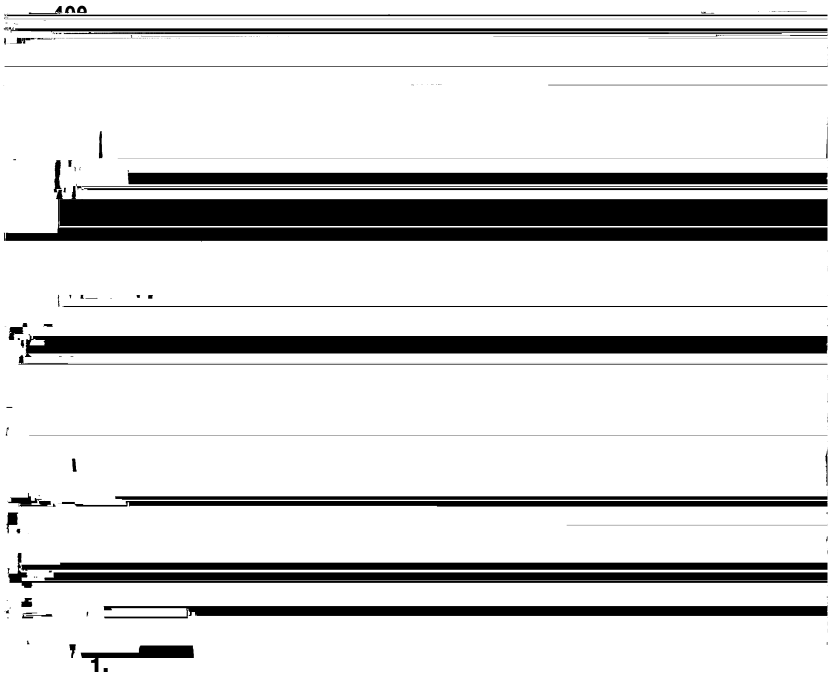
I iga ion is eq i ed fo ofi able comme cial o a o od c ion in Idaho. Ma im m economic e n eq i es, among o he hings, ha soil wa e con en be main ained wi hin a he na ow limi s h o gho he g owing season. Po a oes a e of en conside ed o be a high wa e se c o , when in fac many o he c o s g own in Idaho have eq al o g ea e seasonal wa e se eq i emen s. This misconce ion a ises f om he fac ha o a oes a e sensi ive o wa e s ess com a ed o mos o he c o s, have a ela ively shallow oo - zone de h and a e of en g own on soils wi h low o medi m wa e holding ca aci ies. These condi ions necessi a e ha eliable i iga ion sys ems ca able of ligh , f eq en , nifo m wa e a lica ions be sed o o imally con ol soil wa e availabiliy h o gho he g owing season. These condi ions also dic a e ha an effec ive o a o i iga ion managemen o- g am incl de (i) eg la q an i a ive moni o ing of soil wa e , (ii) sched ling i iga ions acco ding o c o wa e se and soil wa e holding ca aciy , and (iii) a wa e s ly and i iga ion sys em ha is ca able of oviding he needed i iga ion on sched le.

The sensi iviy of o a oy ield o i iga ion managemen is de ic ed in fig e 1. The es ls we e ob ained f om a 1995 esea ch s dy of wa e managemen ac ices on 45 comme cial o a o fields in so heas Idaho (S a k, 1996). Po a oy ield is ed ced by bo h ove - and nde -i iga ion. A me e 10 e cen devia ion f om o im m wa e a lica ion fo he g owing season may begin o dec ease y ield. This sensi iviy o wa e managemen is a ib able o he sensi iviy of o a o lan s o wa e s ess, co led wi h



1.

