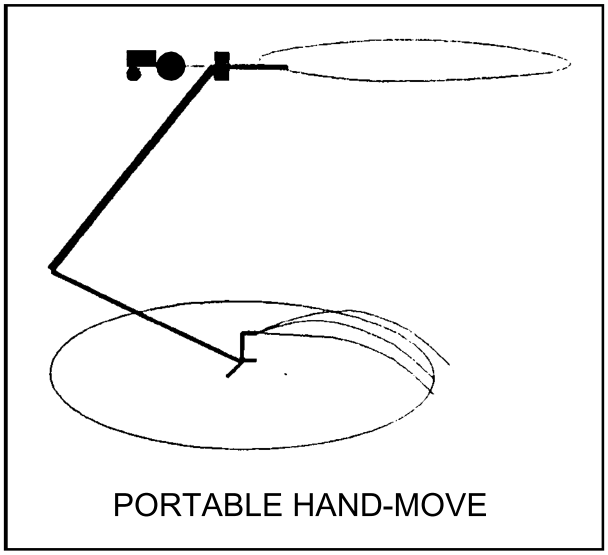


PORTABLE TOWLINE

A towline system is similar to a hand-move system except the lateral is moved to a new set in a single piece by pulling behind a tractor at a significant reduction of labor input for moving pipe. Specially coupled aluminum pipe up to 600 feet in length can be moved in this manner. However, the mainline must be buried or placed in a shallow ditch to allow for tractor traffic. In row crops, travel lanes and turn space require about 10 percent of the land area. The shape of the field has to conform with the length of the lateral. Towlines would be used for larger areas, greater waste volumes and dirtier water than hand-move systems.

MANURE GUN IRRIGATION

Manure guns are large sprinklers with capacities of 100 to 600 gallons per minute at 60 to 100 pounds per square inch nozzle pressure that can cover one-half to over 3 acres at a setting. The large nozzle can pass 3/4-inch-diameter solids and some nozzles are made of rubber which can flex for an extra large solid. The manure gun is set up much like the hand-move system, but the gun replaces the many small sprinklers.

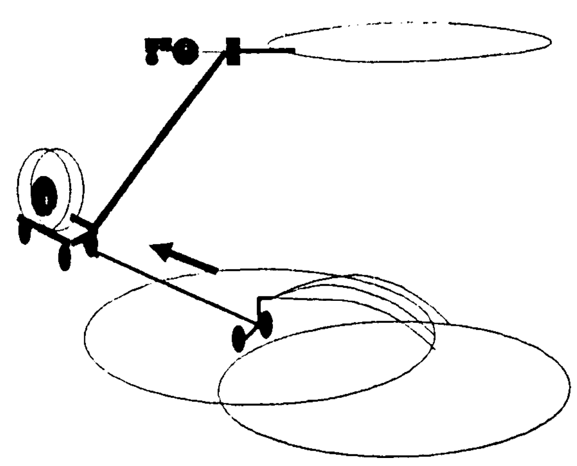


PORTABLE HAND-MOVE

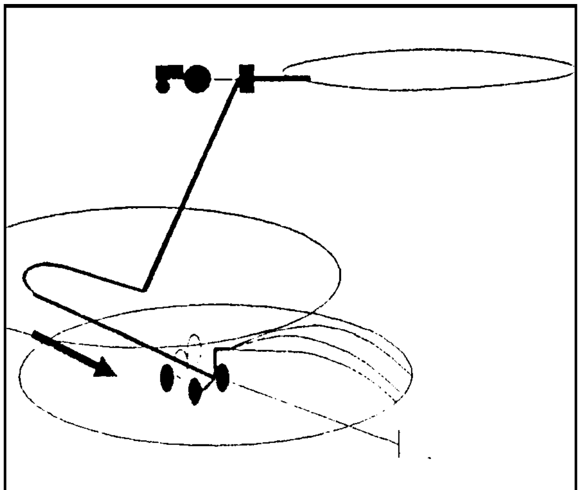
This system adapts well to varying land shapes. One difficulty is the usually high application rate which can cause runoff on moderate slopes. On some soils the gun must be moved frequently to prevent runoff. Moving the gun can be a disagreeable job when irrigating with manure. A gun can be mounted on towline pipe extending beyond the wetted land area to allow the gun to be pulled to a new set by tractor. Guns can be used for all wastes in large quantitites on large land areas. Uniform application of manure across the field may be difficult to achieve because of the characteristics of the flow from manure guns and the large application circles. The high flow rates and high operating pressure of big guns requires high horsepower input.

SELF-PROPELLED BIG GUNS

A self-propelled big gun applicable for waste disposal is a single large sprinkler mounted on wheeled trailer that constantly moves across a field. Movement is caused by a small auxiliary engine which pulls the gun trailer by turning a hose reel stationed at the end of the field. A flexible hose connects the hose reel to a buried plastic or portable aluminum main. Operation consists of anchoring the hose reel trailer and then pulling out the gun trailer to the full length of the hose using a tractor. While irrigating the reel pulls in the hose and moves the gun back to the reel trailer. When totally pulled in, the reel stops, but the irrigation pump continues to operate. Management must keep aware of the position of the gun trailer so that the pump can be stopped. Once a set is completed, the reel trailer is turned to face a new direction or moved to a new location and the gun trailer pulled out for the next set.



HOSE-REEL TRAVELER



CABLE-PULL TRAVELER

A second type of traveler uses a cable and winch to cause movement. The operation is similar to hose reel travelers. Some have the engine and winch mounted on the gun trailer with the cable anchored at the end of the field. One disadvantage of this configuration is the possibility of the drive unit becoming fouled with manure which may increase the service requirements. The hose drags behind the gun trailer and must be wound on a reel as a separate operation before moving to a new set. Some travelers use a water turbine gaining energy from the water being irrigated to provide motion. However, water drive units cannot be used with wastes containing even minimal amounts of solids.

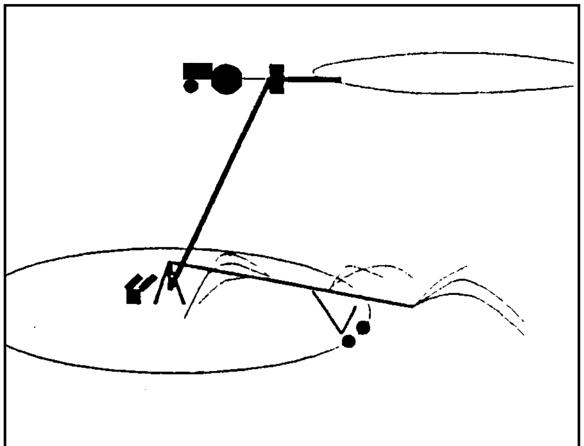
Travelers range in capacity from 50 to 1500 gallons per minute and can irrigate up to 10 acres in one set. The travel speed is adjustable to allow selection of application rates. Travel lanes are spaced at 200 to 300-foot intervals and in row crops may remove several rows from production. A portable aluminum or buried plastic mainline is placed across the center of the field with hose hydrants spaced at travel lanes. Power requirements are moderate to high and depend on the particular situation.

CENTER-PIVOT SPRINKLER IRRIGATION

A center-pivot is a high clearance, self-propelled single lateral that pivots around a hydrant at one end. The irrigated area is in the form of a circle which can range from 10 to 200 acres in area depending on the length of the lateral installed. The lateral can be fixed to a single hydrant or a portable lateral can be moved to any of several hydrants. Hydrants can be connected to buried plastic or portable aluminum mains from the pump. Portable systems for manure application are usually 10 to 20 acres per set but can be designed larger by increasing the lateral length. The lateral is supported by the pivot and by wheeled towers which move around the pivot. The wheels are powered by electricity normally provided by a portable engine drive generator located at the pivot. The wheels travel in the same circular track each revolution and minimize soil compaction and crop damage. Rotation can be selected as full circle or part circle and motion can be stopped or reversed automatically.

The lateral can be fitted with impact sprinklers or big guns arranged to provide a uniform waste application on the irrigated area. The combination of sprinkler or gun design and the variability of travel speed provides the ability to select a wide range of application rates. The power requirement is highly dependent on the system size and can be low to moderate for waste water but increases rapidly as the solids content of the waste increases.

Center-pivots require an unobstructed area within the arc of travel. Rolling terrain can be irrigated if the slopes do not exceed 12 percent. The wheel paths may become deeply rutted in wet areas and require stabilizing fill.



CENTER-PIVOT

WHAT TYPES OF PUMPS CAN BE USED?

The pump must move the waste at a rate and pressure required of the irrigation system. Solids content of the waste is a major consideration in selecting the pump. Generally, the cost and power requirements increase as the solids handling capability, flow rate or pressure needs increase. Pump selection should be at the advice of a professional with knowledge of the particular installation requirements.

Submersible, low pressure centrifugal pumps are suitable for most surface irrigation systems receiving waste water containing occasional solids. Solids handling electric submersible pumps capable of developing the pressure required of sprinkler irrigation systems usually require more than 10 horsepower. Submersible pumps in sumps or tanks are usually provided with a continuous bypass nozzle to divert some of the flow back to the pump inlet as a method of keeping settled waste solids in suspension.

Centrifugal closed impeller pumps used for sprinkler irrigation can be applied to wastes that contain limited solids. Accessory equipment is available which grinds solids to fine enough particles to pass through the pump without clogging. As the solids pumping capability increases, the pump efficiency declines requiring increased power input to provide the desired performance.

Progressing cavity pumps (rotary or helical screw) can move manure slurries at the high heads and high flows required of big gun systems. These pumps can accept a wide range of solids. However, the pump cannot be operated in a dry condition and abrasive or sharp solid objects should not be allowed to enter the intake because the internal boot of the pump is a rubber material that can be destroyed. The inlet should be screened to prevent the entrance of solids of greater size than the sprinkler nozzle. Because the pump is positive displacement, a clogged nozzle could result in burst pipes.

The choice of suction inlet screens is dependent on the application. However, the screen should only allow passage of solids that can go through the irrigation system without causing problems. The screen should be of the largest total surface area practical to maintain adequate flow to the pump. In some installations it may be advisable to make a mesh fence or trash rack surrounding the suction site. Also, a floating square formed from wood lumber will prevent floating objects from moving into the suction site.

WHAT KINDS OF POWER UNITS CAN BE USED?

Pumps can be powered with electric motors, stationary internal combustion engines or pto-driven from farm tractors. Electric motors are the most efficient and require the least maintenance, but require a source of electricity. Motors over 10 horsepower require 3-phase electric service and special demand rates may be established by the power company.

Tractors and stationary engines can be of any fuel type but for long pumping periods diesel units are most efficient. The horsepower of the unit must be matched to the pump requirements. Safety cut-off switches that monitor engine and pump operating conditions should be installed to protect the unit.

WHAT ARE THE MANAGEMENT REQUIREMENTS?

The major management concerns are to apply waste to the soil-plant filter in a manner that prevents runoff or excessive deep percolation of the waste water and to apply waste nutrients in amounts that do not exceed the needs of the crop. These concerns should be addressed in the selection and design of the irrigation system as well as during actual operation.

Odors from wastes being applied through sprinkler irrigation can be a major problem. Select locations away from neighbors and do not irrigate on days that are hot and humid or when the wind direction is toward neighbors. Do not irrigate on weekends or holidays or near heavily traveled public roads.

Irrigating with manure slurries should be followed with a 10 to 15-minute flush of clean water to clear manure solids from the pipes. Deposited solids can corrode metal pipe, cause clogging at the next irrigation and make moving portable systems difficult because of the added weight and slop. The flush water will also wash solids off plant leaves and help prevent ammonia burn during hot weather.

Other management items include timely and correct maintenance of equipment as advised by the equipment manufacturer. Winter storage and maintenance are crucial factors in assuring that the system will function throughout the next season. Rodent nesting in open pipes or control boxes and undrained pipes that have frozen and burst are common problems associated with lax management.

WHAT WILL AN IRRIGATION SYSTEM COST?

An irrigation system is designed to meet a specific objective based on the soils, topography, distance to fields, available application time and solids content of the waste to be irrigated. Because of these factors and the variety of equipment available, the development of a capital cost for these systems (Table 10) is provided here to understand the relative cost for adoption and may not be representative of the investment required of any particular installation.

SUMMARY

Irrigation equipment can be used to transport and apply highly liquid dairy waste to farm fields with greater efficiency than liquid tank spreaders. Care must be used in the selection of components to most favorably match the system capabilities with the farm needs while minimizing the capital and operating costs. Design should involve consultants, equipment dealers and/or extension agricultural engineers with knowledge of utilizing irrigation for waste and nutrient management.

Table 10.

Cost of Irrigation Systems for Dairy Waste Management

type of system	acres per set	investment cost $	labor hrs/10 acres	notes
gated-pipe				
gravity	1	2,000	-	a, c, j
pumped	1	3,000	-	a, c, d, j
solid set	1	4,000	-	a, c, d, j
	5	23,000	-	a, c, d, j
hand-move	0.5	2,500	7	b, c, d, j
tow-line	0.5	3,400	3	b, d, j
big gun	3	8,000	5	b, e, h, j
traveler	10	26,000	1	b, e, g, j
center-pivot	10	20,000	1	b, e, f, h, j
	150	70,000	-	a, e, f, i , j

NOTES:
a. fixed location
b. can be moved at each irrigation to cover many locations depending on labor and with increased investment for main pipe.
c. not recommended for manure slurries
d. includes separate pump power unit
e. pto pump included, tractor or stationary power unit not included
f. diesel electric generator set included
g. 200 gpm
h. 500 gpm
i. 900 gpm
j. labor for normal field operation - does not include major repair or initial setup

APPENDIX

Subject **Page**

FERTIGATION INJECTION WORKSHEET:
ANHYDROUS AMMONIA (4)

EXPLANATION

Data inputs [(a) through (g)] must be suplied from on-farm measurements or information tables on the nitrogen material you plan to use. The letter under each blank space indicates which data item should be used in that blank.

(a) Wetted Radius =__________________________ feet
(b) System Length = _________________________ feet
(c) System Travels ___________ feet in 10 minutes
(d) Pounds N Desired = ___________________ lbs./acre
(e) Nitrogen to be used contains __________% N [express % as a decimal where letter (e) is used in Step 4]
(f) Nitrogen weighs __________________________ lbs.
(g) Gallon per minute well output _______________ gpm

STEP 1 -- Acres under center pivot
Area (square feet) = 3.14 X ______ X ______ = ______ sq. ft.
(a) (a) (h)

Acres under system = ______ ÷ 43,560 = ______ acres
(h) (i)

STEP 2 -- System Speed
Speed (feet/minute) = ______ ÷ 10 = ______ feet/minute
(c) (j)

STEP 3 -- Time required to make one complete revolution (circle)
Circumference = 6.28 X ______ = ______ feet
(b) (k)

______ ÷ ______ (system speed) = ______ minutes per circle
(k) (j) (l)

STEP 4 -- Pounds nitrogen required per acre
Pounds of material/acre = ______ ÷ ______ = ______ lbs/acre
(d) (e) (m)

STEP 5 -- Injection rate of NH_3 in pounds per hour
Rate of injection = ______ X ______ X 60 - ______ = lbs./hr. ÷ 60 = ______ lbs./min.
(m) (i) (l)

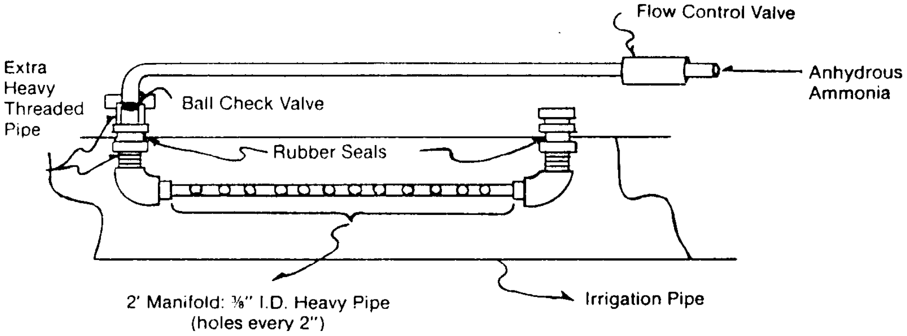
STEP 6 -- Injection rate of inhibitor: See appendix Table A-1.

INJECTION PROCEDURES

1. Anhydrous Ammonia

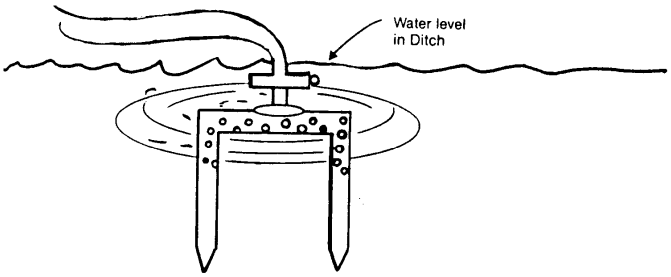
A. Gated Pipe

Install a manifold inside the last 2 feet of the first section of irrigation pipe. The manifold should be extra heavy pipe, 3/8" diameter, 2 feet long with drilled holes every 2 inches.



B. Open Ditch

Install a metering device in the irrigation ditch.



2. Water Conditioner

A. Gated Pipe

Use standard connections with the injection metering pump. Install the connection in the pipe ahead of the anhydrous ammonia manifold (upstream).

B. Open Ditch

Install a metering pump as described for gated pipe or a gravity feed container equipped to provide a constant head. Any barrel can be modified for constant head by installing a 3/8" pipe vertically through the airtight lid to within an inch of the bottom of the barrel.

EXAMPLE OF ANHYDROUS AMMONIA APPLICATION

Field Calculations

Information Required:

1. Time of irrigation, in hours

2. Acres covered by one set

3. Quantity of nitrogen needed per acre

4. Water hardness

5. Flow rate of irrigation water
   - A. N injection rate/hr.
   - B. Inhibitor injection rate/hr.

Example Calculation:

Known: 1. Irrigation time--6 hours
2. Area covered per set--5 acres
3. Nitrogen rate--3 lbs./acre
4. Water hardness--35 ppm
5. Water flow rate--1000 gpm

Calculations:

1. Multiply acres per set by N rate/acre: 5 X 30 = 150 lbs. N required

2. Divide lbs. of N required for 5 acres by 0.82 to determine lbs. of ammonia needed: 150 - 0.82 = 183 lbs. of ammonia

3. Rate of ammonia injection
   183 lbs. ÷ 6 hrs. = 30.5 lbs. of ammonia per hours

4. Rate of inhibitor injection

   A. Go to Table A-1 and read 0.25 lbs. of inhibitor per hour required per 1000 gpm water flow rate at a water hardness of 35 ppm.

   B. Multiply 0.25 lbs. Inhibitor X 6 hours = 1.5 lbs. inhibitor

Table A-1.

Rates of Anhydrous Ammonia and Inhibitor Injection[1/]

Irrigation Water Hardness		Max. Ammonia Application Per 1000 gpm water	Inhibitor Per 1000 gpm water
ppm	Grains/gal.		
35-120	2-7	37 lbs./hr.	0.25 lbs./hr.
120-170	7-10	37 lbs./hr.	0.38 lbs./hr.
170-425	10-25	37 lbs./hr.	0.63 lbs./hr.
425-850	25-50	28 lbs./hr.	0.75 lbs./hr.

[1/] From M-4 1961, "Ammonia Application in Irrigation Water," by Agricultural Ammonia Institute

FERTIGATION INJECTION WORKSHEET:
FERTILIZER SOLUTIONS/SUSPENSIONS (5)

EXPLANATION

Data inputs [(a) through (f)] must be supplied from on-farm measurements or information tables on the fertilizer solution you plan to use. The letter under each blank space indicates which data item should be used in that blank.

(a) Wetted Radius =__________________________feet
(b) System Length = _________________________feet
(c) System Travels ___________ feet in 10 minutes
(d) Pounds Nutrient Desired = ______________ lbs./acre
(e) Fertilizer Solution to be used contains __________% N, P or K [express % as a decimal where letter (e) is used in Step 5]
(f) Fertilizer solution weighs ______________lbs./gallon

STEP 1 -- Polyphosphate and Water Compatibility Test

STEP 2 -- Acres under center pivot
Area (square feet) = 3.14 X ______ X ______ = ______ sq. ft.
(a) (a) (g)

Acres under system = ______ ÷ 43,560 = ______ acres
(g) (h)

STEP 3 -- System Speed
Speed (feet/minute) = ______ ÷ 10 = ______ feet/minute
(c) (i)

STEP 4 -- Time required to make one complete revolution (circle)

Circumference = 6.28 X ______ = ______ feet
(b) (j)

______ ÷ ______ (system speed) = ______ minutes per circle
(j) (i) (k)

STEP 5 -- Gallons nitrogen solution required per acre

Pounds of solution/acre = ______ ÷ ______ = ______ lbs/acre
(d) (e) (m)

Gallons /acre = ______ ÷ ______ = ______ gal./acre
(m) (f) (n)

STEP 6 -- Injection rate of solution in gallons per hour

Rate of injection = ______ X ______ X 60 ÷ ______ = ______ gal./hr.
(n) (h) (k)

FERTIGATION INJECTION (4)

How to calculate for injection of fertilizer solutions/suspensions through center pivot irrigation systems.

Proper calibration for fertilizer injection is important to assure that adequate amounts of fertilizer are distributed evenly over irrigated cropland. Application of too little fertilizer will result in lower yields and lost profit, while too much fertilizer constitutes an uneconomical expenditure.

Several factors are involved in the calibration of a center pivot irrigation system for injection of fertilizer solutions. These factors are:

1. Number of acres covered by system
2. System speed in feet per minute
3. Number of minutes for the system to make one complete revolution (circle)
4. Gallons of nitrogen solution required per acre
5. Injection rate

How to determine the above factors:

Factor 1 - Acres in system
Measure distance from pivot point to end of water throw. This distance will be termed radius. (Radius = R) The following formula may be used to calculate areas in the system:

Area (square feet) = 3.14 X R X R

then:

$$\frac{\text{Area (square feet)}}{\text{43,560 (sq. ft./Acre)}} = \text{Number of acres in system}$$

Factor 2 - System speed in feet per minute
To determine the rate of speed for the system, time the speed of travel at the end wheels in feet per minute. This can easily be done by measuring the distance traveled in 10 minutes and dividing by 10. For example, if a system traveled 95 feet in 10 minutes, its rate of travel would be 95 ÷ 10, or 9.5 feet per minute.

Factor 3 - Time required for system to make one complete revolution
To determine time required for the system to make one complete revolution, measure the distance from the pivot point to the end set of wheels. This distance will be termed length. (Length = L) Use the following formula to calculate the system circumference. (Circumference = C):

$$\frac{C}{\text{Speed of travel (ft/min)}} = \text{Minutes to make one revolution}$$

Factor 4 - Gallons of nitrogen solution required per acre
Once the pounds of nitrogen to be applied have been determined, gallons of solution needed per acre can be calculated using the following formula:

$$\text{Pounds solution per acre} = \frac{\text{Required lbs. of nutrient per acre}}{\text{\% Nutrient in solution to be used (expressed as decimal)}}$$

$$\text{Gallons solution per acre} = \frac{\text{Pounds of solution per acre}}{\text{Weight of solution (lb/gal)}}$$

Weight of solution in lbs/gal for various fertilizer solutions are inclued in the product data listed in Tables A-7, and A-8.

Factor 5 - Determination of Injection rate of solution (gallons/hours)

Using the factors calculated above, we can now calculate the rate of injection required to apply the correct amount of fertilizer solution through your center pivot system. This can be done using the following formula:

$$\text{Rate of injection (gallons/hour)} = \frac{\text{Gallons solution per acre X Total number acres X 60}}{\text{minutes per complete revolution}}$$

FERTIGATION INJECTION WORKSHEET

Example:

Farmer Smith has a center pivot system with a wetted radius (distance from pivot point to end of water throw) of **1490 feet.** The distance from pivot point to end set of wheels is **1390 feet.** The systems travels **80 feet in 10 minutes** as measured from the end set of wheels. His corn is 10" tall and Mr. Smith wishes to apply **50 lbs. of nitrogen** per acre in the form of UAN 28%. UAN 28% contains 28% nitrogen and weighs 10.67 lbs/gal. (This information is listed in Table A-7, page 43, in this brochure). Mr. Smith will use the following steps to calculate the rate of injection at which he must set his injection pump.

STEP 1 **Acres under center pivot**

area (square feet) = 3.14 X 1,490 X 1,490 = 6,971,114 sq ft

Acres under system = 6,971,114 ÷ 43,560 = 160.03 acres

STEP 2 **System Speed**

Speed (ft/min) = 80 ÷ 10 = 8 ft/min

STEP 3 **Time required to make one complete revolution (circle)**

Circumference = 6.28 X 1,390 = 8,729.2 feet

8,729.2 ÷ 8 (system speed) = 1091.15 minutes to make one circle

STEP 4 **Gallons nitrogen solution required per acre**

Pounds of solution per acre = 50 ÷ 0.25 = 200 lbs/acre

Gallons solution per acre = 200 ÷ 10.62 = 18.8 gal/acre

STEP 5 **Injection rate of solution in gallons per hour**

Rate of injection = 18.8 X 160.03 X 60 ÷ 1091.15 = 165.4 gal/hr.

Table A-2.

Quick Reference Table for Area (Acres) Under Center Pivot Systems of Different Lengths

Wetted* Radius (Feet)	Area (Acres)	Wetted Radius (Feet)	Area (Acres)	Wetted Radius (Feet)	Area (Acres)	Wetted Radius (Feet)	Area (Acres)
400	11.53	950	65.06	1500	162.19	2050	302.94
410	12.12	960	66.43	1510	164.36	2060	305.90
420	12.72	970	67.82	1520	166.54	2070	308.87
430	13.33	980	69.23	1530	168.74	2080	311.87
440	13.96	990	70.65	1540	170.96	2090	314.87
450	14.60	1000	72.08	1550	173.18	2100	317.89
460	15.25	1010	73.53	1560	175.42	2110	320.93
470	15.92	1020	75.00	1570	177.68	2120	323.96
480	16.61	1030	76.47	1580	179.95	2130	327.04
490	17.31	1040	77.97	1590	182.24	2140	330.12
500	18.02	1050	79.47	1600	184.54	2150	333.21
510	18.75	1060	80.99	1610	186.85	2160	336.32
520	19.49	1070	82.53	1620	189.18	2170	339.44
530	20.25	1080	84.08	1630	191.52	2180	342.57
540	21.02	1090	85.84	1640	193.88	2190	345.72
550	21.81	1100	87.22	1650	196.25	2200	348.89
560	22.61	1110	88.82	1660	198.64	2210	352.07
570	23.42	1120	90.42	1670	201.04	2220	355.26
580	24.25	1130	92.04	1680	203.45	2230	358.47
590	25.09	1140	93.68	1690	205.88	2240	361.69
600	25.95	1150	95.33	1700	208.32	2250	364.93
610	26.82	1160	97.00	1710	210.78	2260	368.18
620	27.71	1170	98.68	1720	213.25	2270	371.44
630	28.61	1180	100.37	1730	215.74	2280	374.72
640	29.53	1190	102.08	1740	218.24	2290	378.02
650	30.46	1200	103.80	1750	220.76	2300	381.33
660	31.40	1210	105.54	1760	223.29	2310	384.65
670	32.36	1220	107.29	1770	225.83	2320	378.99
680	33.33	1230	109.06	1780	228.39	2330	391.34
690	34.32	1240	110.84	1790	230.97	2340	394.71
700	35.32	1250	112.63	1800	233.55	2350	398.09
710	36.34	1260	114.44	1810	236.16	2360	401.48
720	37.37	1270	116.27	1820	238.77	2370	404.89
730	38.41	1280	116.10	1830	241.40	2380	408.32
740	39.47	1290	119.96	1840	244.05	2390	411.75
750	40.55	1300	121.82	1850	246.71	2400	415.21
760	41.64	1310	123.70	1860	249.38	2410	418.67
770	42.74	1320	125.60	1870	252.07	2420	422.16
780	43.86	1330	127.51	1880	254.78	2430	425.65
790	44.99	1340	129.43	1890	257.49	2440	429.16
800	46.13	1350	131.37	1900	260.22	2450	432.69
810	47.29	1360	133.33	1910	262.97	2460	436.23
820	48.47	1370	135.30	1920	265.73	2470	439.78
830	49.66	1380	137.28	1930	268.51	2480	443.35
840	50.86	1390	139.27	1940	271.30	2490	446.93
850	52.08	1400	141.29	1950	274.10	2500	450.53
860	53.31	1410	143.31	1960	276.92	2510	454.14
870	54.56	1420	145.35	1970	279.75	2520	457.77
880	55.82	1430	147.41	1980	282.60	2530	461.41
890	57.10	1440	149.47	1990	285.46	2540	465.06
900	58.39	1450	151.56	2000	288.34	2550	468.73
910	59.69	1460	153.66	2010	291.23	2560	472.41
920	61.01	1470	155.77	2020	294.13	2570	476.11
930	62.35	1480	157.89	2030	297.05	2580	479.82
940	63.69	1490	160.03	2040	299.99	2590	483.55

*Wetted radius is the distance (in feet) from the pivot point of the system to the farthest reach of the end gun.

Table A-3.

Computing Number of Acres Irrigated per Revolution of Center-Pivot Sprinklers With Various Length Systems

	Acres Irrigated/revolution		
Length (radius) center-pivot spinkler (ft.)	End sprinkler OFF all the time	End sprinkler ON in corners	End sprinkler ON all the time
400	12	14	16
500	18	20	23
600	26	31	33
700	35	41	43
800	46	52	55
900	58	65	69
1000	72	80	83
1100	87	95	100
1200	104	114	117
1300*	122	130	136
1400	141	153	157
1500	162	175	180
1600	185	195	200
1700	208	221	227
1800	234	247	253
1900	260	275	282

*One-fourth section size--Circle inside of 160 acres
Source: University of Nebr. NE Guide G75

Table A-4.

Calibration of Fertilizer Rate Through Sprinkler Irrigation Systems

Lateral Length in feet	No. of Sprinklers (at 40-foot Spacing)	Area Covered by 60-Foot Setting in Acres	Quantity to Apply per Setting for Rate of 100 Pounds per Acre
160	4	0.22	22 lbs.
240	6	0.33	33 lbs.
320	8	0.44	44 lbs.
400	10	0.55	55 lbs.
480	12	0.66	66 lbs.
560	14	0.77	77 lbs.
640	16	0.88	88 lbs.
720	18	0.99	99 lbs.
800	20	1.10	110 lbs.
880	22	1.21	121 lbs.
960	24	1.32	132 lbs.

Example

To apply fertilizer at the rate of 300 lbs. per acre with 400 ft. of lateral moved at 60 ft. setting, lbs. of fertilizer applied at each setting of the lateral are calculated as follows:

Opposite a lateral length of 400 ft. find 55 lbs. of fertilizer to be applied per setting. Multiply 55 by 3 to give 165 lbs. to apply at each setting of the lateral for 300 lbs. per acre.

Table A-5.

Flow in Gallons Per Minute, Using Orifices of Different Sizes at Various Net Pressures*

Net pounds per square inch	Diameter of Orifice** 1/16" approx. g.p.m.	3/32" approx. g.p.m.	1/8" approx. g.p.m.
10	0.20	0.54	1.02
20	0.31	0.79	1.52
30	0.41	1.10	2.00

* Net pressure is the difference between the pressure exerted against the orifice and the pressure in the irrigation system. Example: If the pressure in the fertilizer injector is 15 pounds per square inch and the pressure in the gated pipe is 5 pounds per square inch, the net pressure is 10 pounds per square inch.

** Orifice is made by drilling a hole in the center of a knock-out from an electric connection box. The flow of fertilizer will vary depending on how the orifice is shaped. Check the rate of flow before using the fertilizer injector.

Table A-6.

Variation in Percent of System GPM Due to Change in Pressure

Elevation in ft.		**Equiva-lent in PSI**	**System End Pressure**											
			60	**55**	**50**	**45**	**40**	**35**	**30**	**25**	**20**	**15**	**10**	**5**
70'	=	-30#	-29	-33	-37	-42	-50	-62	-100	--	--	--	--	--
58'	=	-25#	-24	-26	-29	-33	-39	-47	-59	-100	--	--	--	--
46'	=	-20#	-18	-20	-23	-26	-29	-35	-42	-55	-100	--	--	--
35'	=	-15#	-13	-15	-16	-18	-21	-24	-29	-37	-50	-100	--	--
23'	=	-10#	-8.7	-9.5	-11	-12	-13	-16	-18	-23	-29	-42	-100	--
12'	=	-5#	-4.3	-4.7	-5.1	-5.7	-6.5	-7.4	-8.7	-11	-13	-18	-29	-100
Level	=	0	0	0	0	0	0	0	0	0	0	0	0	0
-12'	=	5#	4.1	4.4	4.9	5.4	6.1	6.9	8.0	9.5	12	16	23	41
-23'	=	10#	8.0	8.7	9.5	11	12	14	16	18	23	29	41	73
-35'	=	15#	12	13	14	16	17	20	23	27	32	41	58	100
-46'	=	20#	16	17	18	20	23	25	29	34	41	53	73	124
-58'	=	25#	19	21	23	25	28	31	35	41	50	63	87	145
-70'	=	30#	23	25	27	29	32	36	41	48	58	73	100	165

When pressure variation exceeds = or -10%, then flow control nozzles, pressure regulators or changes in design pressure are recommended to reduce the variation to a + or -5% in flow.

Table A-7.

Weights of Various Liquid Fertilizer Materials

Material	Approximate Pounds Per Gallon
Ammonium Thio-sulfate 12-0-0-26S	11.04
7-21-0 (From electric furnace acid)	10.2
7-21-0 (From wet process acid)	10.51
8-24-0 (From electric furnace acid)	10.5
8-24-0 (From wet process acid)	10.81
10-34-0 (From electric furnace acid)	11.4
10-34-0 (From wet process acid)	11.74
11-37-0 (From electric furnace acid)	11.7
11-37-0 (From wet process acid)	12.05
12-40-0 (From electric furnace acid only)	12.0
20.5-0-0 (Aqua Ammonia)	7.52
28-0-0 (UAN Solution)	10.67
30-0-0 (UAN Solution)	10.86
32-0-0 (UAN Solution)	11.05
Water	8.34

Table A-8.

Amount of Various Nitrogen Fertilizers Required to Give 20, 30 and 40 Pounds of Available Nitrogen Per Acre[1/]

Kind of fertilizer solutions	% N	Wt. per gal. at 60½F. (lb.)	Rate of N per acre, lb. 20 gal/ac	30 gal/ac	40 gal/ac
Urea-Ammonium Nitrate	28	10.65	6.7	10.0	13.4
Urea-Ammonium Nitrate	32	11.06	5.7	8.6	11.4
Ammonium Nitrate	21	10.73	8.9	12.4	17.8

[1/] Fertigation and the Importance of Anti-pollution Devices (Part 1) Fischbach, F. E. Solutions Magazine. March-April, 1977, pp 8-12.

Table A-9.

SOME EXAMPLES OF SOLUTION FORMULATIONS USING AMMONIUM THIO-SULFATE								
		Pounds of Fertilizer Material Required to Make One Ton of Desired Grade						
	Liquid Grade with Sulfur	Thio-Sul 12-0-026	Poly-phosphate 10-34-0	Poly-phosphate 11-37-0	Nitrogen Solutions		Potash 0-0-62	Water H_2O
					28-0-0	32-0-0		
NS	28-0-05S	385				1615		
	24-0-0-10S	770				1230		
	24-0-0-6S	462			1538			
	23-0-0-8S	615			1385			
NPS	11-20-0-11S	847	1082					71
	11-27-0-7S	540	1460					
	16-20-0-6S	462	1082			456		
	12-24-0-8S	616	1298			86		
	17-17-0-7S	539	919			542		
	10-27-0-5S	385		1589				26
	10-25-0-5S	385		1471	29			115
	14-20-0-5S	385		1177	416			22
NPKS	8-20-6-5S	385	1082				194	339
	7-16-6-6S	462	865				194	479
	10-15-5-10S	770	811			58	162	199
	7-15-5-5S	385		883		18	162	552
	10-20-5-5S	385		1177		113	162	163
	10-20-5-5S	385		1177	130		162	146

Table A-10.

Liquid Fertilizer Blend Chart Using "Ammonium Thio-Sulfate" as a Sulfur Source

PERCENT NUTRI-ENT CONTENT PER CWT.	POTASH												WATER	
	4-11-11			4-10-10			3-9-9			2-6-12			0-0-0	
	Lbs. Per CWT.	Extra P_2O_5	Extra N Cont.	Lbs. Per CWT.	Extra P_2O_5	Extra N Cont.	Lbs. Per CWT.	Extra P_2O_5	Extra N Cont.	Lbs. Per CWT.	Extra P_2O_5	Extra N Cont.	Lbs. Per CWT.	Gals. Per CWT.
0.10													00.10	00.01
0.20													00.20	00.02
0.30													00.30	00.04
0.40													00.40	00.05
0.50													00.50	00.06
0.60													00.60	00.07
0.70													00.70	00.08
0.80													00.80	00.10
0.90													00.90	00.11
1	9.09	1.00	.36	10.00	1.00	.4	11.11	1.00	.33	8.33	.5	.17	01.00	00.12
2	18.18	2.00	.72	20.00	2.00	.8	22.22	2.00	.67	16.66	1.00	.33	02.00	00.24
3	27.27	3.00	1.08	30.00	3.00	1.20	33.33	3.00	1.00	24.99	1.50	.5	03.00	00.36
4	36.36	4.00	1.44	40.00	4.00	1.60	44.44	4.00	1.33	33.32	2.00	.67	04.00	00.48
5	45.45	5.00	1.78	50.00	5.00	2.00	55.55	5.00	1.67	41.65	2.50	.64	05.00	00.60
6	54.54	6.00	2.16	60.00	6.00	2.40	66.66	6.00	2.00	49.98	3.00	1.00	06.00	00.72
7	63.63	7.00	2.52	70.00	7.00	2.80	77.77	7.00	2.33	58.31	3.50	1.17	07.00	00.84
8	72.72	8.00	2.88	80.00	8.00	3.20	88.88	8.00	2.67	66.64	4.00	1.33	08.00	00.96
9	81.81	9.00	3.24	90.00	9.00	3.60	99.99	9.00	3.00	74.97	4.50	1.50	09.00	01.08
10	90.90	10.00	3.60	100.00	10.00	4.00				83.30	5.00	1.87	10.00	01.20
11	99.99	11.00	3.96							91.83	5.50	1.84	11.00	01.32
12										99.96	9.00	2.00	12.00	01.44
13													13.00	01.56
14													14.00	01.66
15													15.00	01.80
16													16.00	01.92
17													17.00	02.04
18													18.00	02.16
19													19.00	02.28
20													20.00	02.40
21													21.00	02.52
22													22.00	02.64
23													23.00	02.76
24													24.00	02.88
25													25.00	03.00
26													26.00	03.12
27													27.00	03.24
28													28.00	03.36
29													29.00	03.48
30													30.00	03.60
31													31.00	03.72
32													32.00	03.84
33													33.00	03.96
34													34.00	04.08
35													35.00	04.20
36													36.00	04.32
37													37.00	04.44
38													38.00	04.56
39													39.00	04.68
40													40.00	04.80

Table A-11.

Clear Liquid Nitrogen:Sulfur Formulations Using Ammonium Sulfate (21-0-0-24S) and Ammonium Sulfate Solutions (8-0-0-9S)[1]

EXAMPLES OF CLEAR LIQUID NITROGEN:SULFUR GRADES USING "FLUID GRADE" AMMONIUM SULFATE (21-0-0-24S)

Clear Liquid Grades N-P-K-S	Nitrogen Solutions		Water H_2O (lbs.)	21-0-0-24S (lbs.)	Approx. Weight Per Gal. (lbs.)
	28-0-0 (lbs.)	32-0-0 (lbs.)			
8-0-0-9			1238	762	10.14
9-0-0-8	144		1188	668	10.12
11-0-0-7	348		1068	584	10.18
13-0-0-6	554		956	500	10.25
17-0-0-5	902		680	418	10.48
19-0-0-4	1108		558	334	10.53
21-0-0-3	1314		436	250	10.59
25-0-0-3	1598		152	250	10.82
23-0-0-2	1518		314	168	10.64
25-0-0-1	1724		192	84	10.70
11-0-0-8		250	1082	668	10.19
13-0-0-7		430	986	584	10.30
14-0-0-6		548	952	500	10.36
17-0-0-5		790	792	418	10.52
19-0-0-4		970	696	334	10.59
22-0-0-3		1212	538	250	10.64
25-0-0-3		1399	351	250	10.86
25-0-0-2		1454	378	168	10.82
27-0-0-1		1634	282	84	10.86

Note: All of these grades have a salt out temperature of 32 degrees F. or less. For other NS, NPS, & NPKS grades contact an ammonium sulfate marketing representative.

EXAMPLES OF CLEAR LIQUID NITROGEN:SULFUR GRADES USING AMMONIUM SULFATE SOLUTION (8-0-0-9S)

Clear Liquid Grades N-P-K-S	Nitrogen Solutions		Water H_2O (lbs.)	21-0-0-24S (lbs.)	Approx. Weight Per Gal. (lbs.)
	28-0-0 (lbs.)	32-0-0 (lbs.)			
9-0-0-8	144		78	1778	10.12
11-0-0-7	348		96	1556	10.18
14-0-0-6	620		45	1335	10.31
16.8-0-0-5	885		0	1115	10.44
19-0-0-4	1100		0	900	10.53
21-0-0-3	1310		20	670	10.59
23-0-0-2	1520		35	445	10.64
25-0-0-1	1725		50	225	10.70
10-0-0-8		182	40	1778	10.19
13-0-0-7		425	19	1556	10.30
16-0-0-6		665	0	1335	10.43
18.5-0-0-5		885	0	1115	10.53
21-0-0-4		1090	20	890	10.62
24-0-0-3		1333	0	667	10.74
26.5-0-0-2		1545	10	445	10.82
29-0-0-1		1757	18	225	10.90

Note: All of these grades have a salt out temperature of 32 degrees F. or less. For other NS, NPS, & NPKS grades contact an ammonium sulfate marketing representative.

[1] Courtesy of Allied-Signal Inc.

IRRIGATION WATER MANAGEMENT STRATEGIES FOR SELECTED FIELD CROPS[1]

---

[1] Used by permission of Valmont Industries In: Valley Magazine. Various Issues. Valmont Industries. Hiway 275. Valley, NE 68064.

IRRIGATION SCHEDULING

Too little moisture can stress the plant, too much wastes water, energy, and can wash important nutrients past the root zone.

If the combination of available rain and irrigation water provided your crops the precise amount of water they needed at all times--it would help to maximize crop yields. You would avoid wasting water, energy and nutrients by applying water only when needed by the crop. If you were able to create that kind of moisture balance, you would have mastered the skill--some call it the art--of irrigation scheduling.

In one study, Nebraska researchers concluded that even elementary irrigation scheduling procedures would save water and energy compared to pilot projects which showed 7.3" of excess water was applied each season where irrigation scheduling was not used.

Subsequent studies have indicated that a combination of irrigation scheduling with the kind of uniform, low-volume water application possible with center pivot and linear-move irrigation systems can achieve 35-50% savings in total water application without sacrificing crop yields.

To really understand scheduling, it is necessary to know the characteristics of your soils and crops. Perhaps the key point is that any water used (allowable soil moisture depletion) must be replenished. This means irrigating before soil moisture has been depleted below a set limit. The limit varies with each crop, stage of growth, soil type, and climate. The net amount to be applied at the next irrigation is the amount that has been depleted, except for retaining a certain capacity for rainfall that may occur after the irrigation.

It is absolutely essential to monitor the soil moisture status when you schedule irrigations. Several methods are available to allow the irrigator to physically monitor soil moisture. All methods require taking a soil sample or using some sort of instrument to determine soil moisture based on the calibration of that instrument to a particular soil.

Some of the principal methods are identified in the following paragraphs: Tensiometers measure soil moisture tension. The electrical resistance block system uses small gypsum blocks and a portable alternating current resistance meter to measure electrical resistance in the soil and convert to a soil moisture content. The neuron probe procedure involves using an instrument which measures soil moisture by counting neutrons; a higher count will indicate a wetter soil, a lower count means the soil is drier.

The "appearance and feel" method requires only a soil probe or shovel and is relatively easy to use and accurate once the irrigator has gained some experience. Plus, the irrigator can spot check problem areas in the field such as hard pan areas or different soil conditions.

Irrigation Scheduling Utilizing the "Feel" Method--The following example is a corn crop on silty clay loam soil. Utilizing the feel method of judging available moisture in this field (Table A-12) the soil ribbons out between fingers easily indicating 75% available moisture.

Step I Determine available water capacity of your soil 2" *per foot* (Table A-12).

Step II Determine root depth for your crop 4' (figure A-1).

Step III Multiply Step I *(2" per ft.)* X Step II (4') = Total Available Water when soil is filled to field capacity (8").

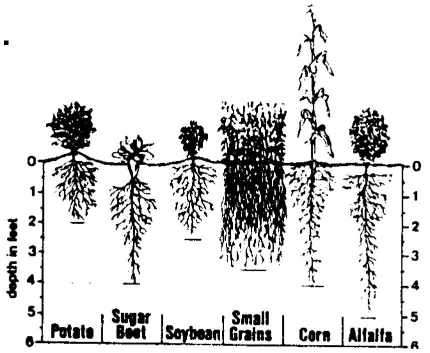
Step IV Multiply total capacity Step III (8") X Available Soil Moisture (Table A-12) Remaining *(75%)* = 6".

Step V Determine Minimum Moisture Level for your crop 1" *per foot* or 50% Soil Moisture Depletion (Table A-13).

Step VI Multiply Minimum Moisture Level Step V *(1" per ft.)* X Root Depth 4' = 4".

Step VII From Soil Moisture remaining Step IV 6" subtract Minimum Moisture Level Step VI 4" = 2". Actual water available for crop use prior to causing crop stress.

fig. A-1.



In this example you have 2" of available moisture. Continue to monitor your soil and apply additional water prior to reaching 50% depletion level (Table A-12).

Table A-12.

Guide for Judging How Much Moisture is Available for Crops

Available Soil Moisture Remaining	Feel or Appearance of Soil			
	Loamy Sand or Sand	Sandy Loam	Loam and Silt Loam	Clay Loam or Silty Clay Cloam
0 percent Wilting Point	Dry, loose, single grained; flows through fingers.	Dry and loose; flows throuh fingers.	Powdery dry; sometimes slightly crusted but breaks down easily into powder.	Hard, baked, cracked; has loose crumbs on surface in some places.
25 percent	Appears to be dry; does not form a ball under pressure.	Appears to be dry; does not form a ball under pressure.	Somewhat crumbly but holds together from pressure.	Somewhat pliable; balls under pressure.
50 percent	Appears to be dry, will not form a ball under pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball under pressure; somewhat plastic; sticks slightly with pressure.	Forms a ball; ribbons out between thumb and forefinger.
75 percent	Sticks together slightly; may form a very weak ball under pressure.	Forms weak ball that breaks easily; does not stick.	Forms ball; very pliable sticks readily if relatively high in clay.	Ribbons out between fingers easily; has a slick feeling.
At field Capacity (100 percent)	On squeezing, no free water appears on soil but wet outline of ball is left on hand.	On squeezing, no free water appears on soil but wet outline of ball is left on hand.	On squeezing, no free water appears on soil but wet outline of ball is left on hand.	On squeezing, no free water appears on soil but wet outline of ball is left on hand.

Note: Ball is formed by squeezing a handful of soil very firmly.

Table A-13.

Available Water Capacity and Minimum Moisture Level for Soil Textural Classes

			Minimum Moisture Level		
Soil Textural Classification		Available Water Capacity	Potatoes	Dry Beans, Corn, Sorghum, Soybeans, Small Grains, or Sugar Beets	Pasture, Alfalfa
		inches /ft.*			
Fine Sands		1.0	0.6	0.5	0.4
Loamy Sand		1.1	0.7	0.6	0.4
Sandy Loam		1.4	0.8	0.7	0.6
Silty Clay or Clay		1.6	1.0	0.8	0.6
Fine Sandy Loam, Silty Clay Loam or Clay Loam		1.8	1.1	0.9	0.7
Sandy Clay Loam		2.0	1.2	1.0	0.8
Loam Very Fine Sandy Loam, or Silt Loam Topsoil	Silty Clay Loam or Silty Clay Subsoil	2.0	1.2	1.0	0.8
Loam, Very Fine Sandy Loam or Silt Loam Topsoil	Medium Textured Subsoil	2.5	1.5	1.3	1.0

*Inches of water per foot of active root zone

IRRIGATING ALFALFA

Produce higher yields by matching the peaks and valleys of alfalfa's changing moisture requirements.

Alfalfa, like other crops, has a characteristic water use pattern. In general, water use will be low in spring and gradually increase to a peak in late July or early August and then gradually decline into the fall; this is primarily a function of air temperature. However, each cutting of the crop alters this pattern. The rate of water use is low immediately following a cutting and reaches a peak at the pre-bud stage. Therefore, a successful irrigation management program for alfalfa must provide enough water to meet the combined overall requirements.