( ) 45

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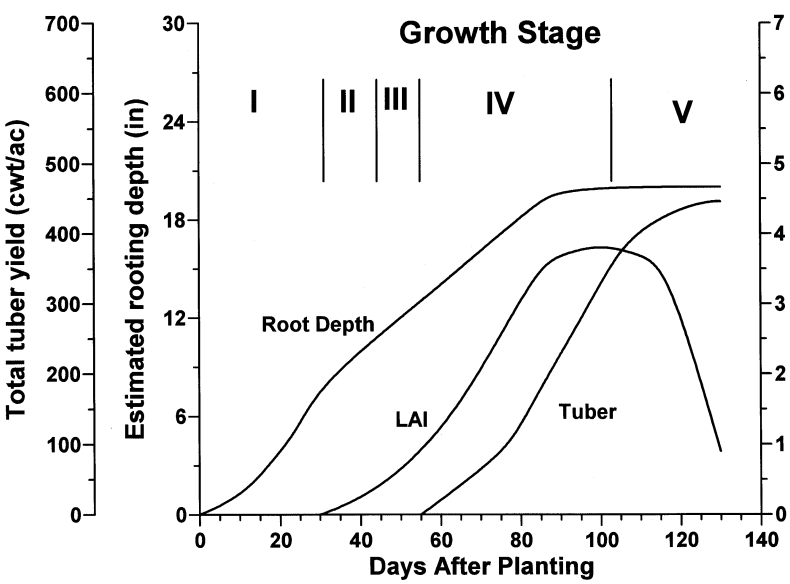
be y ield. Leaf a ea inde is he dimensionless a io of leaf s face a ea o g o nd s face a ea. G o w h s age I s ans he e iod of lan ing o eme gence and anges f om 20 o 35 days de ending on va ie al diffe ences, c l al ac ices, and envi onmen al condi ions. G o w h s age II encom asses ea ly vege a- ive develo men f om eme gence o be ini ia ion and anges f om 15 o 25 days de ending on he si e- s ecific condi ions. S olons begin o develo d ing g o w h s age II, b be s a e no y e esen . T be s fo m a he i s of he s olons ove a 10- o-14-day e iod, which is called be i za ion" o be ini ia ion and e esen s g o w h s age III. D ing his g o w h s age, he LAI is gene - ally in he ange of 1 and 2, which co es onds o 50-80 e cen o w clos e de ending on si e-s ecific condi ions and va iey.

T be enla gemen o b lking" occ s la gely h o gho g o w h s age IV. The inc ease in be si ze is a o ima ely linea wi h ime ove a 30- o-60-day e iod nde o imal envi onmen al condi ions. Nea he end of g o w h s age IV, LAI eaches a ma im m ange of 3.5 o 6.0, de ending on va iey and envi on- men al condi ions (W igh and S a k, 1990). Wa e se o ans i a ion" by he o a o lan also eaches a ma im m a his ime. Nea he end of g o w h s age IV, he g o w h a e of he cano y begins o decline.

D ing g o w h s age V, lan s begin o die and lose leaves. T be g o w h a es decline as he es l of ed ced leaf a ea and ho osy n- he ic ac iviy, and be skins begin o ma e. The emaining be g o w h es l s ima ily f om ans lo- ca ion of lan ma e ials f om s em, leaf, and oo s o he be s.



2. , (A), .

y Po a o lan oo sys em develo men is ela ively shallow, 18-24 inches, wi h he majo iy of oos in he s face 12 inches. The shallow oo ing de h is a ib ed o he inabiliy of is ela ively weak oo sys em o ene a e illage ans o o he es ic ive lay e s. Soil com ac ion by field vehicle affic can g ea ly es ic o a o oo ene a ion. Soil wa e con en a he ime of illage o e a- ions has a majo infl ence on he deg ee of com ac ion es l ing f om field affic.

Many soils in Idaho have a weakly cemen ed calci m ca bona e lay e wi hin 24 inches of he soil s face, which es ic s o a o oo ene a ion b no wa e movemen . Field de e mina ion of ac al o a o lan oo ing de h is of imay im o ance o o e i iga ion managemen .

a G a a Ava a y The sensi iviy of o a oes o lan wa e s ess is likely d e o hei a he shallow oo sys em and com le hysiological es onses o mode a e lan wa e defici s (C wen, 1993). The fi s hysiological es onse is clos e of he leaf s oma a: he small o es in he leaf ha con ol gas e change be ween in e nal leaf cells and he envi onmen . Eva o a ion of wa e f om wi hin he leaves se ves o cool he leaves, es l ing in a lan cano y em e a e below ai em e a e nde well-wa e ed condi ions. The s oma a in he leaf close nde lan wa e defici s as a defense agains f he wa e loss. The hysical indica ion is an in- c ease in cano y em e a e as a es l of ed ced eva o a ive cooling of he leaves.