High yields of alfalfa can be produced under irrigation if:

1. an adequate and reliable water supply is available;
2. a careful program of water management is followed, and
3. all other climate, fertility, cultural and management conditions are at a level that does not limit yield potential.

The seasonal water requirements for alfalfa are commonly expressed in terms of inches of water required per ton of production. No single value can be arrived at which will fit every year, every location, or every management program. For Minnesota conditions, for example, the total seasonal water requirement for a six-ton alfalfa yield is approximately 26" and for an eight-ton yield approximately 34". Western alfalfa growers, on the other hand, with their higher temperatures and sandier soils, might require 6" to 7" of water per ton of alfalfa produced.

Table A-14.

Estimate of Seasonal Irrigation Requirements for Alfalfa Yields of Six and Eight Tons

Yield Goal	Total Seasonal Water Requirements	Soil Moisture Contribution	Effective Rainfall	Irrigation Requirement	
				Net	Gross*
6 ton	26	3	13	10	12
6 ton	26	3	7	16	19
8 ton	34	3	13	18	22
8 ton	34	3	7	24	29

*Gross values are calculated using an application efficiency of 85% and rounding up to nearest full inch.

To arrive at the irrigation requirement for each situation, growers must subtract the amount of soil moisture contributed from the root zone and the effective minimum rainfall from the seasonal water requirement (once established). Table A-14 presents the results of making this calculation for both six-ton and eight-ton yield goals in the upper Midwest. The effective rainfall figures used were calculated for a soil with 6" total available water holding capacity. The depletion level--or amount of the available water allowed to be used before irrigation--has been set at 50%; therefore, in this example, the amount of water supplied from soil moisture is 3" in all cases.

Additional effective rainfall--or that portion of total rainfall that helps supply crop needs during the growing season--is dependent on the soil's moisture holding ability, crop use patterns and the irrigation managment program being followed. Two additional effective rainfall figures are used in this example: 7" (the amount expected in a dry year) and 13" (the amount expected in a "normal" year). Figures used in Table A-14 were calculated using a value from a specific soil situation in combination with other values selected from ranges reported in several research reports. They should not be taken as fixed values, but used as a general guideline in evaluating the adequacy of a water supply.

Table A-15 and the "Example Consumptive Use Curve" are based on a North Dakota State University report: "Irrigation Scheduling by the Checkbook Method." They illustrate both the general water use pattern and the effect of cutting on water demand. The current recommendation for water management on alfalfa is to use a moisture accounting method combined with monitoring actual soil moisture. With this method, water use figures are used as "withdrawals" with rainfall and irrigation amounts being the "deposits." (The soil being irrigated places limits on the check account. If the soil has a total available water holding capacity of 4" and the 50% depletion allowance is used, the limit becomes 2". That is, the irrigation system should be managed to prevent the account--soil moisture--from dropping below the 2" level.)

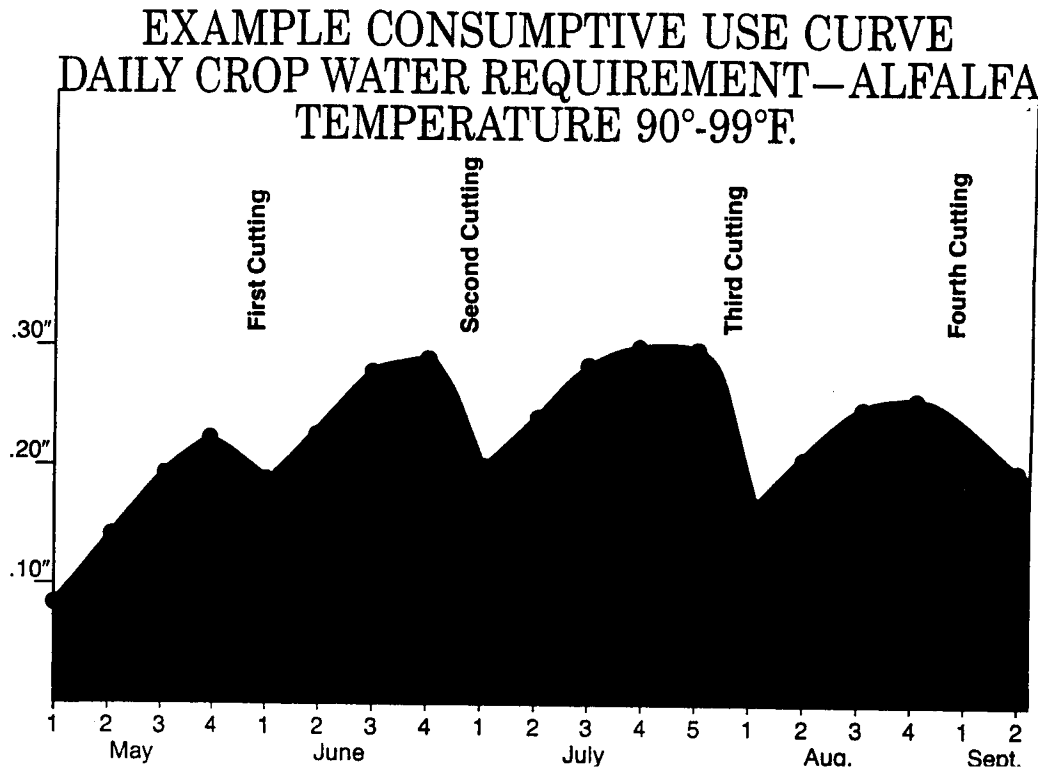

EXAMPLE CONSUMPTIVE USE CURVE
DAILY CROP WATER REQUIREMENT–ALFALFA
TEMPERATURE 90°-99°F.

Table A-15.

Average Daily Water Use (in inches) by Alfalfa

ALFALFA	Use this chart up to the first cutting and for the fourth and consecutive weeks after cutting.								Use this chart for the first three weeks after cutting ("week" refers to week after cutting).								
Month	May				June	July	Aug.	Sept.	June			July			Aug.		
Week	1	2	3	4	All	All	All	All	1	2	3	1	2	3	1	2	3
Temperature 50-59	.04	.04	.05	.06	.09	.09	.08	.07	.06	.07	.09	.06	.07	.09	.05	.06	.08
60-69	.04	.07	.09	.11	.15	.15	.13	.10	.10	.12	.14	.10	.12	.12	.09	.10	.12
70-79	.05	.10	.14	.16	.21	.22	.18	.13	.14	.17	.20	.15	.18	.21	.12	.14	.17
80-89	.06	.12	.17	.19	.25	.26	.22	.17	.17	.20	.24	.17	.21	.25	.15	.18	.21
90-99	.08	.14	.19	.23	.29	.30	.26	.20	.19	.23	.28	.20	.24	.29	.17	.21	.25

For alfalfa, managing water to a 4' depth has been recommended. This suggests placing soil moisture monitoring instruments at about 16" and 32". When used for scheduling purposes, the shallower instrsument indicates when to start irrigations and the deeper instrument is used to check the depth of water penetration in addition to monitoring soil moisture at that level.

The goal of the water management program should be to satisfy the crop requirements while using a minimum amount of water. This makes good economic sense through minimizing pumping costs and conserving both water and energy resources.

Editor's Note: Crop quality can be improved significantly using center pivot and linear irrigation systems and by following good irrigation scheduling and management practices. However, the production of alfalfa under such systems may present several management challenges that require an adjustment of cropping practices to maximize total yield for the entire cropping season. To harvest alfalfa and get water back on the field as soon as possible when using a center pivot, some growers harvest (swath, bale, chop) one-half of the field at a time. As soon as that one-half has been cleared of the crop, the system is operated on that side. In the same manner, alfalfa fields irrigated by linear systems may be split.

*This article is based on material provided by Fred G. Bergsrud from his report "Irrigation of Alfalfa," Department of Agricultural Engineering, University of Minnesota.

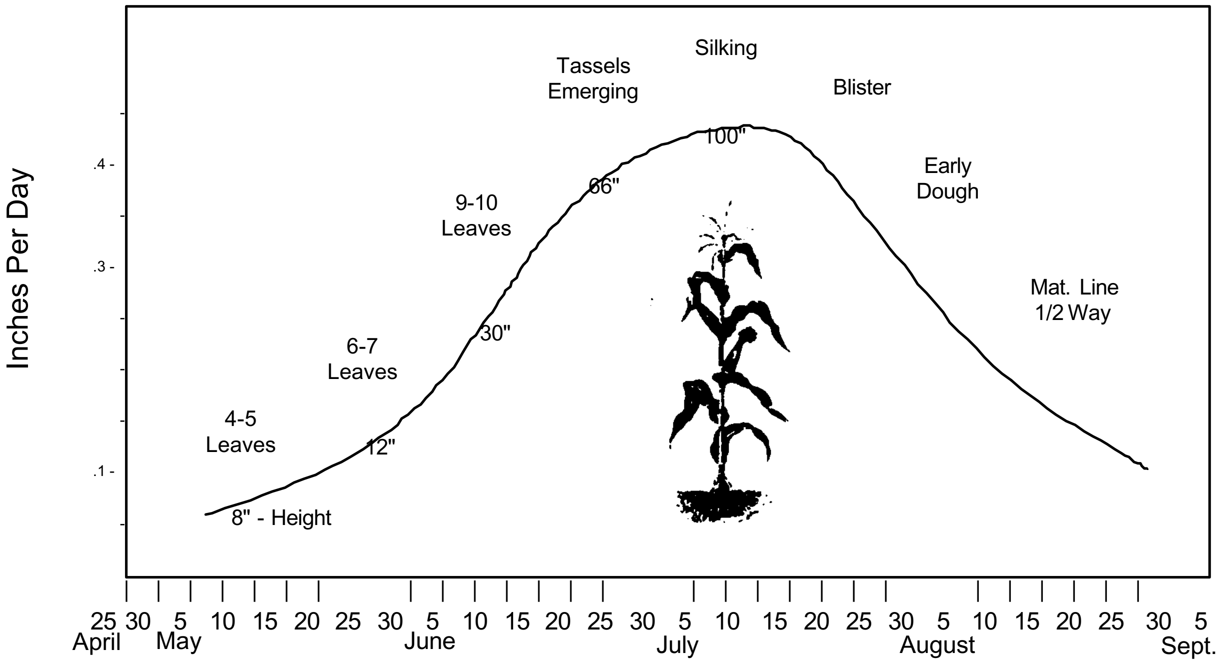
CORN IRRIGATION WATER MANAGEMENT

Timely irrigations on corn can mean extra bushels at harvest and can limit total water application and pumping costs. By Leon New

Corn irrigations that are applied according to the plant's seasonal water-use pattern (figure A-2) are often more productive and lead to good irrigation water use efficiency. Irrigation during stages of growth with high water requirements normally gives corn yields a good boost, while only limited increases are obtained from irrigations during growth stages that require less water.

fig. A-2.

Typical Corn Daily Water Use in the Texas High Plains



Irrigation Quantity and Frequency

Corn typically can respond efficiently to 22 to 26 inches of seasonal irrigation. A preplant application is often beneficial in addition to this, especially where the acreage planted stretches the quantity of irrigation water available. Prewater can contribute to timely planting, enhance seed germination and store water in the soil root zone for use by the plants during high water use growth stages when irrigation capacity may be less than daily plant use.

First irrigation of corn is one of the few opportunities to limit seasonal irrigation without also limiting yield. Dates to achieve best response to the initial summer irrigation are not the same each year because of variations in rainfall, planting dates and hybrids. The irrigation rate is also a major factor influencing when to begin irrigating each year. Soil moisture sensors can aid in identifying the time to begin. Soil moisture can be significantly depleted in the first foot of soil, if good moisture remains in the second and third foot.

Corn water requirements increase rapidly after the plants have 8 to 10 leaves. During the following 3 to 4 weeks, which is the major vegetative growth stage, plants are likely to grow 4 to 5 feet in height.

At the same time, adequate soil moisture is important for proper tassel and ear development inside the plant. Demand for water is particularly high just prior to tasseling.

Silking and Pollination

Highest plant water needs of the season usually occur during silking and pollination and remain high for about 10 days when grain filling begins. During the following 6 to 7 weeks, the primary plant function is to produce grain. Moisture stress during tasseling, silking and pollination periods is normally quite costly due to delayed silking and poor pollination. Adequate soil moisture is especially important for complete pollination and for the following 10 to 14 days to achieve maximum seed per ear. Water requirements are likely to be 4 to 5 inches in 10 days, and even more when temperatures are high, relative humidity is low and wind speed is up.

Blister and Milk Stages

Water requirements remain high during the early stages of grain development, often described as the blister and milk stages. During this time, grain develops and rapidly increases in weight. Adequate soil moisture must be available during the first 4 weeks of grain filling for high volume grain production. Afterward, high soil moisture levels are not as important.

By early dough stage, water requirements normally begin to decrease. However, moistue stress while the dough is soft will limit grain fill. As grain matures, corn water needs decrease rapidly (see figure A-2).

The grain maturity line can be a guide for continuing or terminating irrigation. Corn kernels mature from the outward tip inward toward the cob. As kernel maturity progresses, a distinct yellow-white color separation is visible on each kernel and moves inward form the tip of each kernel. It is also known as the maturity line or starch line.

Measuring Grain Maturity

To identify the maturity line, break a corn ear in half and closely inspect the exposed full kernels. Kernels exposed by the external portion of the broken ear show the maturity line more clearly.

On heavier clay and clay loam soils, irrigate until the maturity line has progressed one-third to one-half the inward distance down the kernel. Try to have a full profile of soil moisture at this stage of grain maturity. This level of soil moisture is usually adequate for the immature portion of the kernel to maure and to maintain plant quality until harvest.

On sandy soils and on fields where individual irrigations have been consistently light during the season... corn may need to be irrigated until the maturity line has moved one-half to two-thirds the distance down the kernel.

Black Layer Formation

Formation of the black layer is a signal of full kernel maturity. The black layer becomes visible after the maturity line reaches the inward tip of the kernel, where the kernel attaches to the cob. A dark brown line first appears and later turns black. It can be located by cutting into the tip of the kernel.

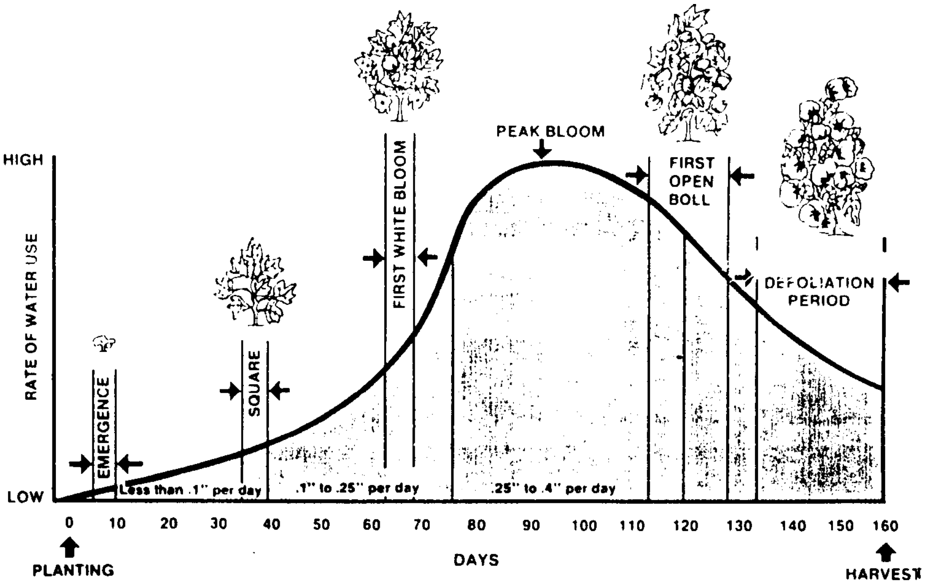
Corn can no longer increase in weight after the black layer appears and reduces in moisture content during the drying period before harvest. The only benefit from irrigation after this stage is to maintain plant quality until harvest.

Cotton Irrigation Water Management[1/]

Water is the most limiting factor in cotton production. Seasonal water use for adequately watered cotton varies from about 24 inches on the Texas High Plains, which has a short growing season, to over 40 inches in Arizona, which has an extended growing period characterized by high temperatures and low humidity conditions. Figure A-3 illustrates the typical seasonal water use pattern for cotton.

fig. A-3.

Rate of Water Use in Relation to Cotton Development



From planting to square initiation (a period of about 40 days) evapotranspiration (ET) is generally less than 0.1 inches per day. Plant water requirements are low due to the limited leaf area. Most of the water used is extracted from the top foot of soil. The bulk of the water loss during this period is due to evaporation.

Water use (ET) increases 0.1 to 0.3 inches per day during the square to early bloom stage (40 to 75 days after planting). The leaf canopy and roots are developing rapidly. Transpiration now exceeds evaporation. Moisture extraction occurs mainly from the top 2 feet of soil although the taproot and some feeder roots extent to deeper depths.

From early bloom to the opening of the first bolls (usually 75 to 120 days after planting), ET values of 0.25 to 0.35 inches per day are common. ET values may exceed 0.4 inch per day during the peak bloom period. The plants have attained their maximum leaf canopies and root densities. Moisture is being extracted from the entire soil profile.

Following the opening of the first bolls until crop termination, ET generally declines from about 0.25 inches per day to as little as 0.1 inches. Actual water use will vary with the condition of the plant, soil moisture status and general growing conditions. If regrowth occurs during periods of ample moisture and warm temperatures, ET levels can increase dramatically, thereby rapidly depleting soil moisture reserves which could have been utilized by subsequent crops.

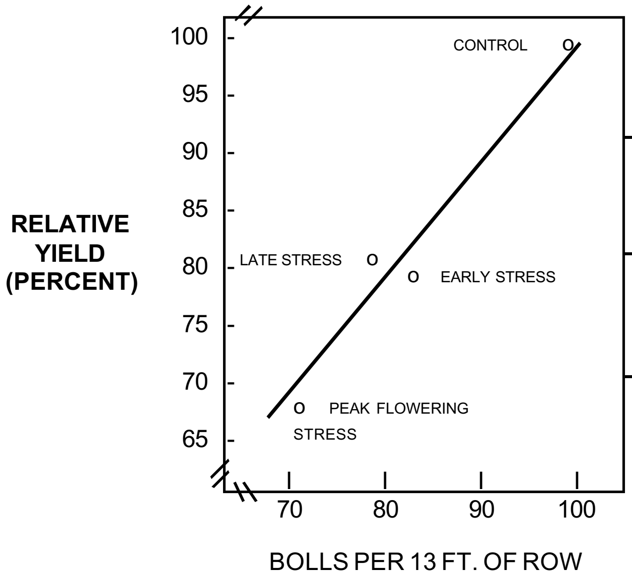
[1/] Supak, J.R. excerpted from Texas Agricultural Extension Service report. L-2297. Texas A&M University Agricultural Research and Extension Center. Lubbock, Texas.

Stress Sensitive Periods

Fruit production, retention and shedding are closely related to availability of soil moisture. Production is optimized with an available moisture status that allows uninterrupted development of fruiting positions while avoiding excessive vegatative development on the one hand, or fruit shedding on the other. In many cases, it has been a common practice to allow cotton to "stress" before applying the first irrigation in order to slow vegatative growth, force root system expansion and enhance early fruit development. However, recent studies have shown that even moderate stress prior to the first irrigation may impede the development of fruiting sites and can ultimately reduce yields.

Numerous trials have been conducted to assess the effects of moisture stress at different times during the bloom period on lint yields. The results of one such study conducted in California are shown in figure A-4. As might be expected, moisture stress during the peak flowering period had the most pronounced negative effect on yield. However, stress either early or late in the blooming period also resulted in significant yield reductions.

fig. A-4.



Relative lint yield and boll production associated with different stress conditions during flowering

Moisture stress during the peak flowering period has the most pronounced negative effect on yield. However, stress either early or late in the blooming period also results in significant yield reductions.

These results suggest that, where possible, severe moisture stress should be avoided throughout the crop development period. Early irrigations may be justified to maintain adequate but not excessive vegetative growth. In production regions with a short growing season, late season water stress may be acceptable or even desirable in that it hastens cut-out and the results in shedding of fruit that would not normally mature.

Irrigation Frequency

The number of summer irrigations and their timing has a significant influence on crop development and water use efficiency. Sprinklers afford much greater control in the amounts of water applied and frequency of applications.

Frequent light irrigations provide a suitable environment for root development in the upper foot of soil where nutrients and water are concentrated and oxygen is most abundant. Gradual depletion of soil moisture reserves through deficit irrigation provides for control of plant growth and development even if rainfall amounts exceed normal expectations.

Irrigation Termination

Ideally, the last irrigation should provide just enough plant available moisture to retain and mature all the bolls that have a reasonable chance of producing lint of acceptable quality under normal growing conditions. Based on long term seasonal conditions at Lubbock, blooms se on August 10 have a 100 percent probability of producing a mature boll of cotton whereas blooms set on August 15 and 25 and September 1, respectively, have only a 71, 29 and 14 percent, respectively, chance of reaching maturity. Consequently, in the Lubbock area, irrigations that bring soil moisture levels to near field capacity should be terminated by mid-August. Deficit irrigations with sprinklers could feasibly be extended until early September to minimize fruit shed.

In any given locale, the last irrigation will be dependent on seasonal conditions, soil type and the type of irrigation system being utilized.

GRAIN SORGHUM IRRIGATION WATER MANAGEMENT

A 3-Year Performance Test By the University of Nebraska Resulted in a 50% Increase in Yield for Irrigated vs. Dryland Production.

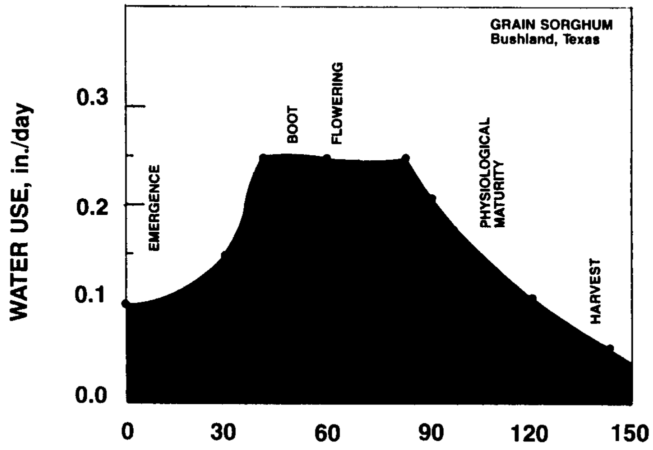
With irrigation, corn has traditionally been grown rather than grain sorghum because of a higher yield potential. However, there is increasing interest in irrigating grain sorghum because less water and lower inputs of fertilizer, labor and energy are required. In a 3-year grain sorghum variety performance test in south central Nebraska, yields were 122 bu./acre (6,832 lbs.) under irrigation and 82 bu./acre (4,592 lbs.) with dryland production, or a 40 bu. (2,240 lbs.) increase due to irrigation.

Grain sorghum production may be an attractive alternative when limited irrigation water is available. Although grain sorghum exhibits drought resistance characteristics, good irrigation water management and adequate soil moisture are essential for optimum yields. This means maintaining the soil moisture supply between field capacity and 50% depletion. By not completely refilling the soil profile, any rainfall received can be more efficiently used.

The daily water use of a grain sorghum plant will be low (less than 0.1" per day) as a seeding and increase to a peak (as much as 0.3" per day or more) during mid-summer when the plant is in the flower-dough stages of growth. (Actual daily water use can vary considerably from day to day depending on temperature, solar radiation, humidity and wind conditions--see figure A-5).

fig. A-5.

Consumptive Water Use Curve/Grain Sorghum



This graph represents grain sorghum evapotranspiration measured in 1988 at Bushland, Texas. The data is representative of fully-irrigated grain sorghum in the Southern High Plains with good yields (actual yield was 134 bu./acre or 7500 lbs./acre). Graph provided by Dr. Terry Howell, USDA-ARS, Bushland, Texas.

Germination, Emergence and Rapid Growth

An adequate supply of soil moisture immediately adjacent to the seed is essential for the seed to germinate, emerge and rapidly develop its early root system. If the soil moisture reservoir of medium textured soils in western Nebraska and Kansas is not filled prior to planting, a pre-plant irrigation can be used to fill the profile. This supply of soil moisture will be sufficient to meet the moisture needs of the crop for approximately 30-40 days during the rapid growth stage without additional precipitation or irrigation during this period. Normal moisture needs of the crop throughout this period in Nebraska will be 5-7" (6-8 1/2" in Texas), or approximately one-third of the total annual needs.