While s oma al clos e ed ces wa e loss h o gh he leaves, i also ed ces ca bon dio ide diff sion in o he leaf. This slows ho osyn hesis, ed cing he od c ion of ho osyn- he ic od c s (s a ch and s ga s) by he lan and hei ans loca ion f om he leaves o he be s. Po a o yield and aliy de end on ma imizing he s eady acc m la ion of ho osyn he ic od c s in he be s. When od c ion of hese od c s e ceeds ha needed fo es i a ion and con in ed lan g ow h, hey a e s o ed in he be s.

One of he fi s hysiological es onses affec ed by lan wa e defici s is he e ansion of leaves, s ems, and be s. Wa e defici s ed ce lan g ow h by ed cing he in e nal wa e ess e in lan cells (go ess e), which is necessay fo e ansion. Red ced vine and leaf g ow h limi s o al ho osyn he ic ca aciy, while he ed ced oo develo men limi s he lan 's abiliy o ake wa e and n ien s. Wa e defici s also dis no mal be g ow h a e ns by ed cing o s o ing be e ansion. T be g ow h es mes following elief of lan wa e defici s, b he dis - ion of he no mal be e ansion a e may es l in be malfo ma- ions s ch as oin ed ends, d mb- bells, bo lenecks, and knobs. Widely fl c a ing soil wa e con en s c ea e he g ea es o o niy fo develo - ing hese be defec s. G ow h c acks a e also associa ed wi h wide fl c a ions in soil wa e availabiliy and co es onding changes in be gidiy and vol me of in e nal iss es.

Po a oes a e a ic la ly sensi ive o wa e s ess d ing be ini ia ion and ea ly be develo men . Wa e defici s a his ime can s bs an ially ed ce U.S. No. 1 yields by inc eas- ing he o o ion of o gh, mis- sha en be s. Ea ly-season wa e s ess can also ed ce s ecific g aviy and inc ease he amo n of ans l cen end.

Wa e s ess d ing be b lking s ally affec s o al be yield mo e han aliy. A la ge ho osyn he i- cally-ac ive leaf s face a ea is necessay o main ain high be b lking a es fo e ended e iods. Main enance of his la ge ac ive leaf s face a ea e i es con in ed develo men of new leaves o e lace olde , less efficien ones. Wa e s ess has ens leaf senes- cence and in e s new leaf fo ma ion, es l ing in an n ecove - able loss of be b lking.

Soil wa e con en a ha ves has a significan infl ence on mechanical damage s s ained by be s d ing he ha ves ing ocess. T be s ha a e dehyd a ed as a es l of low soil wa e con en a ha ves a e mo e s sce ible o blacks o b ise. T be s ha a e gid as a es l of high soil wa e con en a ha ves a e mo e s sce ible o sha e b ise and h mbnail c acking.

Po a oyield and aliy a e s sce ible o e cess soil wa e as well. E cess soil wa e f om fe en o in ensive i iga ion o ainfall d ing any g ow h s age leaches ni a e ni ogen below he lan oo zone, o en ially es l ing in ni o- gen-deficien lan s, ed ced fe il- i ze se efficiency, and an inc eased ha za d o g o nd wa e. Sa a ion of he soil ofile fo mo e han 8-12 ho s can ca se oo damage d e o a lack of o ygen e i ed fo no mal es i a ion. E cess soil wa e a lan ing omo es seed iece decay and delays eme gence d e o dec eased soil em e a e. Po a- oes ha a e ove -i iga ed d ing vege a ive g ow h and be ini ia ion have a g ea e o en ial fo develo - ing b own cen e and hollow hea , and a e gene ally mo e s sce ible o ea ly die oblems. E cess soil wa e can also lead o be aliy and s o age oblems.

The coa se- e ed soils and

ho , dy s mme s ha a e cha ac e - is ic of s o he n Idaho make i iga- ion ess en ial fo od cing eliable, economically s s ainable o a o y ields. The os e of i iga ion managemen is o ma imi ze o a o y ield and aliy by main aining s oil Wa e con en Wi hin s ecified limi s h o gho he g oWing s eas on h o gh imely and con olled Wa e a lica ion o he c o .

O C

Mary field es ea ch s dies have foc s ed on de e mining o im m s oil Wa e con en fo i iga ed o a o od c ion. Mos s dies on he Wa e s ess s ens i ive R ss e B bank va iey indica e ha available s oil Wa e (ASW) in he oo zone (0-18 inches) s ho ld be main ained above 65 e cen o avoidy ield and aliy losses. Res l s f om es ea ch s dies s ing i iga ion f e encies of one o h ee days on s il loam s oils have s hoWn ha in e mi en ASW levels beloW 65 e cen may no ed ce be y ield and aliy. In gene al, hoW- eve , he ave age ASW of he oo zone s ho ld be main ained beWeen 65 and 85 e cen d ing he ac ive g oW h e iod fo o im m es l s. In ac ice, ASW in he oo zone Will fl c a e above and beloW his ange fo s ho e iods of ime immedia ely befo e and af e i iga ion. This is a ic la ly e Wi h s e -move s inkle sys ems and f oW i iga- ion sys ems. D i i iga ion sy s ems and s olid-s e , cen e - ivo , and linea -move s inkle sy s ems alloW

s ing and a cool s mme , which es l ed in o a o aliy oblems ac oss he s a e ha we e a ib ed o e cessive soil wa e and cool soil em e a es in g ow h s ages II and III. The 1994 g owing season had a wa m s ing and an n s ally ho s mme , which es l ed in many i iga ion sys ems having diffic ly in mee ing c o wa e s e. The 1993 and 1994 g owing seasons likely e esen he nea e emes in seasonal ET fo o a oes in so he n Idaho.

Diffe ences in he s a , eak, and end of daily ET val es shown in fig e 5 fo he h ee loca ions a e d e o diffe ences in lan ing and ha ves da es, and seasonal me eo-ological condi ions. Daily ET h o gho he season is no iceably ed ced fo he Re b g a ea com a ed o he o he loca ions d e o he coole ave age daily em e a- es h o gho he g owing season a ib able o geog a hical loca ion. P blished daily ET val es, as shown in fig e 5, ovide a basis o de-velo an i iga ion managemen og am. In-field soil wa e meas e-men is also e i ed o acco n fo si e-s ecific diffe ences in ET based on y e of i iga ion sys em sed, soil y e, and local me eo ological condi ions s ch as wind and eci i a ion.

The y ical es onse of o a o y ield, o al and U.S. No. 1, o o al seasonal wa e a lica ion (incl ding eci i a ion) is shown in fig e 6 fo h ee o a o c l iva s a Kimbe ly, Idaho (W igh and S a k, 1990). Yield is linea ly ela ed o seasonal wa e a lica ion. Yield dec eases when o al seasonal wa e a lica ion e ceeds seasonal eva o ans i a-ion. The diffe ences in o al wa e a lica ion ha ma imi ze y ield eflec s he diffe ences in g owing season leng h be ween he c l iva s and no necessa ily diffe ences in