Reproduction Through Maturity

The most beneficial periods for applying irrigation water are at the boot stage (approximately 7 weeks after emergence) and half-bloom stage (approximately 8 1/2 weeks after emergence). Severe moisture stress during the boot stage may prevent the head from extending completely from the flag leaf sheath, preventing complete pollination at flowering time. Severe moisture stress at half-bloom stage can result in "blasting" and poor grain filling. This condition will cause yields to decrease, and may be further impacted by hot, windy and low humidity weather conditions.

The reproductive stages for grain sorghum take place during a period (about 60 days after emergence) when climatic conditions are not as favorable for plant development. The evapotranspiration demands are at a high level during this period--typically 25 to 40 days long. About 8-10" of water--nearly half the total moisture needs of the plant--are consumed. Some growers plant earlier, others later in order to avoid the hottest period of the summer at this stage of growth.

Adequate water is required by the plant for the maturity process to continue past this point at an optimum rate. By the hard dough stage, about 3/4 of the grain dry weight has accumulated. At physiological maturity, the maximum total dry weight of the plant has occurred. The time from flowering to physiological maturity varies with the hybrid and environmental conditions; however, it represents about 1/3 of the total time from planting.

The total water requirements of the plant during this period are relatively small. However, it is essential that adequate moisture be available to permit the development of full, plump seed and to prevent lodging of the seed.

Optimum Irrigation Management

The management procedure for maintaining the soil moisture supply in the crop root zone between field capacity and 50% depletion will vary by type of soil and irrigation system. For center pivot systems, irrigators will usually make frequent applications of about 1", while continuing to maintain a soil-water deficit to allow room for rainfall. Those irrigating with gravity systems will make larger, less frequent applications.

To ensure a satisfactory soil moisture supply for the grain sorghum crop, particular attention should be given to soil moisture status at these critical stages in the plant's life cycle: germination and seedling stage; boot stage; half-bloom stage; grainfill stage (see Table A-16).

Table A-16.

Identifying Characteristics and Approximate Time Intervals Between Growth Stages of Sorghum

Growth stage	Approx. days after emergence	Identifying Characteristic
0	0	Emergence. Coleoptile visible at soil surface.
1	10	Collar of 3rd leaf visible.
2	20	Collar of 5th leaf visible.
3	30	Growing point differentiation. Approximately 8-leaf stage by previous criteria.
4	40	Final leaf visible in whorl.
5	50	Boot. Head extended into flag leaf sheath.
6	60	Half-bloom. Half of plants at some stage of bloom.
7	70	Soft dough.
8	85	Hard dough.
9	95	Physiological maturity. Maximum dry matter accumulation.

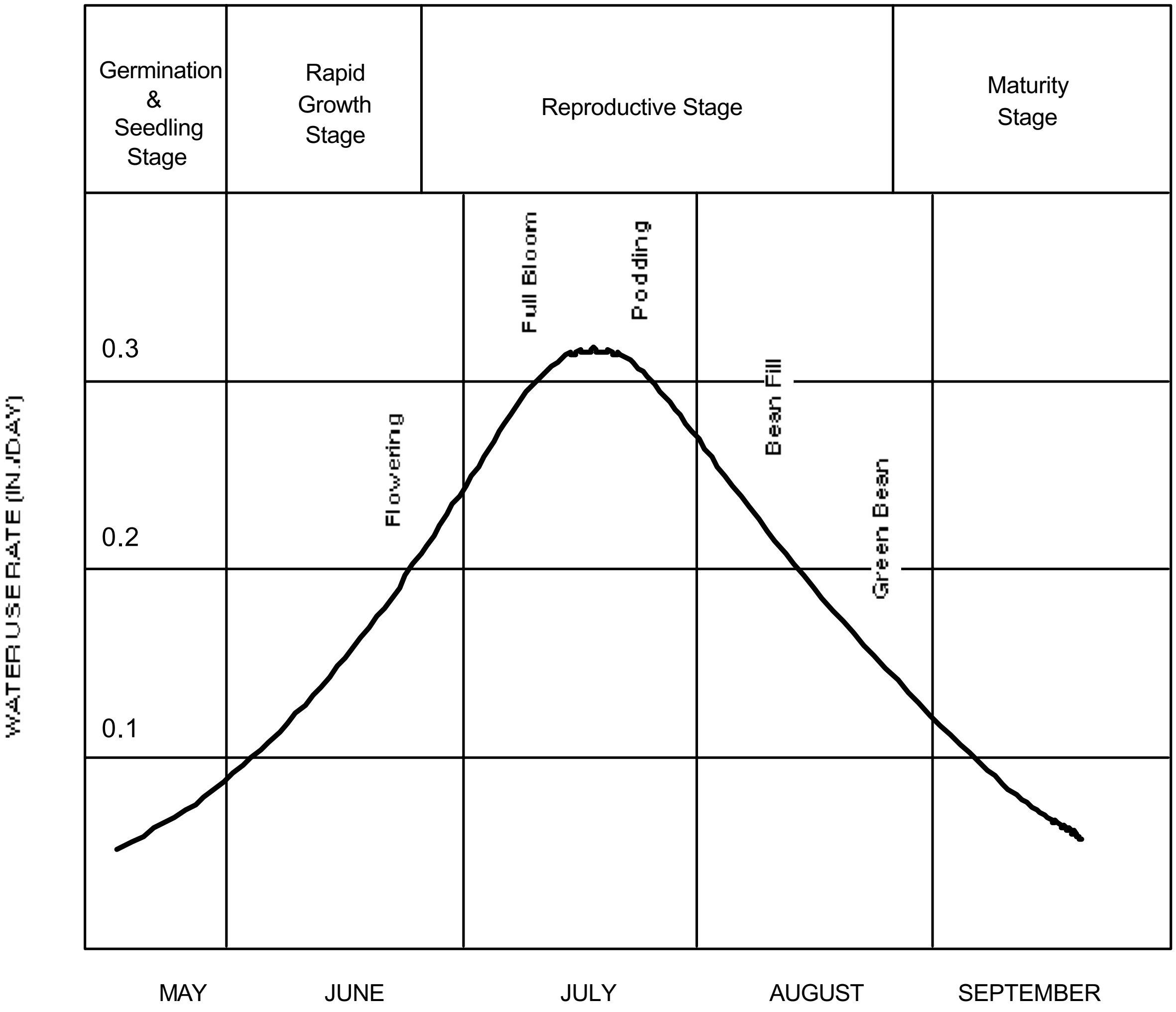
SOYBEAN IRRIGATION WATER MANAGEMENT

1. FIELD CAPACITY AT PLANTING TIME
2. AVOID IRRIGATION DURING VEGETATIVE GROWTH (CONSIDER SOIL TYPE)
3. AVOID IRRIGATION AT FLOWERING
4. ALWAYS IRRIGATE AT POD ELONGATION
5. CONTINUE IRRIGATION DURING SEED ENLARGEMENT UNTIL MATURITY
6. USE A VARIETY THAT WILL NOT HAVE EXCESSIVE GROWTH CAUSING LODGING LOSSES

IMPORTANT: HIGHEST YIELDS WERE ACHIEVED FROM SEVEN OR EIGHT IRRIGATIONS, BUT ONE IRRIGATION AT POD FILL ACHIEVED 90% OF MAXIMUM

fig. A-6.

Characteristic Growth and Water Use Pattern of Soybeans



WHEAT IRRIGATION WATER MANAGEMENT[1]

Irrigation requirements for winter wheat include fall application to establish the crop and to recharge soil moisture.

Wheat ranks third in irrigated crop area inthe United States behind corn and alfalfa, and wheat growers have increased yields by 32% during a 20-year period through the 1980s. About half of the increase in wheat yields is due to improved plant breeding, but increased yields can also be attributed to better crop management, increased fertilizer use and improved irrigation practices and equipment. Studies in the semiarid climate of the Southern High Plains by Jack Musick, USDA Agricultural Engineer, Bushland, Texas, found the annual yield increase for irrigated wheat during a 17-year period through 1984 was double that of dryland wheat.

In the Texas High Plains, thousands of acres of wheat are irrigated by furrow irrigation where application efficiencies are estimated in the range of 50% to 80%. Sprinkler application efficiencies, however--measured from 223 field evaluations of center pivot systems--were in the 80% to 90% range...and were even higher with lower windspeeds.

Irrigation water requirements for winter wheat consist of initial fall application--for crop establishment and to recharge the soil moisture profile--and seasonal irrigations to meet evapotransportation demands. Winter wheat's response to spring irrigation illustrates the importance of early season irrigation--such as application during jointing-which encourages the plant to retain tillers, produce more heads and increase seed numbers for maximum yield. In one study, a stress period during jointing reduced seed numbers by 45%.

The number of mid-season irrigations required for wheat range from only one to as many as six or seven, depending on the region, seasonal ET requirements, initial soil water storage, seasonal rainfall, application amounts, yield goals and irrigation application efficiency.

Average Daily Rate of Water Use by Phenological Periods for Irrigated Winter Wheat Grown under Optimum Soil Moisture, Garden City, KS '57-'59

Period	Water Use Inch per Day
Fall (October	0.07
Winter (November-February)	0.03
Beginning of spring growth to the jointing stage (March-April)	0.09
Jointing-to-boot stage (May 1-15)	0.16
Boot-to-flower stage (May 15-28)	0.25
Flower-to-milk stage of grain (May 28-June 6)	0.35
Milk-to-dough stage of grain (June 6-13)	0.30
Dough stage to maturity (June 13-28)	0.15

A successful irrigation water management practice on Pullman clay loam at Bushland, Texas, has been to apply an irrigation (if needed) for soil profile water storage during fall growth, delay the first spring irrigation to jointing stage in April, and then apply a second spring irrigation during boot stage to flowering. In field trials, yield response has been excellent to one and two well- timed spring irrigations.

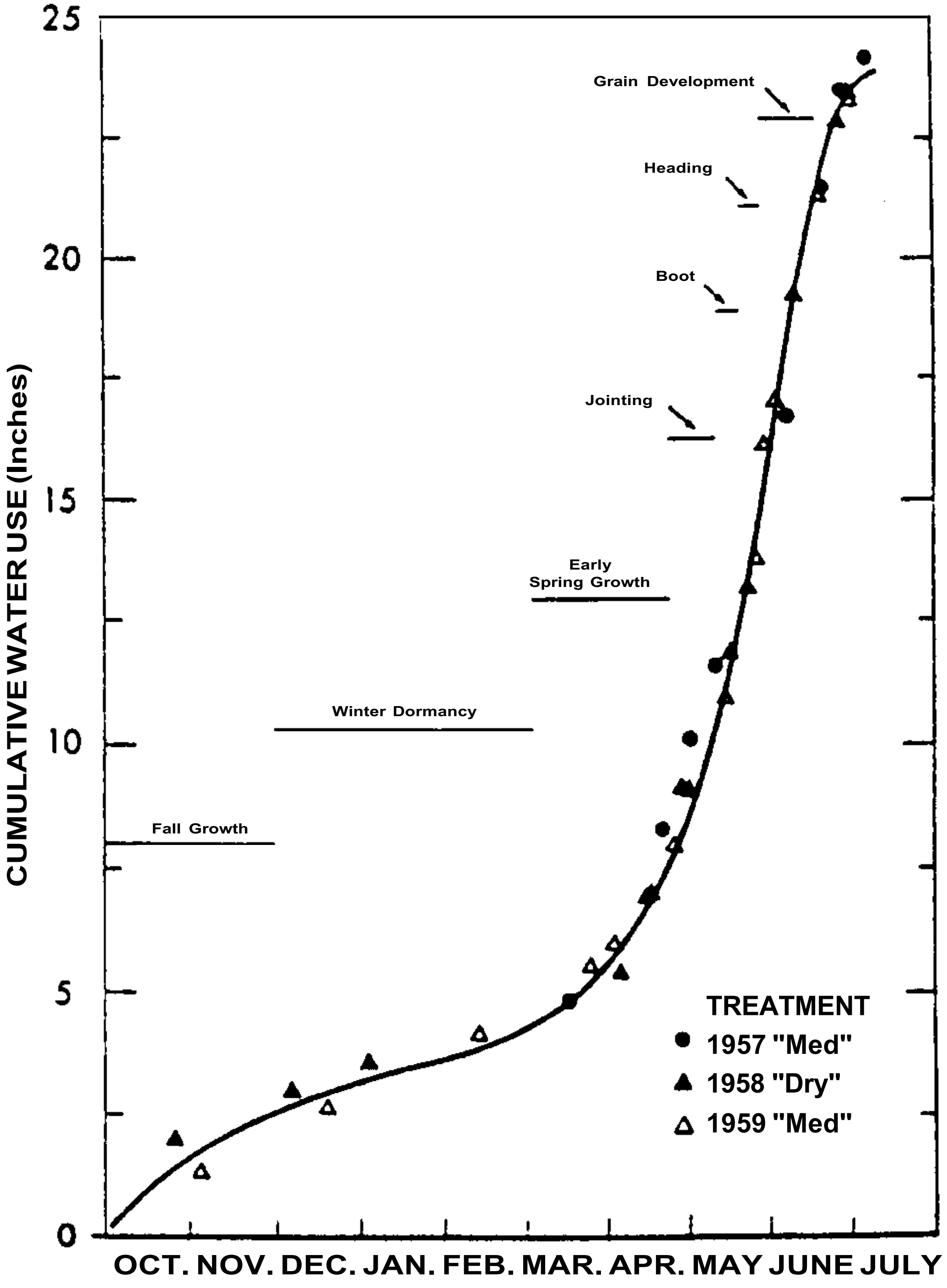
---

[1] Information in this article provided by J. T. Musick, Agricultural Engineer, USDA-Agricultural Research Service, Conservation and Production Research Laboratory. Bushland, TX, and K. B. Porter, Professor of Agronomy, TAES-TAMU, Amarillo, TX.

When seasonal rainfall fails to occur, such as during the 1984 spring season--when the first rains coincided with the end of grain filling--four seasonal irrigations are required for adequate water and high yields. The yield data plotted for different varieties also emphasize the importance of planting a high yielding short wheat (such as TAM 105 or TAM 108) on irrigated land.

fig. A-7.

Cumulative Seasonal Water Use by Irrigated Wheat Grown Under Adequate Soil Moisture for Near Maximum Yields



CALCULATING EVAPOTRANSPIRATION (ET)

Irrigation management strategies continually require evaluation of water and energy efficiencies. In order to evaluate correlation of irrigation water and energy requirements, a reference ET [obtained from local weather station data or calculated herein by equations (A4) - (A8)] plus crop ET calculations need to be combined to reliably estimate crop water use during the growing season.

Calculation of crop ET requires determining several component factors: (i) a ratio of actual crop ET vs. a reference crop ET; (ii) a measure of a basal crop coefficient based off a given crop's photothermal units required for growth from emergence to physiological maturity, with a breakdown of those photothermal units expressed as a fraction of the growing season related to specific crop growth stages; (iii) soil moisture holding capacity and daily soil moisture levels; and (iv) radiant solar energy measurements, measured directly with a pyronometer or obtained from local weather station data.

Calculation of crop ET for any given crop has several component sub-calculations[1/]:

$$\text{CROP ET} = (\overset{A}{K_{cb}} \times \overset{B}{K_a} \times \overset{C}{ET_r}) + (\overset{D}{K_s} \times \overset{C}{ET_r})$$

Explanation of terms A , B , C , and D follow:

A K_{cb} = basal crop coefficient

(A1) $= \dfrac{\left(\dfrac{ET_m}{ET_r}\right)}{Ka}$

(A2) ET_m = measured ET
= soil water depletion (in.) during a given measurement time interval (days).

(A3) ET_r = reference ET by the Jensen-Haise method, with an advection term (A) added.
$= [ET_{JH} + (ET_{JH} \times A)] \times 0.0394$

In equation (A3), the conversion factor 0.0394 <u>should not</u> be used if ET has been obtained already calculated and is expressed in <u>inches</u> of water per day. The conversion factor <u>should be</u> used if ET figures are expressed in <u>milliliters</u> of water per day. If the desired units in the calculation are to be in milliliters, <u>do not</u> use the conversion factor.

(A4) $ET_{JH} = \dfrac{[(0.078 + 0.0252T) \times R]}{L}$

(A5) T = average daily air temperature (C°)
$= \dfrac{T\,max. + T\,min.}{2}$

(A6) R = daily solar radiation in MJM^{-2}:measured directly with a pyronometer (Eppley Model PSP:Eppley Laboratory, Newport, RI; LI-COR Model LI-200S:LI-COR Inc., Lincoln, NE), or obtained from local weather station data.

(A7) L = 2.493 - 0.00214T
T = equation from (A5)

(A8) A = 0.05 X (Tmax - 33)
Tmax = maximum daily temp. C°

[1/] Amos, B., L. R. Stone, and L. D. Bark. 1989. Fraction of thermal units as the base for an evapotranspiration crop coefficient curve for corn. Agron. J. 81:713-717.

B Ka = soil moisture data; obtained as inches of water at given soil depth(s) from gypsum moisture blockapparatus, soil moisture meters, or neutron attenuation equipment.

(B1) $Ka = \frac{ASW\ (\text{in.})}{MASW\ (\text{in.})}$

(B2) ASW = measurement of available soil water (via soil moisture mesurement apparatus).

(B3) MASW = maximum amount of available soil water in a given crop root zone (see table A-17).

(B4) $\text{if } \frac{ASW}{MASW} \geq 0.5, \text{ then } K_a = 1$

(B5) $\text{if } \frac{ASW}{MASW} < 0.5, \text{ then } K_a = \frac{\left(\frac{ASW}{MASW}\right)}{0.5}$

Table A-17.

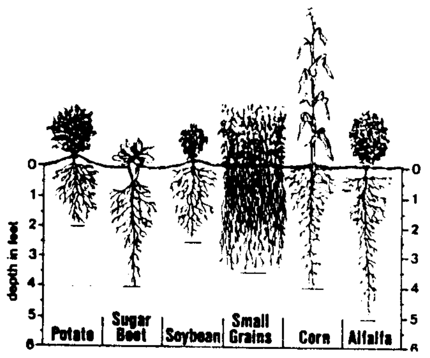
Available Water Capacity and Minimum Moisture Level for Soil Textural Classes

Soil Textural Classification		Available Water Capacity	Minimum Moisture Level		
			Potatoes	Dry Beans, Corn Sorghum, Soybeans, Small Grains, or Sugar Beets	Pasture, Alfalfa
				-------Inches/ft.[a]-------	
Fine Sands		1.0	0.6	0.5	0.4
Loamy Sands		1.1	0.7	0.6	0.4
Sandy Loam		1.4	0.8	0.7	0.6
Silty Clay or Clay		1.6	1.0	0.8	0.6
Fine Sandy Loam, Silty Clay Loam or Clay Loam		1.8	1.1	0.9	0.7
Sandy Clay Loam		2.0	1.2	1.0	0.8
Loam Very Fine Sandy Loam, or Silt Loam Topsoil	Silty Clay Loam or Silty Clay Subsoil	2.0	1.2	1.0	0.8
Loam, Very Fine Sandy Loam or Silt Loam Topsoil	Medium Textured Subsoil	2.5	1.5	1.3	1.0

[a] Inches of water per foot of active root zone.

Step I Determine available water capacity of your soil.

Step II Determine root depth for your crop. →



Step III Multiply Step I X Step II = Total Available Water when soil is filled to field capacity.

Step IV Multiply total capacity Step III X Available Soil Moisture (moisture block).

Step V Determine Minimum Moisture Level for your crop or 50% Soil Moisture Deple-

Step VI Multiply Minimum Moisture Level Step VX Root Depth.

Step VII From Soil Moisture remaining Step IV, subtract Minimum Moisture Level = Actual water available for crop use prior to causing crop stress.

C ET_r = reference ET by Jensen-Haise method, with an advection term (A) added
= refer to section A: (A3-A7)

D K_s = evaporation term following rains ž 4/100 inch; calculated for each of three days after a rainfall event has ended.

$$\text{(D1)}\quad K_S = \underset{\text{day 1}}{[0.8(1.0 - K_{cb})]} + \underset{\text{day 2}}{[0.5(1.0 - K_{cb})]} + \underset{\text{day 3}}{[0.3(1.0 - K_{cb})]}$$

K_{cb} term calculated as in section A: (A1-A7).

Additional field calibration and correlation studies done on selected field crops grown in the Great Plains region has eased the calculation of the K_{cb} term, basal crop coefficient as described in section A: (A1-A8).[1/] Specifically, for grain sorghum, pinto bean, sunflower, pearl millet, and soybean, graphic representations of the relationship between the $\left(\frac{ET_m}{ET_r}\right)$ term shown in equation (A1) and stage of growth [fraction of growing season:0(emergence), 0.2, 0.4, 0.6, 0.8, and 1.0 (physiological maturity)] have been developed to more easily arrive at the $\left(\frac{ET_m}{ET_r}\right)$ term. Referring to figure A-8, by following the horizontal axis representing fraction of growing season for each crop, the $\left(\frac{ET_m}{ET_r}\right)$ figure can be obtained from a corresponding position on the curve drawn for each crop within the graphs.

Example: Crop = Soybean
(refer to figure A-8) Growth Stage = beginning bean fill
= 0.65 fraction of growing season

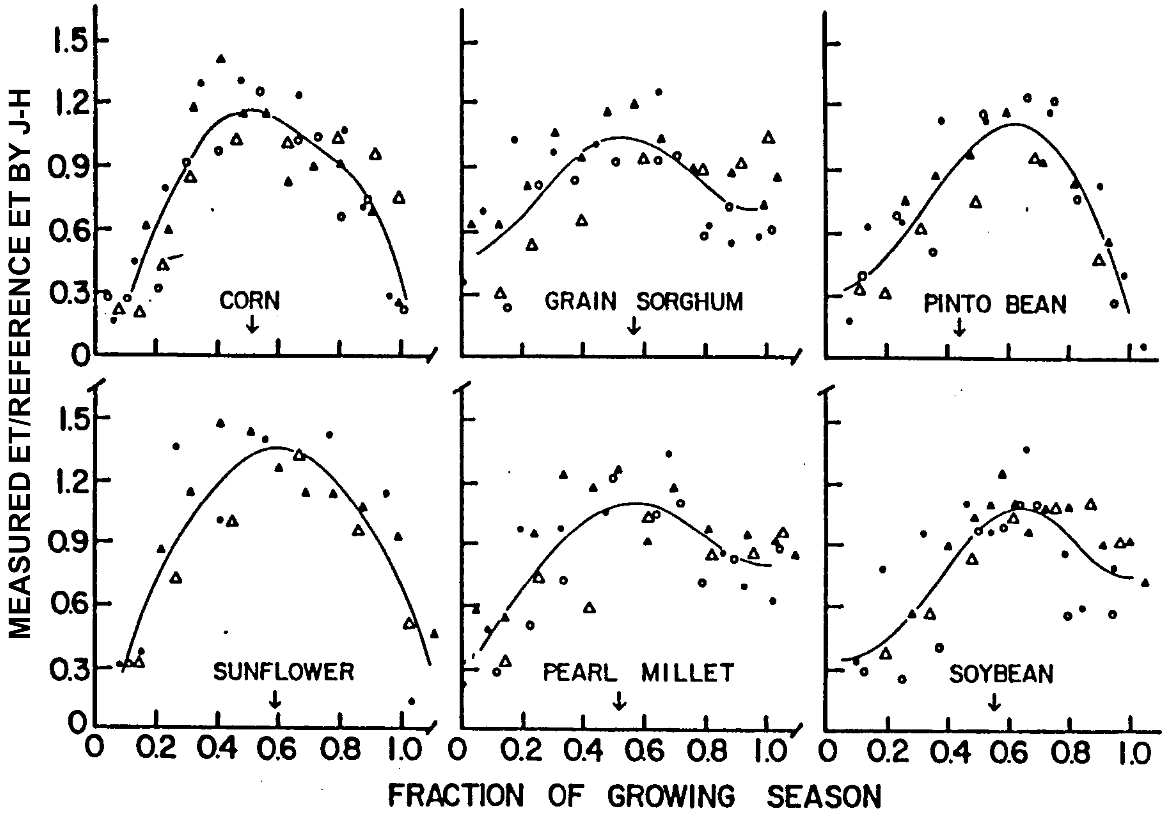
1. Refer to soybean graph section and read along bottom axis:fraction of growing season, to the point approximately at 0.65 (figure A-8).

[1/] Hattendorf, M. J., M.S. Redelfs, B. Amos, L. R. Stone, and R. E. Gwin, Jr. 1988. Comparitive water use characteristics of six row crops. Agron. J. 80:80-85.