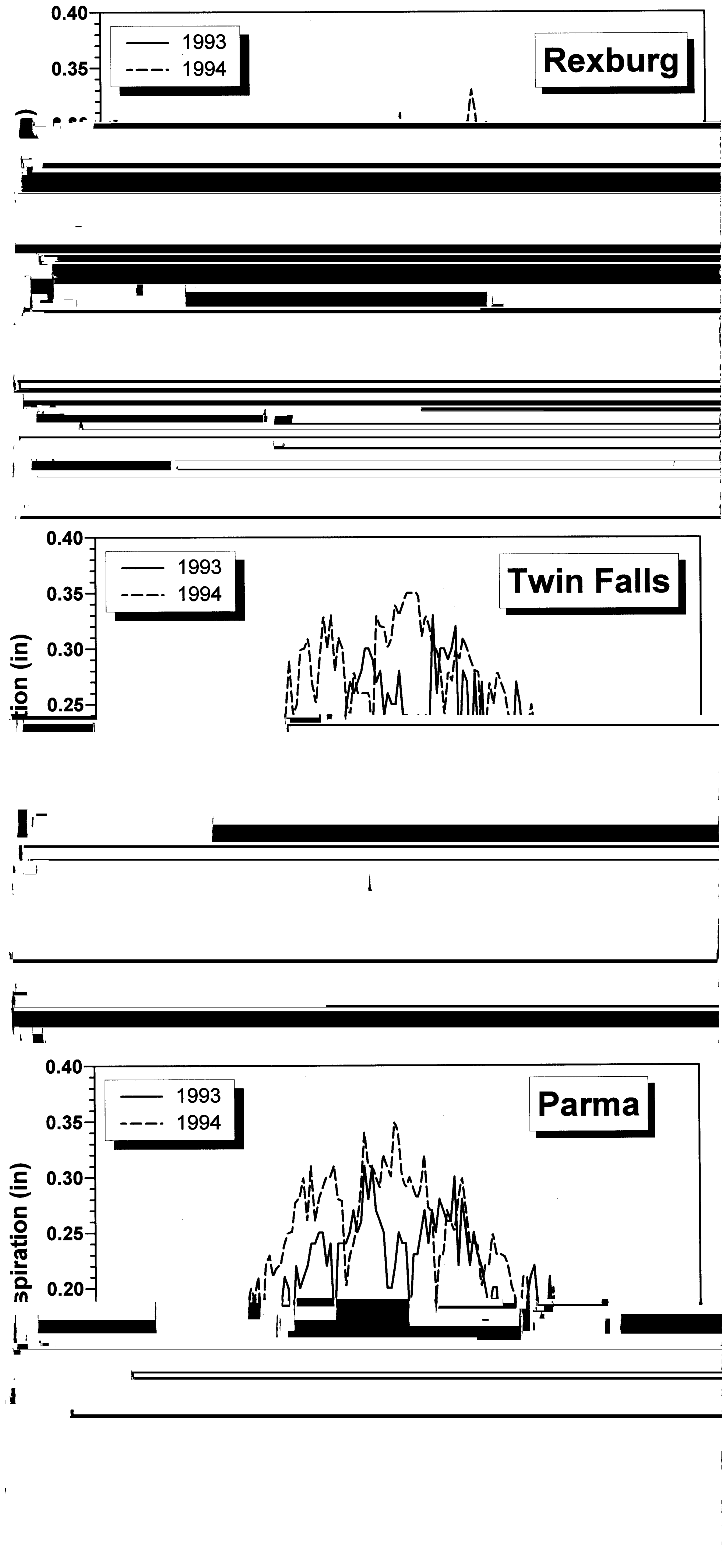
4. .

1. .

(%)

	A				A			(/)
	A		A		A		A	
A	12	7-17	4	2-7	8	5-11	0.96	0.60-1.32
A	14	11-19	6	3-10	8	6-12	0.96	0.72-1.44
A	23	18-28	10	6-16	13	11-15	1.56	1.32-1.80
	26	20-30	12	7-16	15	11-18	1.80	1.32-2.16
	30	22-36	15	9-21	15	11-19	1.80	1.32-2.28
	32	29-35	15	12-18	17	12-20	2.04	1.44-2.40
C	34	30-37	19	17-24	15	12-18	1.80	1.44-2.16
C	36	29-42	21	14-29	15	11-19	1.80	1.32-2.28
C	36	32-39	21	19-24	15	10-20	1.80	1.20-2.40

(., 1990.) C (C 58,/ ., 1990.)) E 7(9 . 0 7 0 21)-2639.7(1 (C -2639.7(32. 0 8334 7.