2. From the 0.65 point, draw a vertical line upward that intersects the curve-line drawn within the graph.
3. Where the vertical line from the 0.65 point intersects the curve-line, draw a horizontal line to the left so as to intersect the vertical axis representing measured ET/reference ET by J-H, the $\left(\frac{ET_m}{ET_r}\right)$ term in equation (A1).
4. For soybean, then, the $\left(\frac{ET_m}{ET_r}\right)$ = 1.09 when at growth stage beginning bean fill, as expressed by fraction of growing season = 0.65.

fig. A-8.

Measured ET/Reference ET by the Jensen-Haise Equation vs. Fraction of growing Season for the Six Row Crops. Arrows Indicated Growth Stages; Silk Emergence in Corn, 50% Bloom in Grain Sorghum and Pearl Millet, Beginning Pod Set in Pinto Bean and Soybean, and 50% Flowering of Disk in Sunflower.



Summary of Thermal or Photothermal Units from Emergence to Physiological Maturity and the Fraction of Total Growing Season Units Accumulated from Emergence to Selected Growth Stages of the Six Crops

Crop	Growth Stage	Sum of thermal or photothermal units	fraction of growing season
Corn	Emerg. to physiol. mat.	1558 (6)†	
	Tassel emergence		0.47 (0.03)
	Silk emergence		0.52 (0.03)
	Blister kernel		0.63 (0.04)
Grain Sorghum	Emerg. to physiol. mat.	1405 (23)	
	Boot		0.47 (0.02)
	50% bloom		0.57 (0.01)
	Soft dough		0.72 (0.02)
Pearl Millet	Emerg. to physiol. mat.	1357 (15)	
	Boot		0.42 (0.03)
	50% bloom		0.52 (0.02)
	Soft dough		0.69 (0.02)
Pinto Bean	Emerg. to physiol. mat.	1246 (66)	
	Beginning bloom		0.34 (0.04)
	Beginning pod set		0.44 (0.03)
	Beginning bean fill		0.52 (0.02)
Soybean	Emerg. to physiol. mat.	2.39 (0.07)	
	Beginning bloom		0.45 (0.01)
	Beginning pod set		0.55 (0.01)
	Beginning bean fill		0.65 (0.01)
Sunflower	Emerg. to physiol. mat.	1522 (17)	
	Bud formation of head		0.31 (0.02)
	50% flowering of disk		0.59 (0.01)

†The value in parentheses is the standard error of the mean, where *n* = 3 for sunflower and *n* = 4 for all other crops.

For corn the entire K_{cb} calculation as shown in section A: (A1-A8) and supported in section B: (B1-B5) can be attained by referring to a graphic representation relating K_{cb} (basal crop coefficient) to fraction of thermal units (figure A-9), supported by Table A-19, which summarizes corn total thermal units from crop emergence to physiological maturity and the fraction of total growing season thermal units accumulated from crop emergence to selected growth stages.[1/]

Example:	Growth Stage	= blister kernel
(refer to figure A-9, and Table A-19)		= 0.62 fraction of thermal units (FTU)

1. Refer to the bottom, horizontal axis labeled fraction of thermal unit (FTU) and find the point corresponding to 0.62 (figure A-9).

[1/] Amos, B., L. R. Stone, and L. D. Bark. 1989. Fraction of thermal units as the base for an evapotranspiration crop coefficient curve for corn. Agron. J. 81:713-717.

2. From the 0.62 point, draw a vertical line upward that intersects the curve-line drawn within the graph.
3. Where the vertical line from the 0.62 point intersects the curve-line, draw a horizontal line to the left so as to intersect the vertical axis representing the basal crop coefficient (K_{cb}) term in equation (A1).
4. When corn is at blister kernel growth stage, as expressed by 0.62 FTU, K_{cb} = 1.

fig. A-9.

Basal Evapotranspiration Crop Coefficient Values vs. Fraction of Thermal Units (1974 through 1982 Data)

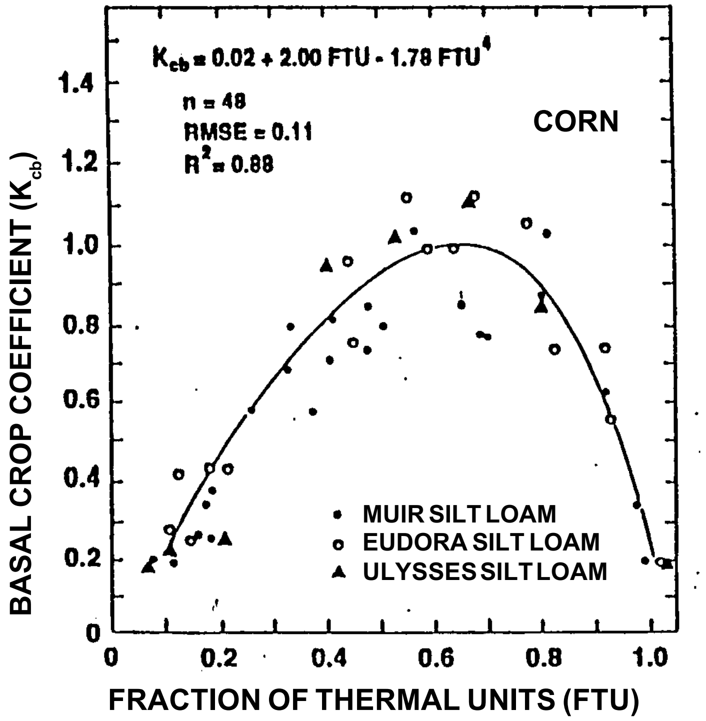


Table A-19.

Summary of Total Thermal Units from Crop Emergence to Physiological Maturity and the Fraction of Total Growing Season Thermal Units Accumulated from Crop Emergence to Selected Growth Stages

Cultivar	Year	Emergence to tasseling	Emergence to silking	Emergence to blister kernel	Emergence to physiological maturity
		fraction of thermal units			thermal units
Combined data	1974-1982	0.45 (7.8)	0.50 (7.5)	0.62 (8.1)	1619 (5.4)
Combined data	1974-1984	0.45 (7.4)	0.50 (7.1)	0.62 (6.8)	1531 (10.7)

†The value in parentheses is the coefficient of variation (%).

The ETr term [section A: (A3-A8)] can most easily be obtained from local weather station data, where the entire ETr term has already been calculated, or where the T term [average daily temperature C½:(A5)] and the R term [daily solar radiation:(A6)] are given for calculation. Remember, check the units of measurement received from weather station and apply the comment following equation (A3) to insure ET calculations are in the desired units (inches or millimeters).

When all necessary crop ET calculations have been made, add the resulting crop ET results to the reference ET figure [obtained from local weather station data or by calculation contained herein by equations (A4) - A8)]. The crop ET values will add consierable consumptive water use to the overall ET figure for any given crop, especially as crops (such as corn, grain soghum or soybeans) attain reproductive stages of growth.

MATERIALS AND AGRONOMICS

OF

SECONDARY AND MICRONUTRIENT ELEMENTS[1/]

[1/] Guidelines supplied by R. D. Curley, C.P.Ag., Soils and Fertilizer Consultant

CALCIUM

SOURCE	% Ca	REMARKS
LIMESTONE:		Very fine material (-325 mesh); dusty, should be handled in a closed system; hydrates; forms insoluble precipitate with phosphorus.
CALCITIC ($CaCO_3$)	40	
DOLOMITIC ($CaCO_3^+MgCO_3$)	30-32	
GYPSUM ($CaSO_4$)	23	15-18% S, Sulfate sulfur source primarily but for peanuts also supplies soluble Ca essential at pegging time; neutral salt, normally used as an ammendment on sodium alkali soils to replace the sodium on the exchange complex with calcium to improve internal drainage and aeration.
CHELATES & LIQUIDS		
PROMESOL 30	8	A liquid calcium "chelated" with tri-hydroxy-glutaric acid; soluble source of calcium in **liquid** fertilizers and for foliar treatments.
CHELATE	3-5	Soluble source of calcium for **liquid** fertilizers and **foliar** application.
CALCIUM NITRATE	19	Highly soluble in water; cannot be used with phosphate formulations; also good source of nitrogen.

CALCIUM

AGRONOMIC CONSIDERATIONS

1. Limestone is used to increase soil pH of acid soils, supplying needed calcium for plant nutrition. Lime also increases soil microbial activity, availability of Mo and phosphate and generally improves soil tilth.

2. High rates of acidifying fertilizers over time increase the need for lime applications.

3. The finer the lime, the quicker the change in soil pH.

4. Low organic matter, sandy soils required relatively low rates of lime to change pH--follow a soil test to determine amount and time of application.

MIXING INSTRUCTIONS

1. Add fine materials to the mixer over the top after the water addition, **slowly**.

2. Add TSPP (tetra sodium phyrophosphate) as a dispersant to the water (1-2%).

3. Use liquid clay, preferably added to the mix last; permitting addition of the lime to pure water. Usually 1% dry clay is sufficient.

4. A practical limit of 60% fine lime in the mix should be observed.

5. Urea added to a lime mix will hydrolize NH_3, creating potential loss of N from the mix and the soil surface if left unincorporated after application. Other ammonium sources of nitrogen (ammonium sulfate) may also volatize to NH_3.

6. Improve calcitic lime mix by added 10% by weight K-Mag at beginning of mix cycle.

MAGNESIUM

SOURCE	% Mg	REMARKS
MAGNESIUM SULFATE ($MgSO_4$) (Epsom Salts) (Kieserite)	10	13% S: highly soluble; fine crystalline material; hygroscopic (takes on water from air); high cost.
MAGNESIUM OXIDE (MgO) (Flo-Mag) Brand Names	58	Particle size is -200 mesh; forms $Mg(OH_2)$ in water importing alkaline reaction (pH) to mix; relatively insoluble in water.
MAGNESIUM CHLORIDE ($MgCl_2$)	8	Liquid; acid pH; corrosive to mild steel; Cl_2 content.
SULFATE OF POTASH-MAGNESIA (Langbeinite)	10-11	
Suspension Grade K-Mag	(10) (16 MgO)	
Fine Sul-Po-Mag	(11) (18 MgO)	
MAGNESIUM NITRATE ($Mg(NO_3)_2$)	6.31	Liquid for foliar and clear liquids; relatively expensive.

PROPERTIES	K-MAG	SUL-PO-MAG
Analysis	0-0-20-10Mg-20S	0-0-22-11Mg-22S
Particle Size	-10 to 100 mesh	-20 mesh
Density	63-66 lbs/ft^3	94-96 lbs/ft^3
Dispersion	Complete in Water to -200 mesh	None, remain as -20 mesh

MAGNESIUM

AGRONOMIC CONSIDERATIONS

1. Deficiencies or insufficiencies found mostly in low pH soils (acid).
2. Low organic matter, sand soils and highly leached soils generally contain lower levels of exchangeable Mg.
3. Mg is a constituent of chlorophyll necessary for carbohydrate synthesis by green plants.
4. Deficiency symptoms show up as yellow to white striping on lower leaves first due to translocation from older to newer plant parts (meristematic tissue).
5. Essential for starch, oils and fats, and sugar formation in plants.
6. Forage plants containing less than .2% Mg produce high incidence of grass tetany in ruminant animals (Hypomagnesemia)

MIXING INSTRUCTIONS

1. **Fine dry products--**
   a. $MgSO_4$ and Mg Oxide--slowly add to the mixer over the top or through an eductor **before addition of phosphate.**
   b. Suspension Grade K-Mag--add to the mixer over the top, at medium rate, to the water prior **to addition of any fertilizer salts and disperse for 3-5 minutes.**
   c. Fine Sul-Po-Mag--add as the last ingredient to the mix.
2. **Liquid products--**add at any time during the mix cycle, preerably ahead of phosphate.
3. Do not exceed ratio of 1.5 parts K-Mag: 1 part formulation water. For desirable fluidity, add UAN solution to the **dispersed** K-Mag to block the hydration process; flush mix tank and applicator with 50-100 gallons of UAN solution or liquid clay (8%).
4. Practical limit to 2-2.5% Mg in phosphate mixes which cannot be stored.

SULFUR

SOURCE	% S	REMARKS
AMMONIUM SULFATE	24	21% N; sulfate sulfur source, low solubility; fine crystalline material.
SULFATE OF POTASH-MAGNESIA	20-22	Suspension grade K-Mag or fine Sul-Po-Mag; somewhat abrasive (K-Mag) to extremely abrasiave (Sul-Po-Mag); contains 20-22% K_2O and 10-11% Mg (16-18% MgO).
POTASSIUM SULFATE	-17-18	50-52% K_2O; fine crystalline material.
MAGNESIUM SULFATE	12-13	10% Mg; epsom salts ($MgSO_4$); fine crystalline-material; somewhat expensive.
CALCIUM SULFATE (GYPSUM)	15-18	Fine powdered by-product of coal fired power plants and phosphoric acid production; economical close to source of production; high impurity content.
ELEMENTAL (WETTABLE) SULFUR	90	Very fine powder; dusty, irritates skin; insoluble; acid forming (good for Fe and Mn mixes).
AMMONIUM THIOSULFATE	26	12% N; liquid form, non-pressure, no free ammonia; reducing agent.
POTASSIUM THIOSULFATE	17	25% K; liquid form, non-pressure, no free ammonia, reducing agent.
AMMONIUM BISULFITE	17	8.5% N; liquid form, non-pressure, no free ammonia.
SULFATES OF MICRONUTRIENTS	Zn - 18% S Mn - 13-18% S Fe - 19% S Cu - 13% S	All sulfate sulfur sources which should be credited in formulations.

SULFUR

AGRONOMIC CONSIDERATIONS

1. Deficiency or insufficiency is most likely in acid, sandy soils and medium-textured soils of low organic matter.

2. Release as available sulfur from decomposition of organic matter; therefore, cool, wet soils may not supply sufficient sulfur during early growth stages of young seedlings. May leach out of root zone with water.

3. Essential for protein synthesis (nitrate reduction; a constituent of cysteine and methionine (amino acids).

4. N:S ratio of 10:1 in plants necessary for normal functioning and digestibility.

5. Elemental S must be oxidized to $SO_4^=$ (Sulfate) before plants can utilize it. Formation of sulfuric acid occurs with oxidation.

MIXING INSTRUCTIONS

1. **All fine dry materials except wettable S and AN**--add to the mixer over the top, with restraint, after adding phosphate.

2. **Do not** recommend gypsum (calcium sulfate) to be added to **phosphate** mixes. Best system is in water suspension alone.

3. WETTABLE SULFUR--best added to mixes as a pre-mixed N-S base containing 1.5% clay.

4. AMMONIUM SULFATE--best added as a premix solution (8-0-0-9S) or suspension (10.5-0-0-12S) at end of mix cycle.

5. Add liquid Ammonium Thiosulfate and Ammonium Bisulfite at any point in the mix--**preferably ahead of phosphate.**

ZINC

SOURCE	% Zn	REMARKS
ZINC SULFATE	36	Fine $ZnSO_4H_2O$ (monhydrate); contains 18% S; most widely used; economical source; pure form.
ZINC OXIDE	78-80	High grade; pure form; economical; fine.
ZINC CHLORIDE	50	$ZnCl_2$; mostly used in chelate manufacture; corrosive.
ZINC CARBONATE	52-56	$ZnCO_3$; foams badly, more expensive; flakes.
ZINCITE	25	Mixture of Zinc Oxide and Zinc Sulfate; granular.
SYNTHETIC CHELATE	6-14.5	Liquid most common form, lower analysis; EDTA most effective chelating agent in general.
AMMONIA COMPLEX	10	$Zn(NH_3)^{++}$--may contain 5% S if made from $ZnSO_4$.
LIGNOSULFONATES	7	Ke-Min powder or liquid--7% Zn maximum.

ZINC

AGRONOMIC CONSIDERATIONS

1. Deficiency in high pH soils due to low zinc solubility (Far West & Great Plains).

2. Leachable in sandy soils, creating deficiency under high rainfall or irrigation practices of overwatering.

3. Essential for chlorophyll formation; reactions in plants.

4. Sensitive plants--corn and sorghum acreages in U.S.:
    Corn--80 million (36 million west of Mississippi River)
    Sorghum--15 million (13 million west of Mississippi River)

5. $Zn(NH_3)^{++}$ complex not very effective in alkaline (high pH) soils.

MIXING INSTRUCTIONS

1. **All fine dry materials**--must be wetted thoroughly to prevent "balling" and floating to the top of the mix. Add the fine material over the top with restraint while agitating and recirculating the **water and nitrogen solution only.** DO NOT ADD PHOSPHATES BEFORE ADDING THESE FINE ZINC MATERIALS!

2. Using an eductor may create a partially wetted, crusty material that plugs up the eductor and puts balls in the mix that are difficult to disperse.

3. LIQUID CHELATES MAY BE ADDED AT END OF MIX CYCLE IF DESIRED.

4. FREE NH_3 from $Zn(NH_3)^{++}$ complex may overammoniate the phosphate causing insoluble globules to form. $Zn(NH_3)^{++}$ reacts with the phosphate, reducing the complex to a common inorganic $Zn\text{-}NH_4\text{-}PO_4$.

MANGANESE

SOURCE	% Mn	REMARKS
MANGANESE SULFATE	23-28	Fine, dusty, hazardous to breathe dust; $MnSO_4H_2O$ (monohydrate); contains about 13% S.
MANGANESE OXIDE	40-68	MnO (manganous oxide which is soluble); MnO_2 is not a soluble source for plants.
GRANUSOL 40		Porous granules which disperse in water with agitation (from American Minerals, Inc.)
MANGANOUS-MANGANIC OXIDE	28	Fine powder; may be too insoluble.
TECH-MAN-GAM	27	Manganese ammonium sulfate--contains 2.5% N and 17% S; fine powder, dusty.
SYNTHETIC CHELATES	5-12	EDTA source not desirable in high Fe soils but other chelates may be satisfactory.
LIGNOSULFONATES	10	Fine powder, reactive with phosphate, 10% Mn is maximum content possible.

MANGANESE

AGRONOMIC CONSIDERATIONS

1. Deficiency or insufficiency most likely in high pH soils due to low Mn solubility (Far West and Great Plains).
2. Legume crops (Soybeans, Lentils, Guar, Alfalfa) most sensitive to manganese insufficiency.
3. Manganese is essential for chlorophyll formation in plants.
4. Acid forming non-phosphate fertilizers are the best carriers of manganese, Ex. 5-0-0-30S-5Mn made with wettable sulfur, UAN and manganese, ammonium sulfate.
5. Manganese-EDTA may be rendered ineffective in high iron soils due to Fe substitution for Mn in the chelate.
6. Soybean Acreage - U.S. 70 million acres
   Iowa - 7 million
   Nebraska - 2 million
   Kansas - 1.6 million
   Illinois - 7 million

MIXING INSTRUCTIONS

1. **All fine dry materials**--add to the mixer, over the top, before adding the phosphate to prevent balling and floating. Dispersion and wetting will occur satisfactorily in **water** and **nitrogen solution**; except **Granusol** which should b dispersed in **water** only.
2. Liquid or chelated material may be added at any time during the mix cycle. preferably last.
3. Adding dry materials through an eductor may create partial wetting, forming a crust which plugs up the eductor.
4. Thickening of phosphate mixes will occur due to reaction of the Mn with phosphate, reducing the practical Mn content to about 2% Mn. Viscosity with orthophosphates is less than with polyphosphates

IRON

SOURCE	% Fe	REMARKS
FERROUS SULFATE	20	$FeSO_4$, $7H_2O$; fine material; contains 19% S.
FERRIC SULFATE	20-31	$Fe_2(SO_4)_3$,$9H_2O$; varies from fine to coarse.
FERROUS-AMMONIUM SULFATE	14	Combination of ferrous sulfate and ammonium sulfate; excellent solubility, contains about 17% S, 10% N.
FERROUS CARBONATE	42	$FeCO_3H_2O$; may foam badly, must be added to the mix slowly.
SYNTHETIC CHELATES	5-12	Fe HEDTA
10		Fe DTPA (CHEL330)
6		Fe EDDHA (CHEL 138, the most effective chelate)
LIGNOSULFONATES	11	By-products of wood-pulp processing; varying degrees of refining (Georgia Pacific's Ke-Mn highly stable); all react with phosphate which render them essentially inorganic iron compounds; act as dispersing agents, reducing viscosity of suspension mixes.

IRON

AGRONOMIC CONSIDERATIONS

1. Deficiency occurs predominantly in high pH soils with free calcium carbonates but may also occur on neutral, low organic matter soils (Far West & Great Plains mostly).
2. Essential for chlorophyll formation.
3. Varietal (Genetic) differences in iron uptake/Utilization makes some plants iron efficient and some iron ineffcieint. *Most sensitive crops--Corn, Sorghum, Citrus, Soybeans.
4. Acreages of major crops in Western U.S. create large potential for iron market.
5. Acid forming, non-phosphate, fertilizers are the best carriers of iron--Ex. 5-0-0-30S-5Fe made with ferrous sulfate, wettable sulfur and UAN.

MIXING INSTRUCTIONS

1. **All dry materials**--add to the mixer, over the top, **before adding phosphate**, to prevent balling and floating. Dispersion and wetting will occur satisfactorily in **water** and nitrogen solution.
2. The eductor may have a tendency to clog due to formation fo a crust in the throat of the hopper.
3. Thickening of the mix will occur due to reaction of **phosphate** with the iron, which reduces practical Fe content to around 2% Fe.
4. Foaming may be a problem when adding $FeSO_4$ to N-S mixes made with wettable sulfur--add a defoaming agent to water.
5. Liquid or chelated materials may be added at any time in the mix cycle, preferably last.

COPPER

SOURCE	% Cu	REMARKS
COPPER SULFATE (Monohydrate)	35	$CuSO_4,H_2O$; fine crystalline product; blue; contains about 12% S.
COPPER SULFATE (Pentahydrate)	25	$CuSO_45H_2O$; fine crystalline product.
CUPROUS OXIDE	89	Cu_2O; fine powder.
CUPRIC OXIDE	75	CuO; fine powder.
COPPER CHLORIDE	17	$CuCl_2$; crystal.
SYNTHETIC CHELATES	8-13	Cu-EDTA
9		Cu-HEDTA
LIGNOSULFONATES	7	Fine powder; reactive with phosphates, 7% Cu is maximum content possible.

COPPER

AGRONOMIC CONSIDERATIONS

1. All inorganic sources are considered equally effective agronomically.
2. Very narrow range between deficiency and toxicity in crop plants with long term persistence in the soil.
3. Broadcast applications only safe method of applying.
4. Viscosity problems due to copper reactions with phosphate but no apparent effect agronomically.
5. Lignosulfonate reactivity with phosphates makes them of questionable value in suspensions containing P.
6. Chelate effectiveness questionable for soil treatments.

MIXING INSTRUCTIONS

1. **All dry materials**--add to the mixer, over the top, before adding phosphate, to prevent balling and floating. Dispersion and wetting will occur satisfactorily in water and nitrogen solution.
2. Adding dry materials sthrough an eductor may create partial wetting, forming a crust which may plug up the eductor.
3. Liquid chelate materials may be added at any time during the mix cycle, preferably last.
4. Thickening of phosphate mixes will occur due to reaction reducing the practical Cu content to 2% or less. Viscosity with orthophosphates is **lower** than with polyphosphates.

BORON

SOURCE	% B	REMARKS
FERTILIZER BORATE 48	14.5	-60 mesh; excellent for suspensions.
SOLUBOR	20.5	Highly soluble, for clear liquids.

BORON

AGRONOMIC CONSIDERATIONS

1. Agronomic effectiveness not affected by mixing in N-P-K fertilizers.
2. Calcium and magnesium may form insoluble boron compounds and; therefore, may be incompatible with lime, gypsum and various Mg sources.
3. Manganese and magnesium combinations may form an insoluble hydroxide but agronomic effectiveness is not known.
4. Deficiency found in low organic matter, sandy soils and under drouthy conditions.
5. Narrow range between deficiency and toxicity. Alfalfa most sensitive crop; critical for seed crops.

MIXING INSTRUCTIONS

1. Borate 48 powder should be added to the mix before adding the phosphate to prevent balling and floatation.
2. May be added to the mix through an eductor with excellent results; before phosphate is added.
3. Broadcast applications exclusively.

MOLYBDENUM

SOURCE	% Mo	REMARKS
SODIUM MOLYBDATE	39	$Na_2MoO_42H_2O$; fine powder.
AMMONIUM MOLYBDATE	54	$(NH_4)_6(MoO_7O_{24})$; fine powder.

SUSPENSION FORMULATION CONSIDERATIONS

In order to adequately supply some formulations containing potash, magnesium and sulfur through sprinkler irrigation systems, clay suspensions have to be made with correct ratios of water, clay and suspended fertilizer material. Properly suspending fertilizer material in solution demands good clay gel strength (i.e., complete dispersion of clay in a 7:1 ratio of water to clay) before the rest of the water and fertilizer material can be added. Fertilizer material used in suspensions has to be either able to completely dissolve in water with slight mixing, or be of a fine mesh (at least -200 mesh size) state. Fine mesh suspended fertilizer material can be successfully injected through center pivot systems but a separate storage tank fitting with agitation via recirculation bypass to the storage tank is required. Also, all screens in the conventional system must be removed to prevent "screen blinding" and resulting system shutdown.

Example fertilizer formulation sheets follow (Tables A-20 through A-27), giving correct amounts and orders of addition of formulations successfully applied through sprinkler systems as suspensions.

Table A-20.

Worksheet: KCl and Water

Materials and Order of Addition	Pounds Per Ton
Water	280
Clay[1/]	40
Water	518
KCl[2/]	1162
TOTALS	2000

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
0	0	36	0	0	0

NOTES & COMMENTS:

1. 2% clay as dry clay; fluid clay would be the preferred clay source.
2. KCl as 0-0-62

Guidelines supplied by R. D. Curley, C.P.Ag., Consultant

Table A-21.

Worksheet: KCl and Water + UAN 28 (Suspension)

Materials and Order of Addition	Pounds Per Ton
Water[1]	296
Clay[2]	40
UAN 28%[1]	857
KCl[3]	807
TOTALS	2000

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
12	0	25	0	0	0

NOTES & COMMENTS:

1. 43% water + water equivalent; UAN 28 is 40% water, which is water equivalent.
2. 2% clay as dry clay; fluid clay would be the preferred clay source.
3. KCl as 0-0-62

Table A-22.

Worksheet: Flowable Sulfur + UAN 28

Materials and Order of Addition	Pounds Per Ton
Water[1]	270
Clay[2]	30
Water[1]	319
90% S[3]	667
UAN 28	714

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
10	0	0	0	30	

NOTES & COMMENTS:

1. 43% water + water equivalent; UAN 28 is 40% water, which is water equivalent.
2. 2% clay as dry clay; fluid clay would be the preferred clay source.
3. Sulfur material must be fine mesh grade (-200 mesh or, 2 or 44 micron size).

Guidelines supplied by R. D. Curley, C.P.Ag., Consultant

Table A-23.

Worksheet: Suspension Utilizing MgO

Materials and Order of Addition	Pounds Per Ton
Water	509
Clay[1/]	40
UAN 32%	1250
MgO[2/]	172
KCl[3/]	129

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
20	0	4	5	0	0

NOTES & COMMENTS:

1. 2% clay as dry clay; fluid clay would be the preferred clay source.
2. MgO as Flo-Mag: product of Martin Marietta Chemicals.
3. KCl as 0-0-62

Table A-24.

Worksheet: KCl and Water + UAN 28 (Non-suspension)

Materials and Order of Addition	Pounds Per Ton
Water	475
UAN 28%	1428
KCl[1/]	97
TOTALS	2000

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
20	0	3			

NOTES & COMMENTS:

1. KCl as 0-0-62

Guidelines supplied by R. D. Curley, C.P.Ag., Consultant

Table A-25.

Worksheet: N-K-S Solution (Non-suspension)

Materials and Order of Addition	Pounds Per Ton
Water	299
UAN 28%	1296
12-0-0-26S[1]	308
KCl	97
TOTALS	2000

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
20	0	3		4	

NOTES & COMMENTS:

1. 12-0-0-26S as ammonium thiosulfate.

Table A-26.

Worksheet: N-K-S Solution (Non-suspension)

Materials and Order of Addition	Pounds Per Ton
Water	425
UAN 28%	811
8-0-0-9S[1]	667
KCl[2]	97
TOTALS	2000

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
14	0	3		3	

NOTES & COMMENTS:

1. 8-0-0-9S as ammonium sulfate solution.
2. KCL as 0-0-62

Guidelines supplied by R. D. Curley, C.P.Ag., Consultant

Table A-27.

Worksheet: N-K-S Solution (Non-suspension)

Materials and Order of Addition	Pounds Per Ton
Water	394
UAN 28%	1175
21-0-0-24S[1/]	334
KCl[2/]	97
TOTALS	2000

GRADE/NUTRIENT RATE					
N	P	K	Mg	S	Zn
20	0	3		4	

NOTES & COMMENTS:

1. 21-0-0-24S as solution grade ammonium sulfate.
2. KCl as 0-0-62

Guidelines supplied by R. D. Curley, C.P.Ag., Consultant

Table A-28.

Suspension Formulations Using 3-10-30 Base

				POUNDS	
RATIO	GRADE	RAW MATERIALS	1 TON	3 TONS	5 TONS
1:3:3	6-18-18	3-10-30	1200	3600	6000
		12-40-0	600	1800	3000
		28-0-0	43	129	215
		Water	157	471	785
	4-12-27	3-10-30	1800	5400	9000
		12-40-0	150	450	750
		28-0-0	29	87	145
		Water	21	63	105
1:3:6	4-12-24	3-10-30	1600	4800	8000
		12-40-0	200	600	1000
		28-0-0	29	87	145
		Water	171	513	855
1:2:2	8-16-16	3-10-30	1067	3201	5335
		12-40-0	535	1605	2675
		28-0-0	229	687	1145
		Water	169	507	845
1:2:4	6-12-24	3-10-30	1600	4800	8000
		12-40-0	200	600	1000
		28-0-0	171	513	855
		Water	29	87	145
1:2:3	7-14-21	3-10-30	1400	4200	7000
		12-40-0	350	1050	1250
		28-0-0	200	600	1000
		Water	50	150	250
1:3:2	7-21-14	3-10-30	933	2799	4665
		12-40-0	817	2451	4085
		28-0-0	50	150	250
		Water	200	600	1000
1:3:2	7-23-15	3-10-30	1000	3000	5000
		12-40-0	900	2700	4500
		28-0-0	7	21	35
		Water	93	279	465
	9-30-10	3-10-30	667	2001	3335
		12-40-0	1333	3999	6665
1:3:1	9-27-9	3-10-30	600	1800	3000
		12-40-0	1200	3600	6000
		28-0-0	64	192	320
		Water	136	408	680
1:1:2	10-10-20	3-10-30	1333	3999	6665
		12-40-0	167	501	835
		28-0-0	500	1500	2500
1:1:1	13-13-13	3-10-30	867	2601	4335
		12-40-0	433	1299	2165
		28-0-0	650	1950	3250
		Water	50	150	250

Table A-28 continued

				POUNDS	
RATIO	GRADE	RAW MATERIALS	1 TON	3 TONS	5 TONS
1:2:1	10-20-10	3-10-30	667	2001	3335
		12-40-0	833	1299	4165
		28-0-0	286	858	1430
		Water	214	642	1070
2:3:1	14-21-7	3-10-30	467	1401	2335
		12-40-0	933	2799	4665
		28-0-0	550	1650	2750
		Water	50	150	250
2:4:1	12-24-6	3-10-30	400	1200	2000
		12-40-0	1100	3300	5500
		28-0-0	343	1029	1715
		Water	157	471	785
2:3:2	12-18-12	3-10-30	800	2400	4000
		12-40-0	700	2100	3500
		28-0-0	471	1413	2355
		Water	29	87	145
2:3:3	10-15-15	3-10-30	1000	3000	5000
		12-40-0	500	1500	2500
		28-0-0	393	1179	1965
		Water	107	321	535
2:1:1	18-9-9	3-10-30	600	1800	3000
		12-40-0	300	900	1500
		28-0-0	1093	3279	5465
		Water	7	21	35
3:2:1	18-12-6	3-10-30	400	1200	2000
		12-40-0	500	1500	2500
		28-0-0	1029	3087	5145
		Water	71	213	355
3:3:1	16-18-6	3-10-30	400	1200	2000
		12-40-0	800	2400	4000
		28-0-0	757	2271	3785
		Water	43	129	219
3:3:2	15-15-10	3-10-30	667	2001	3335
		12-40-0	583	1749	2915
		28-0-0	750	2250	3750
	16-20-6	3-10-30	400	1200	2000
		12-40-0	900	2700	4500
		32-0-0	667	2001	3335
		Water	33	99	165
3:4:1	15-20-5	3-10-30	333	999	1665
		12-40-0	918	2754	4590
		28-0-0	643	1929	3215
		Water	106	318	530
4:3:1	20-15-5	3-10-30	333	999	1665
		12-40-0	667	2001	3335
		32-0-0	969	2907	4845
		Water	31	93	155
2:2:1	16-16-8	3-10-30	533	1599	2665
		12-40-0	667	2001	3335
		28-0-0	800	2400	4000

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-29.

Suspension Formulations Using 4-12-27 Base

				POUNDS	
RATIO	GRADE	RAW MATERIALS	1 TON	3 TONS	5 TONS
1:3:3	6-18-18	4-12-27	1333	3999	6665
		12-40-0	500	1500	2500
		28-0-0	25	75	125
		Water	142	426	710
1:3:6	4-12-24	4-12-27	1780	5340	8900
		12-40-0	70	210	350
		Water	150	450	750
1:2:2	8-16-16	4-12-27	1185	3555	5925
		12-40-0	445	1335	2225
		28-0-0	214	642	1070
		Water	156	468	780
1:2:4	6-12-24	4-12-27	1780	5340	8900
		12-40-0	70	210	350
		28-0-0	146	438	730
		Water	4	12	20
1:2:3	7-14-21	4-12-27	1556	4668	7780
		12-40-0	233	699	1165
		28-0-0	179	537	895
		Water	32	96	160
1:3:2	7-23-15	4-12-27	1111	3333	5555
		12-40-0	818	2454	4090
		Water	71	213	355
1:3:1	9-29-10	4-12-27	741	2223	3705
		12-40-0	1229	3687	6145
		28-0-0	11	33	55
		Water	19	57	95
1:3:1	9-27-9	4-12-27	667	2001	3335
		12-40-0	1150	3450	5750
		28-0-0	54	162	270
		Water	129	387	645
1:1:2	9-10-20	4-12-27	1482	4446	7410
		12-40-0	55	165	275
		28-0-0	407	1221	2035
		Water	56	168	280
1:1:2	10-10-20	4-12-27	1482	4446	7410
		12-40-0	55	165	275
		32-0-0	422	1266	2110
		Water	41	123	205
1:1:1	13-13-13	4-12-27	963	2889	4815
		12-40-0	363	1089	1815
		28-0-0	636	1908	3180
		Water	38	144	190
1:2:1	10-20-10	4-12-27	741	2223	3705
		12-40-0	778	2334	3890
		28-0-0	279	837	1395
		Water	202	606	1010

Table A-29 continued

				POUNDS	
RATIO	**GRADE**	**RAW MATERIALS**	**1 TON**	**3 TONS**	**5 TONS**
2:3:1	14-21-7	4-12-27	519	1557	2595
		12-40-0	895	2685	4475
		28-0-0	546	1638	2730
		Water	40	120	200
2:4:1	12-24-6	4-12-27	444	1332	2220
		12-40-0	1068	3204	5340
		28-0-0	336	1008	1680
		Water	152	456	760
2:3:2	12-18-12	4-12-27	889	2667	4445
		12-40-0	635	1905	3175
		28-0-0	457	1371	2285
		Water	21	63	105
2:3:3	10-15-15	4-12-27	1112	3336	5560
		12-40-0	418	1254	2090
		28-0-0	379	1137	1895
		Water	91	273	455
2:1:1	18-9-9	4-12-27	667	2001	3335
		12-40-0	250	750	1250
		28-0-0	1083	3249	5415
3:2:1	18-12-6	4-12-27	444	1332	2220
		12-40-0	468	1404	2340
		28-0-0	1025	3075	5125
		Water	63	189	315
	16-18-6	4-12-27	444	1332	2220
		12-40-0	768	2304	3840
		28-0-0	754	2262	3770
		Water	34	102	170
3:3:2	15-15-10	4-12-27	741	2223	3705
		12-40-0	528	1584	2640
		32-0-0	650	1950	3250
		Water	81	243	405
2:3:1	16-20-6	4-12-27	444	1332	2220
		12-40-0	868	2604	4340
		32-0-0	622	1866	3110
		Water	66	198	330
3:4:1	15-20-5	4-12-27	371	1113	1855
		12-40-0	890	2670	4450
		28-0-0	639	1917	3195
		Water	100	300	500
4:3:1	20-15-5	4-12-27	370	1110	1850
		12-40-0	640	1920	3200
		32-0-0	963	2889	4815
		Water	27	81	135
2:2:1	16-16-8	4-12-27	588	1764	2940
		12-40-0	623	1869	3115
		28-0-0	789	2367	3945

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-30.

Suspension Formulations Using 5-15-30 Base

				POUNDS	
RATIO	**GRADE**	**RAW MATERIALS**	**1 TON**	**3 TONS**	**5 TONS**
1:3:3	6-18-18	5-15-30	1200	3600	6000
		12-40-0	450	1350	2250
		28-0-0	22	66	110
		Water	328	984	1640
1:3:3	7-21-21	5-15-30	1400	4200	7000
		12-40-0	525	1575	2625
		28-0-0	25	75	125
		Water	50	150	250
1:2:2	9-18-18	5-15-30	1200	3600	6000
		12-40-0	450	1350	2250
		28-0-0	236	708	1180
		Water	114	342	570
1:2:2	8-16-16	5-15-30	1067	3201	5335
		12-40-0	400	1200	2000
		28-0-0	211	633	1055
		Water	322	966	1610
1:2:4	6-12-24	5-15-30	1600	4800	8000
		12-40-0	—	—	—
		28-0-0	143	429	715
		Water	257	771	1285
1:2:3	7-14-21	5-15-30	1400	4200	7000
		12-40-0	175	525	875
		28-0-0	175	525	875
		Water	250	750	1250
1:2:3	8-16-24	5-15-30	1600	4800	8000
		12-40-0	200	600	1000
		28-0-0	200	600	1000
1:3:2	8-24-16	5-15-30	1067	3201	5335
		12-40-0	800	2400	4000
		28-0-0	38	114	190
		Water	95	285	475
1:3:2	8-26-16	5-15-30	1067	3201	5335
		12-40-0	900	2700	4500
		28-0-0	—	—	—
		Water	33	99	165
1:3:2	7-21-14	5-15-30	934	2802	4670
		12-40-0	700	2100	3500
		28-0-0	32	96	160
		Water	334	1002	1670
1:3:2	7-23-15	5-15-30	1000	3000	5000
		12-40-0	775	2325	3875
		28-0-0	—	—	—
		Water	225	675	1125
1:3:1	10-30-10	5-15-30	667	2001	3335
		12-40-0	1250	3750	6250
		28-0-0	61	183	305
		Water	22	66	110
1:1:2	10-10-20	5-15-30	1334	4002	6670
		12-40-0	—	—	—
		28-0-0	475	1425	2375
		Water	191	573	955
1:1:1	13-13-13	5-15-30	867	2601	4335
		12-40-0	325	975	1625
		28-0-0	636	1908	3180
		Water	172	516	860
1:1:1	14-14-14	5-15-30	934	2802	4670
		12-40-0	350	1050	1750
		28-0-0	686	2058	3430
		Water	30	90	150
1:2:1	12-24-12	5-15-30	800	2400	4000
		12-40-0	900	2700	4500
		32-0-0	288	864	1440
		Water	12	36	60
1:2:1	11-22-11	5-15-30	734	2202	3670
		12-40-0	825	2475	4125
		28-0-0	300	900	1500
		Water	141	423	705

Table A-30 continued

				POUNDS	
RATIO	GRADE	RAW MATERIALS	1 TON	3 TONS	5TONS
2:3:1	14-21-7	5-15-30	467	1401	2335
		12-40-0	875	2625	4375
		28-0-0	543	1629	2715
		Water	115	345	575
2:4:1	12-24-6	5-15-30	400	1200	2000
		12-40-0	1050	3150	5250
		28-0-0	264	792	1320
		Water	286	858	1430
	12-28-7	5-15-30	467	1401	2335
		12-40-0	1225	3675	6125
		28-0-0	250	750	1250
		Water	58	174	290
	13-26-6	5-15-30	400	1200	2000
		12-40-0	1150	3450	5750
		28-0-0	364	1092	1820
		Water	86	258	430
2:3:2	12-18-12	5-15-30	800	2400	4000
		12-40-0	600	1800	3000
		28-0-0	457	1371	2285
		Water	143	429	715
2:3:3	10-15-15	5-15-30	1000	3000	5000
		12-40-0	375	1125	1875
		28-0-0	375	1125	1875
		Water	250	750	1250
	12-17-17	5-15-30	1134	3402	5670
		12-40-0	425	1275	2125
		32-0-0	413	1239	2065
		Water	28	84	140
2:1:1	18-9-9	5-15-30	600	1800	3000
		12-40-0	225	675	1125
		28-0-0	1082	3246	5410
		Water	93	279	465
2:1:1	18-10-10	5-15-30	667	2001	3335
		12-40-0	250	750	1250
		28-0-0	1061	3183	5305
		Water	22	66	110
3:2:1	18-12-6	5-15-30	400	1200	2000
		12-40-0	450	1350	2250
		28-0-0	1021	3063	5105
		Water	129	387	645
	16-18-6	5-15-30	400	1200	2000
		12-40-0	750	2250	3750
		28-0-0	750	2250	3750
		Water	100	300	500
3:3:2	15-15-10	5-15-30	667	2001	3335
		12-40-0	500	1500	2500
		28-0-0	740	2220	3700
		Water	93	279	465
	16-20-6	5-15-30	400	1200	2000
		12-40-0	850	2550	4250
		28-0-0	707	2121	3535
		Water	43	129	215
3:4:1	15-20-5	5-15-30	334	1002	1670
		12-40-0	875	2625	4375
		28-0-0	636	1908	3180
		Water	155	465	755
4:3:1	20-15-5	5-15-30	334	1002	1670
		12-40-0	625	1875	3125
		32-0-0	963	2889	4815
		Water	78	234	390
2:2:1	16-16-8	5-15-30	534	1602	2670
		12-40-0	600	1800	3000
		32-0-0	793	2379	3965
		Water	73	219	365

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-31

Liquid Formulations Using 10-34-0[1/] As the Only Source of P_2O_5

		Ammonium Polyphosphates 10-34-0		Water		UAN Solution (32-0-0)		Potash (0-0-60)	Estimated Salting-Out Temperature
Ratio	**Grade**	**Lbs/Ton**	**Gal.Ton**	**Lbs/Ton**	**Gal.Ton**	**Lbs./Ton**	**Gal./Ton**	**Lbs./Ton**	**(^{O}F)**
1:1:0	16-16-0	941	82.6	354	42.4	705	63.7	—	26
1:2:0	13-26-0	1530	134.2	136	16.3	334	30.1	—	18
1:3:0	10-30-0	1765	154.8	162	19.4	73	6.6	—	0
1:1:1	8-8-8	471	41.3	909	109.0	353	31.9	267	41
1:1:1	9-9-9	529	46.4	774	92.8	397	35.9	300	43
1:2:1	8-16-8	941	82.5	587	70.4	205	18.5	267	37
1:3:1	7-21-7	1235	108.3	480	57.6	51	4.6	234	12
1:3:1	6-18-6	1059	92.9	697	83.6	44	4.0	200	10
1:1:2	5-5-10	294	25.7	1150	137.9	222	20.0	334	20
1:2:2	5-10-10	588	51.5	947	113.5	131	11.8	334	18
1:2:2	4-10-10	588	51.5	10.12	121.3	66	6.0	334	5
1:3:2	5-15-10	882	77.3	746	89.4	38	3.5	334	44
2:8:1	8-25-3	1471	129.0	389	46.6	40	3.6	100	0
1:1:3	4-4-12	235	20.6	1187	142.3	178	16.0	400	20
1:2:3	4-8-12	471	41.3	1026	123.0	103	9.3	400	32
1:3:6	2-6-12	353	31.0	1232	147.7	15	1.3	400	28
1:3:3	3-9-9	529	46.4	1149	137.8	22	1.9	300	0
2:1:0	20-10-0	588	51.6	347	41.7	1065	96.2	—	0
2:1:1	10-5-5	294	25.8	1008	120.9	531	48.0	167	32
2:1:1	12-6-6	353	31.0	807	96.8	640	57.9	200	43
2:2:1	10-10-5	588	51.6	801	96.0	444	40.1	167	32
2:3:1	10-15-5	882	77.3	601	72.1	350	31.7	167	23
2:4:1	10-20-5	1176	103.1	398	47.7	259	23.4	167	35
2:1:2	6-3-6	176	15.4	1302	156.1	322	29.1	200	18
2:1:2	10-5-10	294	25.8	839	100.6	533	48.2	334	68
2:3:2	8-12-8	706	61.9	746	89.4	281	25.4	267	32
2:1:3	6-3-9	176	15.4	1202	144.1	322	29.1	300	27
2:2:3	6-6-9	353	30.9	1081	129.6	266	24.0	300	32
2:3:3	6-9-9	529	46.4	958	114.9	213	19.2	300	32
3:1:0	21-7-0	412	36.1	404	48.4	1184	107.0	—	0
3:2:0	18-12-0	706	61.9	358	42.9	936	84.7	—	0
3:1:1	12-4-4	235	20.7	953	114.3	678	61.3	134	28
3:1:1	15-5-5	294	25.8	725	86.9	846	76.5	167	46
3:2:1	12-8-4	471	41.3	792	94.9	603	54.6	134	32
3:3:1	12-12-4	706	61.9	629	75.4	531	48.0	134	32
3:4:1	12-16-4	941	82.6	469	56.2	456	41.2	134	32
3:1:2	9-3-6	177	15.6	1116	133.8	507	45.9	200	32
3:2:2	9-6-6	353	30.9	994	119.2	453	40.9	200	36
3:3:2	9-9-6	529	46.4	871	104.4	400	36.1	200	36
3:1:3	6-2-6	118	10.3	1344	161.2	338	30.6	200	18
3:2:3	6-4-6	235	20.7	1262	151.3	303	36.3	200	18
4:1:0	24-6-0	353	30.9	257	30.9	1390	125.7	—	20
4:1:1	12-3-3	176	15.4	1027	123.1	697	63.0	100	18
4:2:1	12-6-3	353	30.9	906	108.6	641	57.9	100	18
4:3:1	12-9-3	529	46.4	787	94.4	584	52.9	100	18
4:4:1	12-12-3	706	61.9	663	79.5	531	48.0	100	23
4:1:2	8-2-4	118	10.3	1285	154.1	463	41.9	134	14
4:3:2	8-6-4	353	30.9	1122	134.5	391	35.3	134	9
4:1:3	8-2-6	118	10.3	1219	146.2	463	41.8	200	32
4:2:3	8-4-6	235	20.6	1137	136.3	428	38.7	200	32
4:3:3	8-6-6	353	30.9	1056	126.6	391	35.3	200	28
4:4:3	8-8-6	471	41.3	976	117.0	353	31.9	200	28
4:3:4	8-6-8	353	30.9	989	119.6	391	35.3	267	40

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-32.