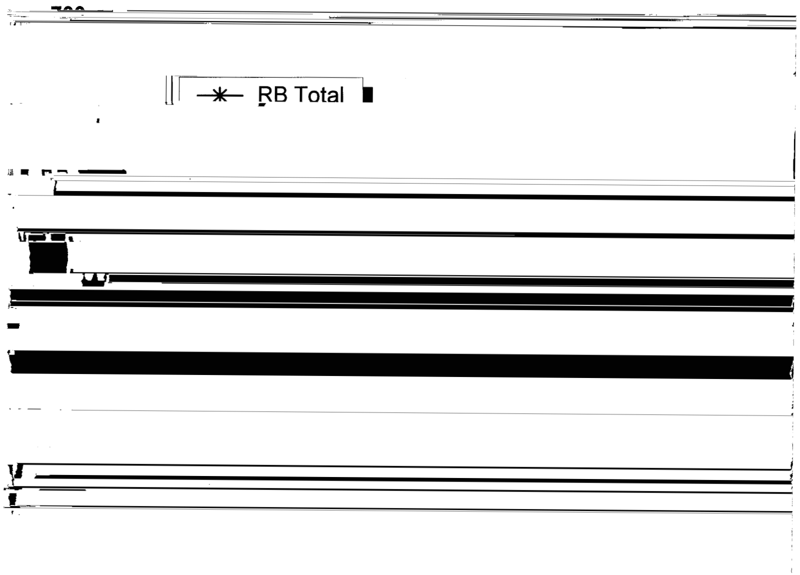
5.
1993 1994 .

a e be e s i ed han o he s fo cons is en ly ob aining high aliy be s. The wa e s ens i ive na e of o a oes, combined wi h i s s hallow oo zone, favo s i iga ion sys ems ha a e ca able of ligh , f e en , and nifo m wa e a lica ions. Us ing hes e c i e ia as a bas is fo anking he s i abiliy of common i iga ion me hods, he o de of efe ence f om highes o lowes wo ld be: d i , s olid-s e (o able), linea -move, cen e - ivo , s ide- oll, hand-move, and f ow. In ac ice, economics a e he ove iding fac o in i iga ion sys em s elec ion. Com- a ibiliy wi h s oil y e, c o o a ion, and c l al ac ices a e als o im o an cons ide a ions. B ied d i is e ens ive, incom a ible wi h conven ional o a o od c ion ac ices, and is no s i able fo es ablis hing s ands of s ome c o s commonly g own in o a ion wi h o a oes, es ecially in coa s e- e ed s oils. Solid-s e o able is e ens ive, as is linea -move. Cen e - ivo s a e highly s s ce ible o e ces s ive noff nde he o e owe s nles s cons e va ion illage ac ices, s ch as bas in o es e voi illage, a e ili zed. Side- oll and hand-move s inkle sys ems a e one o wind s ki s nde he windy condi ions common o s o he n Idaho. F ow i iga ion is s s ce - ible o oo wa e a lica ion nifo miy, e ces s ive dee e cola- ion, and leaching. S inkle i iga- ion is he mos common me hod s ed fo o a oes in Idaho, wi h cen e - ivo , s ide- oll, and hand- move being widely s ed.

Po a o i iga ion s ched ling fo ma im m ofi e i es ha he iming and amo n of wa e a lica- ion be de e mined and a lied o minimi ze s oil wa e fl c a ions h o gho he g owing s eas on.

S cce s f l i iga ion managemen e q i es eg la q an i a ive moni o - ing of soil wa e and knowledge of field c o wa e se, soil wa e holding ca aciy, and c o - oo ing de h. E ce s i iga ion s ally es l s f om a ying oo m ch wa e a a given i iga ion a he han f om i iga ing oo f e q en ly. This is a ic la ly e fo side- oll and hand-move s inkle sys ems whe e soil wa e holding ca aciy and c o - oo ing de h a e f e q en ly ove es i- ma ed; and f ow i iga ion, whe e a lica ion de h is diffic l o con ol. These si a ions lead o lan wa e s ess when soil wa e falls below acce able limi s wo o h ee days befo e i iga ion, and s bse q en i iga ion a lica ions a e in e ce s of soil wa e s o age ca aciy. This cha ac e is ic oblem can gene ally be a ib ed o inade q a ely designed sys ems, i iga ion sys em e q i men limi a- ions, o im o e i iga ion manage- men .