Liquid Formulations Using 10-34-0[1/] As the Only Source of P_2O_5

		Ammonium Polyphosphates 10-34-0		Water		UAN Solution (30-0-0)		Potash (0-0-60)	Estimated Salting-Out Temperature
Ratio	Grade	Lbs/Ton	Gal.Ton	Lbs/Ton	Gal.Ton	Lbs./Ton	Gal./Ton	Lbs./Ton	(^{O}F)
1:1:0	16-16-0	941	82.6	307	36.8	752	69.3	—	26
1:2:0	13-26-0	1530	134.2	114	13.7	356	32.8	—	18
1:3:0	10-30-0	1765	154.8	157	18.8	78	7.2	—	0
1:1:1	8-8-8	471	41.3	894	107.2	377	34.7	258	41
1:1:1	9-9-9	529	46.4	758	90.9	423	39.0	290	43
1:2:1	8-16-8	941	82.5	582	69.8	219	20.2	258	37
1:3:1	7-21-7	1235	108.3	485	58.2	54	5.0	226	12
1:3:1	6-18-6	1059	92.9	700	83.9	47	4.3	194	10
1:1:2	5-5-10	294	25.7	1146	137.4	237	21.8	323	20
1:2:2	5-10-10	588	51.5	948	113.8	140	12.9	323	18
1:2:2	4-10-10	588	51.5	1019	122.2	70	6.5	323	5
1:3:2	5-15-10	882	77.3	754	90.4	41	3.8	323	44
2:8:1	8-25-3	1471	129.0	389	46.6	43	4.0	97	0
1:1:3	4-4-12	235	20.6	1188	142.4	190	17.5	387	20
1:2:3	4-8-12	471	41.3	1032	123.7	110	10.1	387	32
1:3:6	2-6-12	353	31.0	1244	149.2	16	1.5	387	28
1:3:3	3-9-9	529	46.4	1157	138.8	24	2.2	290	0
2:1:0	20-10-0	588	51.6	276	33.1	1136	104.7	—	0
2:1:1	10-5-5	294	25.8	979	117.4	566	52.2	161	32
2:1:1	12-6-6	353	31.0	770	92.4	683	62.9	194	43
2:2:1	10-10-5	588	51.6	777	93.3	474	43.6	161	32
2:2:1	10-12-6	706	61.9	667	80.1	433	39.9	194	—
2:3:1	10-15-5	882	77.3	584	70.0	373	34.4	161	23
2:4:1	10-20-5	1176	103.1	387	46.4	276	25.5	161	35
2:1:2	6-3-6	176	15.4	1287	154.3	343	31.7	194	18
2:1:2	10-5-10	294	25.8	814	97.7	569	52.3	323	68
2:3:2	8-12-8	706	61.9	736	88.4	300	27.6	258	32
2:1:3	6-3-9	176	15.4	1191	142.8	343	31.7	290	27
2:2:3	6-6-9	353	30.0	1073	128.8	284	26.1	290	32
2:3:3	6-9-9	529	46.4	954	114.4	227	20.9	290	32
3:1:0	21-7-0	412	36.1	325	39.0	1263	116.4	—	0
3:2:0	18-12-0	706	61.9	296	35.5	998	92.0	—	0
3:1:1	12-4-4	235	20.7	913	109.5	723	66.7	129	28
3:1:1	15-5-5	294	25.8	643	77.1	902	83.2	161	46
3:2:1	12-8-4	471	41.3	757	90.8	643	59.3	129	32
3:3:1	12-12-4	706	61.9	599	71.8	566	52.2	129	32
3:4:1	12-16-4	941	82.6	444	53.2	486	44.8	129	32
3:1:2	9-3-6	177	15.6	1088	131.5	541	49.8	194	32
3:2:2	9-6-6	353	30.9	970	116.3	483	44.5	194	36
3:3:2	9-9-6	529	46.4	850	102.0	427	39.3	194	36
3:1:3	6-2-6	118	10.3	1327	159.1	361	33.3	194	18
3:2:3	6-4-6	235	20.7	1248	149.6	323	29.8	194	18
4:1:0	24-6-0	353	30.9	164	19.7	1483	136.7	—	20
4:1:1	12-3-3	176	15.4	984	118.0	743	68.5	97	18
4:2:1	12-6-3	353	30.9	866	104.0	684	63.0	97	18
4:3:1	12-9-3	529	46.4	751	90.2	623	57.4	97	18
4:4:1	12-12-3	706	61.9	631	75.7	566	52.2	97	23
4:1:2	8-2-4	118	10.3	1259	151.1	494	45.5	129	14
4:3:2	8-6-4	353	30.9	1101	132.0	417	38.4	129	9
4:1:3	8-2-6	118	10.3	1194	143.3	494	45.5	194	32
4:2:3	8-4-6	235	20.6	1114	133.7	457	42.1	194	32
4:3:3	8-6-6	353	30.9	1036	124.2	417	38.4	194	28
4:4:3	8-8-6	471	41.3	958	115.0	377	34.7	194	28
4:3:4	8-6-8	353	30.0	972	116.5	417	38.4	258	40

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-33.

Liquid Formulations Using 10-34-0[1/] As the Only Source of P_2O_5

		Ammonium Polyphosphates 10-34-0		Water		UAN Solution (28-0-0)		Potash (0-0-60)	Estimated Salting-Out Temperature
Ratio	Grade	Lbs/Ton	Gal.Ton	Lbs/Ton	Gal.Ton	Lbs./Ton	Gal./Ton	Lbs./Ton	(°F)
1:1:0	16-16-0	941	82.6	252	30.2	807	75.4	—	26
1:2:0	13-26-0	1530	134.2	88	10.6	382	35.7	—	18
1:3:0	10-30-0	1765	154.8	151	18.1	84	7.9	—	0
1:1:1	8-8-8	471	41.3	859	103.0	403	37.7	267	41
1:1:1	9-9-9	529	46.4	717	86.0	454	42.4	300	43
1:2:1	8-16-8	941	82.5	557	66.8	235	22.0	267	37
1:3:1	7-21-7	1235	108.3	472	56.6	59	5.5	234	12
1:3:1	6-18-6	1059	92.9	691	82.9	50	4.7	200	10
1:1:2	5-5-10	294	25.7	1120	134.3	252	23.6	334	20
1:2:2	5-10-10	588	51.5	931	111.6	147	13.8	334	18
1:2:2	4-10-10	588	51.5	1002	120.1	76	7.1	334	5
1:3:2	5-15-10	882	77.3	742	89.0	42	3.9	334	44
2:8:1	8-25-3	1471	129.0	383	45.9	46	4.3	100	0
1:1:3	4-4-12	235	20.6	1163	139.4	202	18.9	400	20
1:2:3	4-8-12	471	41.3	1011	121.2	118	11.0	400	32
1:3:6	2-6-12	353	31.0	1159	139.0	88	8.2	400	28
1:3:3	3-9-9	529	46.4	1146	137.4	25	2.5	300	0
2:1:0	20-10-0	588	51.6	193	23.1	1219	113.9	—	0
2:1:1	10-5-5	294	25.8	930	111.5	609	56.9	167	32
2:1:1	12-6-6	353	31.0	716	85.9	731	68.3	200	43
2:2:1	10-10-5	588	51.6	741	88.8	504	47.1	167	32
2:3:1	10-15-5	882	77.3	552	66.2	399	37.3	167	23
2:4:1	10-20-5	1176	103.1	363	43.5	294	27.5	167	35
2:1:2	6-3-6	176	15.4	1258	150.8	366	34.2	200	18
2:1:2	10-5-10	294	25.8	763	91.5	609	56.0	334	68
2:3:2	8-12-8	706	61.9	708	84.9	319	29.8	267	32
2:1:3	6-3-9	176	15.4	1158	138.8	366	34.2	300	27
2:2:3	6-6-9	353	30.9	1044	125.2	303	28.3	300	32
2:3:3	6-9-9	529	46.4	931	111.6	240	22.4	300	32
3:1:0	21-7-0	412	36.1	235	28.2	1353	126.4	—	0
3:2:0	18-12-0	706	61.9	260	31.2	1034	96.6	—	0
3:1:1	12-4-4	235	20.7	858	102.9	773	72.3	134	28
3:1:1	15-5-5	294	25.8	571	68.5	968	90.3	167	46
3:2:1	12-8-4	471	41.3	706	84.7	689	64.4	134	32
3:3:1	12-12-4	706	61.9	555	66.5	605	56.5	134	32
3:4:1	12-16-4	941	82.6	404	48.4	521	48.7	134	32
3:1:2	9-3-6	177	15.6	1043	125.1	580	54.2	200	32
3:2:2	9-6-6	353	30.0	930	111.5	517	48.3	200	36
3:3:2	9-9-6	529	46.4	817	98.0	454	42.4	200	36
3:1:3	6-2-6	118	10.3	1296	155.4	386	36.1	200	18
3:2:3	6-4-6	235	20.7	1220	146.3	345	32.2	200	18
4:1:0	24-6-0	353	30.9	159	19.1	1588	148.4	—	20
4:1:1	12-3-3	176	15.4	930	111.5	794	74.2	100	18
4:2:1	12-6-3	353	30.9	816	97.8	731	68.3	100	18
4:3:1	12-9-3	529	46.4	703	84.3	668	62.4	100	18
4:4:1	12-12-3	706	61.9	589	70.6	605	56.5	100	23
4:1:2	8-2-4	118	10.3	1219	146.2	529	49.5	134	14
4:3:2	8-6-4	353	30.0	1068	128.1	445	41.6	134	9
4:1:3	8-2-6	118	10.3	1153	138.2	529	49.5	200	32
4:2:3	8-4-6	235	20.6	1077	129.1	488	45.6	200	32
4:3:3	8-6-6	353	30.9	1002	120.1	445	41.6	200	28
4:4:3	8-8-6	471	41.3	926	111.0	403	37.7	200	28
4:3:4	8-6-8	353	30.9	935	112.1	445	41.6	267	40

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-34A.

Recommended Grades and Ratios
UAN 32 / 10-34-0 / 4-10-10

	Recommended	UAN 32		Water		10-34-0		4-10-10	Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Pounds	Temp. (°F)
1:10	18-18-0	797	72	144	17	1059	93		35
	15-15-0	662	60	455	55	883	77		10
1:2:0	13-26-0	334	30	136	16	1530	134		25
2:1:0	20-10-0	1065	96	347	42	588	52		10
1:1:1	8-8-8	301	27	99	12		—	1600	42
1:2:1	7-14-7	138	12	49	6	413	36	1400	20
1:3:1	6-18-6	5	.5	89	11	706	62	1200	5
1:2:2	4-8-8	50	5	350	42		—	1600	9
2:1:1	12-6-6	600	54	200	24		—	1200	43
	10-5-5	500	45	500	60		—	1000	36
2:2:1	10-10-5	411	37	294	35	295	26	1000	37
2:3:1	10-15-5	316	28	95	11	589	52	1000	39
2:4:1	8-16-4	180	16	314	38	706	62	800	25
2:8:1	8-25-3	21	2	85	10	1294	114	600	20
3:1:1	15-5-5	813	73	187	23		—	1000	49
	12-4-4	650	59	550	66		—	800	32
3:2:1	12-8-4	577	52	387	47	236	21	800	36
3:3:1	12-12-4	503	45	226	27	471	41	800	39
3:4:1	12-16-4	430	39	64	8	706	62	800	40
4:1:1	16-4-4	900	81	300	36		—	800	34
4:2:1	12-6-3	620	56	603	73	177	16	600	30
4:3:1	12-9-3	565	51	482	58	353	31	600	23
4:4:1	12-12-3	510	46	360	43	530	46	600	25
4:3:3	8-6-6	350	32	450	54		—	1200	34
4:4:3	8-8-6	314	28	368	44	118	10	1200	34
2:2:1	10-12-6	366	33	81	10	353	31	1200	40

Table A-34B.

Recommended Grades and Ratios
UAN 28 / 10-34-0 / 4-10-10

	Recommended	UAN 32		Water		10-34-0		4-10-10	Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Pounds	Temp. (°F)
1:10	18-18-0	797	72	144	17	1059	93		35
	15-15-0	662	60	455	55	883	77		10
1:2:0	13-26-0	334	30	136	16	1530	134		25
2:1:0	20-10-0	1065	96	347	42	588	52		10
1:1:1	8-8-8	301	27	99	12		—	1600	42
1:2:1	7-14-7	138	12	49	6	413	36	1400	20
1:3:1	6-18-6	5	.5	89	11	706	62	1200	5
1:2:2	4-8-8	50	5	350	42		—	1600	9
2:1:1	12-6-6	600	54	200	24		—	1200	43
	10-5-5	500	45	500	60		—	1000	36
2:2:1	10-10-5	411	37	294	35	295	26	1000	37
2:3:1	10-15-5	316	28	95	11	589	52	1000	39
2:4:1	8-16-4	180	16	314	38	706	62	800	25
2:8:1	8-25-3	21	2	85	10	1294	114	600	20
3:1:1	15-5-5	813	73	187	23		—	1000	49
	12-4-4	650	59	550	66		—	800	32
3:2:1	12-8-4	577	52	387	47	236	21	800	36
3:3:1	12-12-4	503	45	226	27	471	41	800	39
3:4:1	12-16-4	430	39	64	8	706	62	800	40
4:1:1	16-4-4	900	81	300	36		—	800	34
4:2:1	12-6-3	620	56	603	73	177	16	600	30
4:3:1	12-9-3	565	51	482	58	353	31	600	23
4:4:1	12-12-3	510	46	360	43	530	46	600	25
4:3:3	8-6-6	350	32	450	54		—	1200	34
4:4:3	8-8-6	314	28	368	44	118	10	1200	34
2:2:1	10-12-6	366	33	81	10	353	31	1200	40

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-34C.

Recommended Grades and Ratios
UAN 32 / 10-34-0 / 2-6-12

	Recommended	UAN 32		Water		10-34-0		2-6-12		Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Temp. (^{O}F)
1:10	18-18-0	794	72	147	18	1059	93	0	0	35
	15-15-0	688	62	430	51	882	77	0	0	10
1:2:0	13-26-0	334	30	137	16	1529	134	0	0	25
2:1:0	20-10-0	1065	96	347	42	588	52	0	0	10
1:1:1	8-8-8	344	31	88	11	235	21	1333	127	42
1:2:1	7-14-7	172	16	43	5	618	54	1167	111	20
1:3:1	6-18-6	34	3	5	0.6	882	77	1000	95	5
1:2:2	4-8-8	94	8	338	41	235	21	1333	127	9
2:1:1	12-6-6	631	57	193	23	176	15	1000	95	43
	10-5-5	25	2	995	12	147	13	833	79	36
2:2:1	10-10-5	409	37	243	29	515	45	833	79	37
2:3:1	10-15-5	389	35	43	5	735	64	833	79	39
2:4:1	8-16-4	203	18	306	37	824	72	667	64	25
2:8:1	8-25-3	38	3	80	10	1382	121	500	48	20
3:1:1	15-5-5	837	76	183	22	147	13	833	79	49
	12-4-4	672	61	543	65	118	10	667	64	32
3:2:1	12-8-4	597	54	736	88	353	31	667	64	36
3:3:1	12-12-4	525	47	220	26	588	52	667	64	39
3:4:1	12-16-4	453	41	59	7	824	72	667	64	40
4:1:1	16-4-4	922	83	293	35	118	10	667	64	34
4:2:1	12-6-3	634	57	601	72	265	23	500	48	30
4:3:1	12-9-3	612	55	447	54	441	38	500	48	23
4:4:1	12-12-3	525	47	357	43	618	54	500	48	25
4:3:3	8-6-6	381	34	443	53	176	15	1000	95	34
4:4:3	8-8-6	347	31	359	43	294	26	1000	95	34
2:2:1	10-12-6	397	36	74	9	529	46	1000	95	40

Table A-34D.

Recommended Grades and Ratios
UAN 28 / 10-34-0 / 4-10-10

	Recommended	UAN 32		Water		10-34-0		2-6-12		Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Temp. (^{O}F)
1:10	18-18-0	907	85	34	4	1059	93	0	0	35
	15-15-0	786	82	332	40	882	77	0	0	10
1:2:0	13-26-0	382	36	89	11	1529	134	0	0	25
2:1:0	20-10-0	1217	114	195	23	588	52	0	0	10
1:1:1	8-8-8	393	37	39	5	235	21	1333	127	42
1:2:1	7-14-7	196	18	19	3	618	54	1167	111	20
1:3:1	6-18-6	39	4	79	9	882	77	1000	95	5
1:2:2	4-8-8	107	10	325	39	235	21	1333	127	9
2:1:1	12-6-6	721	67	103	12	176	15	1000	95	43
	10-5-5	29	3	991	119	147	13	833	79	36
2:2:1	10-10-5	468	44	184	22	515	45	833	79	37
2:3:1	10-15-5	340	32	92	11	735	64	833	79	39
2:4:1	8-16-4	232	22	277	33	824	72	667	64	25
2:8:1	8-25-3	43	4	75	9	1382	121	500	48	20
3:1:1	15-5-5	957	89	63	8	147	13	833	79	49
	12-4-4	768	72	447	54	118	10	667	64	32
3:2:1	12-8-4	682	64	298	36	353	31	667	64	36
3:3:1	12-12-4	600	56	145	17	588	52	667	64	39
3:4:1	12-16-4	517	48	0	0	824	72	667	64	40
4:1:1	16-4-4	1054	99	161	19	118	10	667	64	34
4:2:1	12-6-3	725	68	510	61	265	23	500	48	30
4:3:1	12-9-3	700	65	359	43	441	38	500	48	23
4:4:1	12-12-3	600	56	282	34	618	54	500	48	25
4:3:3	8-6-6	436	41	388	47	176	15	1000	95	34
4:4:3	8-8-6	396	37	310	37	294	26	1000	95	34
2:2:1	10-12-6	454	42	17	2	529	46	1000	95	40

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-35A.

Recommended Grades and Ratios1/
UAN Solutions / 11-37-0 / 4-10-10

	Recommended	UAN 32		Water		11-37-0		4-10-10		Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Temp.(°F)
1:10	18-18-0	797	72	232	28	971	83	0	0	35
	15-15-0	662	70	529	64	809	69	0	0	10
1:2:0	13-26-0	334	30	264	32	1402	120	0	0	25
2:1:0	20-10-0	1065	96	396	48	539	46	0	0	10
1:1:1	8-8-8	301	27	99	12	—	—	1600	152	42
1:2:1	7-14-7	138	12	84	10	378	32	1400	133	20
1:3:1	6-18-6	5	.45	139	17	656	56	1200	114	5
1:2:2	4-8-8	50	5	350	42	—	—	1600	152	9
2:1:1	12-6-6	600	54	200	24	—	—	1200	114	43
	10-5-5	500	45	500	60	—	—	1000	95	36
2:2:1	10-10-5	411	37	319	38	270	23	1000	95	37
2:3:1	10-15-5	316	29	144	17	540	46	1000	95	39
2:4:1	8-16-4	180	16	373	45	647	55	800	76	25
2:8:1	8-25-3	21	2	193	23	1186	101	600	57	20
3:1:1	15-5-5	813	74	187	22	—	—	1000	95	49
	12-4-4	650	59	550	66	—	—	800	76	32
3:2:1	12-8-4	577	52	407	49	216	18	800	76	36
3:3:1	12-12-4	503	45	166	20	431	37	800	76	39
3:4:1	12-16-4	430	39	123	15	647	55	800	76	40
4:1:1	16-4-4	900	81	300	36	—	—	800	76	34
4:2:1	12-6-3	620	56	618	74	162	14	600	57	30
4:3:1	12-9-3	565	51	511	61	324	28	600	57	23
4:4:1	12-12-3	510	46	404	49	486	42	600	57	25
4:3:3	8-6-6	350	31	450	54	—	—	1200	114	34
4:4:3	8-8-6	314	28	368	44	108	9	1200	114	34
2:2:1	10-12-6	365	33	110	13	325	28	1200	114	40

Table A-35B.

Recommended Grades and Ratios1/
UAN Solutions / 11-37-0 / 4-10-10

	Recommended	UAN 32		Water		11-37-0		4-10-10		Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Temp.(°F)
1:10	18-18-0	911	85	118	14	971	83	0	0	35
	15-15-0	756	71	435	52	809	69	0	0	10
1:2:0	13-26-0	382	36	216	26	1402	120	0	0	25
2:1:0	20-10-0	1217	114	244	29	539	46	0	0	10
1:1:1	8-8-8	343	32	57	7	—	—	1600	152	42
1:2:1	7-14-7	157	15	65	8	378	32	1400	133	20
1:3:1	6-18-6	5	.46	139	17	656	56	1200	114	5
1:2:2	4-8-8	58	5	342	41	—	—	1600	152	9
2:1:1	12-6-6	686	64	114	14	—	—	1200	114	43
	10-5-5	572	53	428	51	—	—	1000	95	36
2:2:1	10-10-5	470	44	260	31	270	23	1000	95	37
2:3:1	10-15-5	362	34	98	12	540	46	1000	95	39
2:4:1	8-16-4	205	19	348	42	647	55	800	76	25
2:8:1	8-25-3	25	2	189	23	1186	101	600	57	20
3:1:1	15-5-5	929	86	71	9	—	—	1000	95	49
	12-4-4	743	69	457	55	—	—	800	76	32
3:2:1	12-8-4	659	62	325	39	216	18	800	76	36
3:3:1	12-12-4	575	54	194	23	431	37	800	76	39
3:4:1	12-16-4	491	46	62	7	647	55	800	76	40
4:1:1	16-4-4	1029	96	171	21	—	—	800	76	34
4:2:1	12-6-3	709	66	529	64	162	14	600	57	30
4:3:1	12-9-3	646	60	430	52	324	28	600	57	23
4:4:1	12-12-3	583	54	331	40	486	42	600	57	25
4:3:3	8-6-6	400	37	400	48	—	—	1200	114	34
4:4:3	8-8-6	358	33	334	40	108	9	1200	114	34

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

2:2:1	10-12-6	418	39	57	7	325	28	1200	114	40

Table A-35C.

Recommended Grades and Ratios
UAN Solutions / 11-37-0 / 2-6-12

	Recommended	UAN 32		Water		11-37-0		2-6-12		Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Temp. (^{o}F)
1:10	18-18-0	794	72	957	115	971	83	0	0	35
	15-15-0	688	62	504	60	808	69	0	0	10
1:2:0	13-26-0	334	30	264	32	1402	120	0	0	25
2:1:0	20-10-0	1065	96	396	48	539	46	0	0	10
1:1:1	8-8-8	344	31	108	13	215	18	1333	127	42
1:2:1	7-14-7	172	16	95	11	566	8	1167	111	20
1:3:1	6-18-6	34	3	158	19	808	69	1000	95	5
1:2:2	4-8-8	94	8	358	43	215	18	1333	127	9
2:1:1	12-6-6	631	57	208	25	161	14	1000	95	43
	10-5-5	25	2	1007	121	135	12	833	79	36
2:2:1	10-10-5	409	37	286	34	472	40	833	79	37
2:3:1	10-15-5	389	35	105	13	673	58	833	79	39
2:4:1	8-16-4	203	18	375	45	755	65	667	64	25
2:8:1	8-25-3	38	3	195	23	1267	108	500	48	20
3:1:1	15-5-5	837	76	195	23	135	12	833	79	49
	12-4-4	672	61	553	66	108	9	667	64	32
3:2:1	12-8-4	597	54	412	61	324	28	667	64	36
3:3:1	12-12-4	525	47	269	32	539	46	667	64	39
3:4:1	12-16-4	453	41	125	15	755	65	667	64	40
4:1:1	16-4-4	922	83	303	36	108	9	667	64	34
4:2:1	12-6-3	634	57	623	75	243	21	500	48	30
4:3:1	12-9-3	612	55	484	58	404	35	500	48	23
4:4:1	12-12-3	525	47	409	50	566	48	500	48	25
4:3:3	8-6-6	381	34	458	55	161	14	1000	95	34
4:4:3	8-8-6	347	31	384	47	269	23	1000	95	34
2:2:1	10-12-6	397	36	118	14	485	41	1000	95	40

Table A-35D.

Recommended Grades and Ratios
UAN Solutions / 11-37-0 / 2-6-1

	Recommended	UAN 32		Water		11-37-0		2-6-12		Estimated Salting-Out
Ratio	Grade	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	#/Ton	Gal.	Temp. (^{o}F)
1:10	18-18-0	907	85	944	113	971	83	0	0	35
	15-15-0	786	82	406	48	808	69	0	0	10
1:2:0	13-26-0	382	36	216	26	1402	120	0	0	25
2:1:0	20-10-0	1217	114	244	29	539	46	0	0	10
1:1:1	8-8-8	393	37	59	7	215	18	1333	127	42
1:2:1	7-14-7	196	18	71	8	566	8	1167	111	20
1:3:1	6-18-6	39	4	153	18	808	69	1000	95	5
1:2:2	4-8-8	107	10	345	41	215	18	1333	127	9
2:1:1	12-6-6	721	67	118	14	161	14	1000	95	43
	10-5-5	29	3	1003	120	135	12	833	79	36
2:2:1	10-10-5	468	44	227	27	472	40	833	79	37
2:3:1	10-15-5	340	32	154	18	673	58	833	79	39
2:4:1	8-16-4	232	22	346	41	755	65	667	64	25
2:8:1	8-25-3	43	4	190	23	1267	108	500	48	20
3:1:1	15-5-5	957	89	75	9	135	12	833	79	49
	12-4-4	768	72	457	55	108	9	667	64	32
3:2:1	12-8-4	682	64	327	39	324	28	667	64	36
3:3:1	12-12-4	600	56	194	23	539	46	667	64	39
3:4:1	12-16-4	517	48	61	7	755	65	667	64	40
4:1:1	16-4-4	1054	99	171	21	108	9	667	64	34
4:2:1	12-6-3	725	68	532	64	243	21	500	48	30
4:3:1	12-9-3	700	65	396	48	404	35	500	48	23
4:4:1	12-12-3	600	56	334	40	566	48	500	48	25
4:3:3	8-6-6	436	41	403	48	161	14	1000	95	34
4:4:3	8-8-6	396	37	1665	200	269	23	1000	95	34
2:2:1	10-12-6	454	42	1939	232	485	41	1000	95	40

Guidelines supplied by R. D. Curley, C.P. Ag., Consultant

Table A-36.

Typical Formulations for Liquid Fertilizers that Include 11-37-0 as a Sequestrant for Wet-Process Phosphoric Acid

Ratio	Grade	Liquid Base Solution 11-37-0	Wet-Process Phosphoric Acid (0-54-0)	Aqua Ammonia (20-0-0)	Urea-Ammonium Nitrate Solution (32-0-0)	Potassium chloride (0-0-62)	Water	Estimated Salting-Out Temperatures (°F)[a]
		Pounds per ton						
1:1:0	14-14-0[b]	151	415	375	589	—	470	32
1:2:0	10-20-0[b]	216	593	533	218	—	440	25
1:3:0	8-24-0[bc]	260	711	657	—	—	372	19
1:1:1	8-8-8	130	207	186	339	258	880	48
1:2:1	8-16-8	259	415	373	178	258	517	44
1:3:1	6-18-6[c]	292	467	440	—	194	607	3
1:1:2	5-5-10	81	130	115	212	323	1139	18
1:2:2	5-10-10	162	259	233	111	323	912	32
1:3:2	4-12-8[c]	195	311	292	—	258	944	<0
1:2:3	4-8-12	130	207	185	91	387	1000	46
2:1:0	16-8-0[b]	86	237	214	837	—	526	32
2:3:0	10-15-0[b]	162	444	400	319	—	675	0
2:1:1	12-6-6	97	156	140	629	194	784	52
2:2:1	10-10-5	162	259	233	424	161	761	37
2:3:1	10-15-5	243	389	350	322	161	535	47
2:4:1	8-16-4	259	415	375	178	129	644	<0
2:1:2	8-4-8	65	104	95	419	258	1059	49
2:3:2	8-12-8	195	311	280	259	258	697	37
3:1:0	18-6-0[b]	86	237	213	837	—	627	<0
3:2:0	15-10-0[b]	108	296	265	734	—	597	3
3:4:0	12-16-0[b]	173	474	425	425	—	503	47
3:1:1	15-5-5	81	130	117	837	161	674	55
3:2:1	12-8-4	130	207	185	591	129	758	46
4:1:0	24-6-0[b]	69	178	160	1378	—	219	32
4:3:0	20-15-0[b]	162	444	400	944	—	50	77
4:1:1	12-3-3	49	78	70	691	97	1015	<0
4:2:1	12-6-3	97	156	140	628	97	882	18
4:3:1	12-9-3	146	233	210	569	97	745	32
4:1:2	8-2-4	32	52	45	459	129	1283	17
4:3:2	8-6-4	97	156	140	378	129	1100	8

[a] Salting-out temperatures shown were obtained with liquid fertilizers produced from orthophosphoric acid. Use of 11-37-0 with 65% polyphosphate should lower the salting-out temperature.

[b] For these non-potash grades, 20% of the P_2O_5 was supplied as 11-37-0; for potash grades, 30% of the P_2O_5 was supplied as 11-37-0.

[c] In these grades, the P_2O_5 was ammoniated to an N:P_2O_5 weight ratio of 1:3. In the remaining grades, only the P_2O_5 supplied as wet-process acid was ammoniated to this ratio.

Guidelines Supplied by R. D. Curley, C.P. Ag., Consultant

Table A-37A.

Typical Formulations for Liquid Cold Mix Fertilizer Plants

Ratio	Grade	Liquid Base Solution 11-37-0	Urea-Ammonium Nitrate Solution (32-0-0)	Potassium chloride (0-0-62)	Water	Estimated Salting-Out Temperatures (°F)[a]
		Pounds per ton of Product				
1:1:0	19-19-0	1027	834	—	139	< 32
1:2:0	15-30-0	1620[a]	380[a]	—	—	< 32
1:3:0	12-36-0	1940[a]	60[a]	—	—	< 32
1:1:1	8-8-8	432	352	258	958	44
1:2:1	8-16-8	865	203	258	674	32
1:3:1	7-21-7	1135	47	226	592	8
1:1:2	5-5-10	270	220	323	1187	20
1:2:2	5-10-10	541	127	323	1009	20
1:3:2	5-15-10	811	34	323	832	44
1:1:3	4-4-12	216	176	387	1221	14
1:2:3	4-8-12	432	102	387	1079	38
1:3:3	3-9-9	486	20	290	1204	<0
2:1:0	22-11-0	595	1172	—	233	< 32
2:1:1	10-5-5	270	532	161	1037	32
2:2:1	10-10-5	541	439	161	859	34
2:3:1	10-15-5	811	347	161	681	31
2:4:1	10-20-5	1081	253	161	505	35
2:1:2	8-4-8	216	426	258	1100	41
2:3:2	8-12-8	649	277	258	816	37
2:1:3	6-3-9	162	319	290	1229	26
2:2:3	6-6-9	324	264	290	1122	32
2:3:3	6-9-9	486	208	290	1016	14
3:1:0	24-8-0	432	1352	—	216	< 32
3:2:0	21-14-0	757	1053	—	190	< 32
3:1:1	12-4-4	216	676	129	979	30
3:2:1	12-8-4	432	602	129	837	30
3:3:1	12-12-4	649	527	129	695	34
3:4:1	12-16-4	865	453	129	553	37
3:1:2	9-3-6	162	507	194	1137	32
3:2:2	9-6-6	324	451	194	1031	34
3:3:2	9-9-6	86	395	194	925	37
3:4:2	9-12-6	649	339	194	818	32
3:1:3	6-2-6	108	338	194	1360	20
3:2:3	6-4-6	216	301	194	1289	16
4:1:0	24-6-0	324	1389	—	287	< 32
4:1:1	12-3-3	162	694	97	1047	16
4:2:1	12-6-3	324	639	97	940	16
4:3:1	12-9-3	486	583	97	834	20
4:4:1	12-12-3	649	527	97	727	18
4:1:2	8-2-4	108	463	129	1300	13
4:3:2	8-6-4	324	389	129	1158	11
4:1:3	8-2-6	108	463	194	1235	23
4:2:3	8-4-6	216	426	194	1164	30
4:3:3	8-6-6	324	389	194	1093	30
4:4:3	8-8-6	432	352	194	1022	30
4:3:4	8-6-8	324	389	258	1029	41

[a] Slight overage in analysis required to make grade.

Guidelines Supplied by R. D. Curley, C.P. Ag., Consultant

Supplement—Table A-37B.

Typical Formulations for Liquid Cold Mix Fertilizer Plants

Ratio	Grade	Liquid Base Solution 11-37-0	Urea-Ammonium Nitrate Solution (32-0-0)	Water	Potassium chloride (0-0-62)	Estimated Salting-Out Temperatures (°F)
		Gallons per ton of Product			Pounds	
1:1:0	19-19-0	87.8	75.8	16.7	—	< 32
1:2:0	15-30-0	138.5	34.5	—	—	< 32
1:3:0	12-36-0	165.8	5.5	—	—	< 32
1:1:1	8-8-8	36.9	32.0	115.0	258	44
1:2:1	8-16-8	73.9	18.5	80.9	258	32
1:3:1	7-21-7	97.0	4.3	71.1	226	8
1:1:2	5-5-10	23.1	20.0	142.5	323	20
1:2:2	5-10-10	46.2	11.5	121.1	323	20
1:3:2	5-15-10	69.3	30.9	99.9	323	44
1:1:3	4-4-12	18.5	16.0	146.6	387	14
1:2:3	4-8-12	36.9	9.3	129.5	387	38
1:3:3	3-9-9	41.5	1.8	144.5	290	< 0
2:1:0	22-11-0	50.9	106.5	28.0	—	< 32
2:1:1	10-5-5	23.1	48.4	124.5	161	32
2:2:1	10-10-5	46.2	39.9	103.1	161	34
2:3:1	10-15-5	69.3	31.5	81.8	161	31
2:4:1	10-20-5	92.4	23.0	60.6	161	35
2:1:2	8-4-8	18.5	38.7	132.1	258	41
2:3:2	8-12-8	55.5	25.2	98.0	258	37
2:1:3	6-3-9	13.9	29.0	147.5	290	26
2:2:3	6-6-9	27.7	24.0	134.7	290	32
2:3:3	6-9-9	41.5	18.9	122.0	290	14
3:1:0	24-8-0	36.9	122.9	25.9	—	< 32
3:2:0	21-14-0	64.7	95.7	22.8	—	< 32
3:1:1	12-4-4	18.5	61.5	117.5	129	30
3:2:1	12-8-4	36.9	54.7	100.5	129	30
3:3:1	12-12-4	55.5	47.9	83.4	129	34
3:4:1	12-16-4	73.9	41.2	66.4	129	37
3:1:2	9-3-6	13.9	46.1	136.5	194	32
3:2:2	9-6-6	27.7	41.0	123.8	194	34
3:3:2	9-9-6	41.5	35.9	111.0	194	37
3:4:2	9-12-6	55.5	30.8	98.2	194	32
3:1:3	6-2-6	9.2	30.7	163.3	194	20
3:2:3	6-4-6	18.5	27.4	154.7	194	16
4:1:0	24-6-0	27.7	126.3	34.5	—	< 32
4:1:1	12-3-3	13.9	63.1	125.7	97	16
4:2:1	12-6-3	27.7	58.1	112.8	97	16
4:3:1	12-9-3	41.5	53.0	100.1	97	20
4:4:1	12-12-3	55.5	47.9	87.3	97	18
4:1:2	8-2-4	9.2	42.1	156.1	129	13
4:3:2	8-6-4	27.7	35.4	139.0	129	11
4:1:3	8-2-6	9.2	42.1	148.3	194	23
4:2:3	8-4-6	18.5	38.7	139.7	194	30
4:3:3	8-6-6	27.7	35.4	131.2	194	30
4:4:3	8-8-6	36.9	32.0	122.7	194	30
4:3:4	8-6-8	27.7	35.4	123.5	258	41

Guidelines Supplied by R. D. Curley, C.P. Ag., Consultant

Supplement—Table A-38

Typical Formulations for Liquid Cold Mix Fertilizer Plants

Ratio	Grade	Liquid Base Solution 11-37-0	Urea-Ammonium Nitrate Solution (30-0-0)	Potassium chloride (0-0-62)	Water	Estimated Salting-Out Temperatures (^{O}F)
		Pounds per ton of Product				
1:1:0	19-19-0	1027	889	—	84	< 32
1:2:0	14-28-0	1514	378	—	108	< 32
1:3:0	11-33-0	1784	80	—	136	< 32
1:1:1	8-8-8	432	375	258	935	44
1:2:1	8-16-8	865	216	258	661	32
1:3:1	7-21-7	1135	50	226	589	8
1:1:2	5-5-10	270	234	323	1173	20
1:2:2	5-10-10	541	135	323	1001	20
1:3:2	5-15-10	811	36	323	830	44
1:1:3	4-4-12	216	188	387	1209	14
1:2:3	4-8-12	432	109	387	1072	38
1:3:3	3-9-9	486	21	290	1203	< 0
2:1:0	22-11-0	595	1240	—	156	< 32
2:1:1	10-5-5	270	567	161	1002	32
2:2:1	10-10-5	541	468	161	830	34
2:3:1	10-15-5	811	370	161	658	31
2:4:1	10-20-5	1081	270	161	488	35
2:1:2	8-4-8	216	454	258	1072	41
2:3:2	8-12-8	649	296	258	797	37
2:1:3	6-3-9	162	341	290	1207	26
2:2:3	6-6-9	324	282	290	1104	32
2:3:3	6-9-9	486	222	290	1002	14
3:1:0	24-8-0	432	1441	—	127	< 32
3:2:0	21-14-0	757	1122	—	121	< 32
3:1:1	12-4-4	216	721	129	934	30
3:2:1	12-8-4	432	642	129	797	30
3:3:1	12-12-4	849	562	129	660	34
3:4:1	12-16-4	865	483	120	523	37
3:1:2	9-3-6	162	540	194	1104	32
3:2:2	9-6-6	324	480	194	1002	34
3:3:2	9-9-6	486	421	194	899	37
3:4:2	9-12-6	649	361	194	796	32
3:1:3	6-2-6	108	360	194	1338	20
3:2:3	6-4-6	216	321	194	1269	16
4:1:0	24-6-0	324	1481	—	195	< 32
4:1:1	12-3-3	162	740	97	1001	16
4:2:1	12-6-3	324	681	97	898	16
4:3:1	12-9-3	486	621	97	796	20
4:4:1	12-12-3	649	562	97	692	18
4:1:2	8-2-4	108	494	129	1269	13
4:3:2	8-6-4	324	415	129	1132	11
4:1:3	8-2-6	108	494	194	1204	23
4:2:3	8-4-6	216	454	194	1136	30
4:3:3	8-6-6	324	415	194	1067	30
4:4:3	8-8-6	432	375	194	999	30
4:3:4	8-6-8	324	415	258	1003	41

Guidelines Supplied by R. D. Curley, C.P. Ag., Consultant

Supplement—Table A-39A

Typical Formulations for Liquid Cold Mix Fertilizer Plants

Ratio	Grade	Liquid Base Solution 11-37-0	Urea-Ammonium Nitrate Solution (28-0-0)	Potassium chloride (0-0-62)	Water	Estimated Salting-Out Temperatures (°F)
		Pounds per ton of Product				
1:1:0	19-19-0	1027	953	—	20	32
1:2:0	14-28-0	1514	405	—	81	32
1:3:0	11-33-0	1784	86	—	130	32
1:1:1	8-8-8	432	402	258	908	44
1:2:1	8-16-8	865	232	258	645	32
1:3:1	7-21-7	1135	54	226	585	8
1:1:2	5-5-10	270	251	323	1156	20
1:2:2	5-10-10	541	145	323	991	20
1:3:2	5-15-10	811	39	323	827	44
1:1:3	4-4-12	216	201	387	1196	14
1:2:3	4-8-12	432	117	387	1064	38
1:3:3	3-9-9	486	23	290	1201	0
2:1:0	22-11-0	595	1339	—	66	32
2:1:1	10-5-5	270	608	161	961	32
2:2:1	10-10-5	541	502	161	796	34
2:3:1	10-15-5	811	397	161	631	31
2:4:1	10-20-5	1081	289	161	469	35
2:1:2	8-4-8	216	487	258	1039	41
2:3:2	8-12-8	649	317	258	776	37
2:1:3	6-3-9	162	365	290	1183	26
2:2:3	6-6-9	324	302	290	1084	32
2:3:3	6-9-9	486	238	290	986	14
3:1:0	24-8-0	432	1545	—	23	32
3:2:0	21-14-0	757	1203	—	40	32
3:1:1	12-4-4	216	773	129	882	30
3:2:1	12-8-4	432	688	129	751	30
3:3:1	12-12-4	649	602	129	620	34
3:4:1	12-16-4	865	518	129	488	37
3:1:2	9-3-6	162	579	194	1065	32
3:2:2	9-6-6	324	515	194	967	34
3:3:2	9-9-6	486	451	194	869	37
3:4:2	9-12-6	649	387	194	770	32
3:1:3	6-2-6	108	386	194	1312	20
3:2:3	6-4-6	216	344	194	1246	16
4:1:0	24-6-0	324	1587	—	89	32
4:1:1	12-3-3	162	793	97	948	16
4:2:1	12-6-3	324	760	97	849	16
4:3:1	12-9-3	486	666	97	751	20
4:4:1	12-12-3	649	602	97	652	18
4:1:2	8-2-4	108	529	129	1234	13
4:3:2	8-6-4	324	445	129	1102	11
4:1:3	8-2-6	108	529	194	1169	23
4:2:3	8-4-6	216	487	194	1103	30
4:3:3	8-6-6	324	445	194	1037	30
4:4:3	8-8-6	432	402	194	972	30
4:3:4	8-6-8	324	445	258	973	41

Supplement—Table A-39B.

Typical Formulations for Liquid Cold Mix Fertilizer Plants

Ratio	Grade	Liquid Base Solution 11-37-0	Urea-Ammonium Nitrate Solution (28-0-0)	Water	Potassium chloride (0-0-62)	Estimated Salting-Out Temperatures (°F)
		Pounds per ton of Product			Pounds	
1:1:0	19-19-0	87.8	89-1	2.4	—	32
1:2:0	14-28-0	138.5	37.9	9.7	—	32
1:3:0	11-33-0	165.8	8.0	15.6	—	32
1:1:1	8-8-8	36.9	37.6	109.0	258	44
1:2:1	8-16-8	73.9	21.7	77.4	258	32
1:3:1	7-21-7	97.0	5.1	70.2	226	8
1:1:2	5-5-10	23.1	23.5	138.8	323	20
1:2:2	5-10-10	46.2	13.6	119.0	323	20
1:3:2	5-15-10	69.3	3.6	99.3	323	44
1:1:3	4-4-12	18.5	18.8	143.6	387	14
1:2:3	4-8-12	36.9	10.9	127.7	387	38
1:3:3	3-9-9	41.5	2.2	144.2	290	0
2:1:0	22-11-0	50.9	125.1	7.9	—	32
2:1:1	10-5-5	23.1	56.8	115.4	161	32
2:2:1	10-10-5	46.2	46.9	95.6	161	34
2:3:1	10-15-5	69.3	37.1	75.8	161	31
2:4:1	10-20-5	92.4	27.0	56.3	161	35
2:1:2	8-4-8	18.5	45.5	124.7	258	41
2:3:2	8-12-8	55.5	29.6	93.2	258	37
2:1:3	6-3-9	13.0	34.1	142.0	290	26
2:2:3	6-6-9	27.7	28.2	130.1	290	32
2:3:3	6-9-9	41.5	22.2	118.4	290	14
3:1:0	24-8-0	36.9	144.4	2.8	—	32
3:2:0	21-14-0	64.7	112.4	4.8	—	32
3:1:1	12-4-4	18.5	72.2	105.9	129	30
3:2:1	12-8-4	36.9	64.3	90.2	129	30
3:3:1	12-12-4	55.5	56.3	74.4	129	34
3:4:1	12-16-4	73.9	48.4	58.6	129	37
3:1:2	9-3-6	13.9	54.1	127.9	194	32
3:2:2	9-6-6	27.7	48.1	116.1	194	34
3:3:2	9-9-6	41.5	42.2	104.3	194	37
3:4:2	9-12-6	55.5	36.2	92.4	194	32
3:1:3	6-2-6	9.2	36.1	157.5	194	20
3:2:3	6-4-6	18.5	32.2	149.6	194	16
4:1:0	24-6-0	27.7	148.3	106.8	—	32
4:1:1	12-3-3	13.9	74.1	113.8	97	16
4:2:1	12-6-3	27.7	68.2	101.9	97	16
4:3:1	12-9-3	41.5	62.2	90.2	97	20
4:4:1	12-12-3	55.5	56.3	78.3	97	18
4:1:2	8-2-4	9.2	49.4	148.1	129	13
4:3:2	8-6-4	27.7	41.67	132.3	129	11
4:1:3	8-2-6	9.2	49.4	140.3	194	23
4:2:3	8-4-6	18.5	45.5	132.4	194	30
4:3:3	8-6-6	27.7	41.6	124.5	194	30
4:4:3	8-8-6	36.9	37.6	116.7	194	30
4:3:4	8-6-8	27.7	41.6	116.8	258	41

FERTIGATION/CHEMIGATION SCHEDULE [1/]

Name

		WEEKS AFTER EMERGENCE														
	PREPLANT ----lbs/A---	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
										lbs/A						
N																
P																
K																
Mg																
Ca																
S																
Zn																
Mn																
Fe																
Cu																
B																
Herbicide																
Insecticide																
Fungicide																

FIELD:
YIELD GOAL:

COMMENTS:

ST.: STARTER
S.D.: SIDE DRESS
SP.: SPRINKLER

[1/] Refer to Table 4, "Suggested Fertigation Schedule for Corn and Grain Sorghum" on page 7 of the text for example format.

REFERENCES CITED

1. Achorn, F. P. 1984. Acid fertilizers. Great Plains Fertility Workshop, Denver, CO 12 p.
2. Anonymous. 1962. Agricultural ammonia handbook. Agricultural Ammonia Institute, Memphis, TN 92 p.
3. Baker, W. 1988. Personal communication. Eli Lilly and Company, Omaha NE
4. Christenson, D.R. 1990. Effect of irrigation and nitrogen on corn yield and profit. In: Proceedings of North Central Extension-Industry Soil Fertility Conference. St. Louis, MO. Nov. 14-15, 1990. pp. 14-20.
5. Columbia Nitrogen Corporation. Corn Fertigation: An Update on the management of water and fertilizer 10 p.
6. Curley, R. D. 1974. Nutri-Gation. Personal communication.
7. Dowler, C. C. 1985. Co-chemigation Showing Promise. Solutions Magazine. January, 1985. pp. 36-43.
8. Duis, J. H. 1969. Polyphosphates in irrigation. Solutions Magazine. March-April, 1969,
9. Fischbach, P.E. 1964. Irrigate, fertilize in one operation. Nebr. Quart. Summer, pp. 15-17.
10. Gascho, G. J., J. E. Hook, and G. A. Mitchell. 1984. Sprinkler applied and side-dressed nitrogen for irrigated corn grown on sand. Agron. J. 76: 77-81.
11. Goos, R. J. 1987. Ammonium thiosulfate as a urease inhibitor. A suggested mechanism. In Proc. Seventeenth North Central Extension and Industry Soil Fertility Workshop. St. Louis, MO Oct. 28-29, 1987.
12. Hach Company. 1989. Smart pivot turns ag research in new directions. In: Agrichemical Age. Aug./ Sept., 1989. pp. 24-26.
13. Hergert, G. W. 1976. Sprinkler application of fertilizer nutrients. Solutions Magazine, 1976.
14. Johnson, A. W., J. R. Young, E. D. Threadgill, C. C. Dowler, and D. R. Sumner. 1987. Chemigation's strong future. Agrichemical Age. February, 1987. pp 8-9.
15. Mulliner, H. R. Applying anhydrous ammonia in irrigation water. University of Nebraska.
16. Ratledge, G. L. 1981. Applications of fertilizer and chemicals through center pivot irrigation systems. Short Course on Center Pivot Irrigation, Lubbock, TX.
17. Rhodes, F. N. 1991. Effect of irrigation and tillage on corn yield. In: Mechanized Irrigation: Practical Economics. Valmont Industries. Hiway 275, Valley, NE 68064.
18. Todhunter, J. A. 1985. Review agents before opting for chemigation. Agrichemical Age. February, 1985. p.20.
19. Valmont Industries. 1991. C:A:M:S (Computer Aided Management System). In: Valley Magazine. Vol. 5, No. 2. Summer, 1991. pp. 4-5.

20. Van de Walle, R. H. 1984. Personal communication. Martin Marietta, Baltimore, MD.

21. Walker, W. 1984. The importance of Boron Soil Testing and Plant Analysis for Today's Crop Production. Presented at U.S. Borax Boron Symposium, Rochester, Minnesota 194.

22. Watson, M. E. 1984. Boron: presented at U.S. Borax Boron Symposium, Rochester, Minnesota 1984.

23. Watts, R. 1984. Personal communication. Scoular Grain, Imperial, NE.

INDEX

CONVERSIONS, EQUIVALENTS, AND ABBREVIATIONS

1. Common Conversions

To convert P to P_2O_5, multiply by 2.29
To convert K to K_2O, multiply by 1.23
To convert Mg to MgO, multiply by 1.658
To convert Ca to $CaCO_3$, multiply by 2.50
To convert SO_4 to S, multiply by 0.333
To convert NO_3 to N, multiply by 0.226

2. Equivalent Weight of Ions

Cations	Equivalent Weight	Anions	Equivalent Weight
Calcium (Ca)	20	Carbonate (CO_3)	30
Magnesium (Mg)	12	Bicarbonate (HCO_3)	61
Sodium (Na)	23	Sulfate (SO_4)	38
		Chloride (Cl)	35.5

3. Symbols--Abbreviations--Conversions

EC..	Electrical Conductivity in mhos / cm
EC X 10^{-3}............................	Electrical Conductivity in millimhos / cm
EC X 10^{-6}............................	Electrical Conductivity in micromhos / cm
SAR......................................	Sodium Absorption Ratio
meq..	Milliequivalent
meq/L.....................................	Millequivalent/L
ppm.......................................	Parts per million
L...	Liter

grains per gallon to parts per million ppm = 17.1 x grains per gallon
one U.S. gallon weighs 8.345 pounds
one cubic foot of water weighs 62.43 pounds
< less than
> greater than
450 gallons per minute (gpm) = 1 acre-inch per hour
1 cubic foot per second (cfs) = 1 acre-inch per hour
pounds of water = 226,500 x acre-inches
one acre foot of water weights 1,360 tons
ppm x 0.23 = lbs./acre inch