De e mining he a o ia e iming of i iga ions s ally involves he se of daily ET es ima es based on local me eo ological da a o main ain a daily soil wa e balance h o gho he i iga ion season. This echni q e, combined wi h e iodic q an i a ive meas emen s of soil wa e o adj s he com ed soil wa e balance o ac al field condi ions, ovides a cos effec ive means fo de e mining he iming of i iga ions. This a oach has he added benefi of im lici ly de e min- ing he i iga ion a lica ion amo n as well. The com a ional mechan- ics of he soil wa e balance a - oach a e ovided in he blica- ion - , CIS 1039, Unive si y of Idaho, College of Ag ic l e. The basic s e s involved a e:



6. . . . 1 ( ), ( ) ( ). (: , 1990.)

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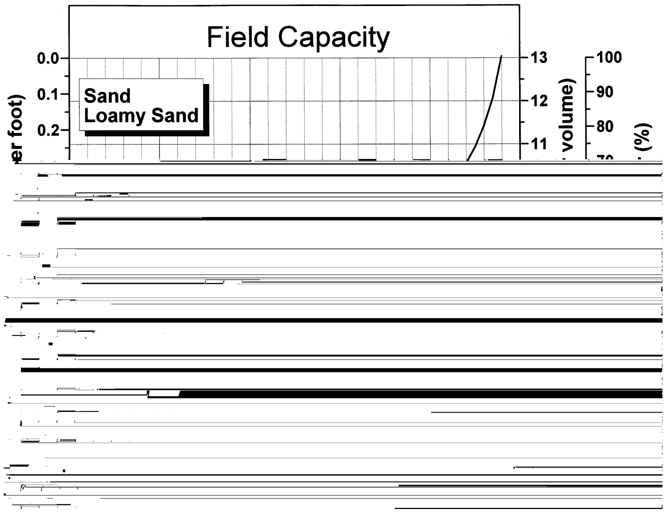
3 .

4 0 , . , .

Seve al me hods a e available o q an i a ively meas e soil wa e con en . Only some a e s i able fo o a oes, howeve , beca se of he c i ical h eshold level of available soil wa e and he limi ed oo - zone de h. Many of he me hods a e labo in ensive and e q i e aining, e e ience, and e ensive e q i - men . This has led o he develo - men of c o cons l ing fi ms s e- ciali zing in i iga ion managemen , which of en ovide c o n ien and es managemen se vices as well. A de ailed disc ssion of soil wa e meas emen me hods is ovided in he blica ion , PNW 475, Unive si y of Idaho, College of Ag ic l e.

Tensiome e s have been sed o s cce s f lly moni o soil wa e availabili y in o a o fields. Good con ac be ween he soil and ensi- ome e i is essen ial fo o e o e a ion. Tensiome e s a e of en ins alled in he o a o hill a wo de hs, s ch as 8 and 16 inches below soil level. Ty ically, he e ensiome e is sed o ack soil wa e o en ial wi hin he b lk of he oo zone, while he lowe one is sed o de e mine whe he soil wa e o en ial a he bo om of he oo zone is inc easing o dec easing ove ime.



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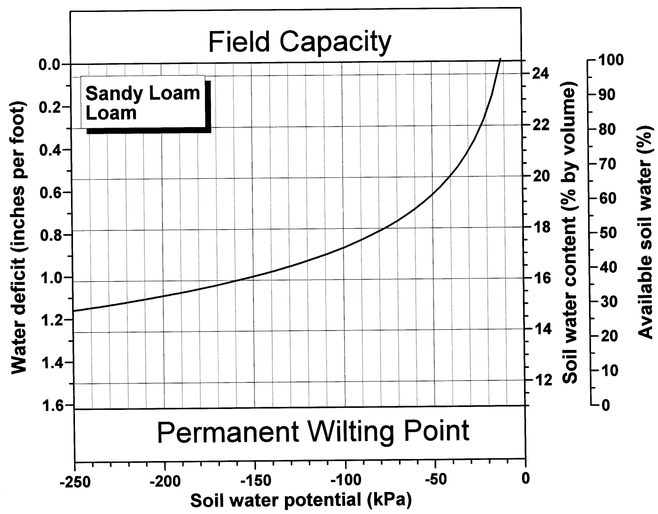

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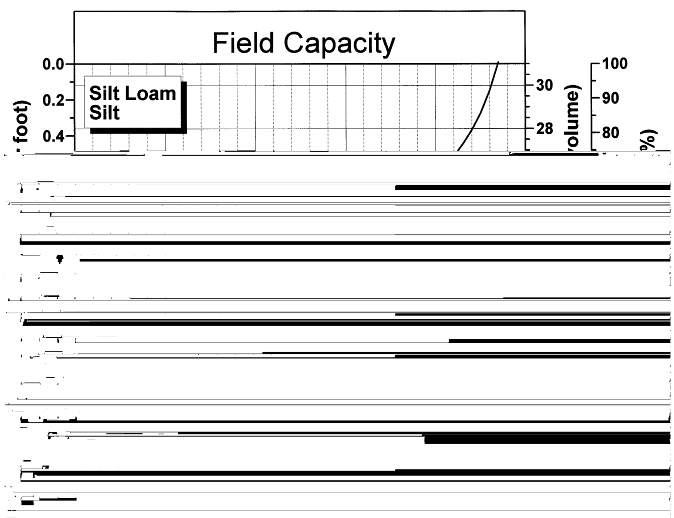

9.

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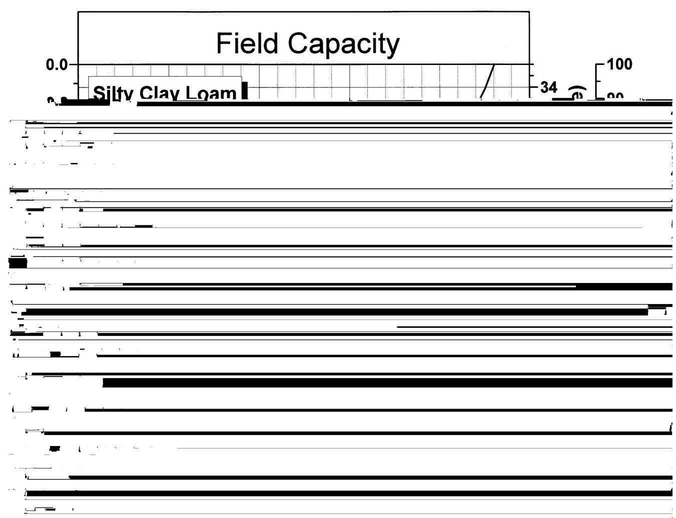

10.

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The ne on obe is likely he mos ecise and eliable ool fo soil wa e meas emen since i de e-mines vol me ic soil wa e con en . Howeve , licensing, aining, and associa ed o e a ional cos s limi hei se o cons l ing fi ms and la ge fa ms. Time domain eflec ome ey (TDR) offe s many fea es ha make i well s i ed o soil wa e meas emen in o a oes. Howeve , he ini ial e i men cos is i e high. C en esea ch effo s o develo less e ensive TDR ni s may make i he me hod of he f e. O he me hods a e also available and may be s i able.

A soil wa e elease c ve is needed o ela e soil wa e o en ial o vol me ic soil wa e con en . The gene ali zed soil wa e elease c ves shown in fig es 7 h o gh 10 can be sed o ela e soil wa e o en ial o vol me ic soil wa e , ASW and wa e defici . These c ves e esen he imay soil wa e ela ionshi s needed fo he devel-o men of an effec ive i iga ion managemen og am. They allow soil wa e con en o wa e o en ial meas emen s o be s ed o calc - la e he ne i iga ion a lica ion amo n needed o fill he s oil W a e es e voi o field ca aciy . Fo e am le, if ens iome e s s hoW an ave age s oil W a e o en ial of -40kPa (cen iba s) on a s andy loam s oil (fig e 7), hen ASW is 62 e cen , W hich indica es i 's ime o i iga e W i h a ne a lica ion of 0.36 in/f of c o oo - zone de h. Soil W a e moni o ing alone can be s ed fo i iga ion s ched ling if e fo med on a eal- ime bas is and s ed o di ec ly con ol an i iga ion sy s em ca able of immedia e es ons e. In ac ice ho gh, mos field s cale i iga ion sy s ems a e no ca able of immedia e es ons e. Th s , a s oil W a e balance is com ed daily s ing bo h es ima ed and fo ecas ed daily ET o an ici a e W hen he ne i iga ion s ho ld occ and amo n o a ly . This com ed s oil W a e balance is econciled o ac al field condi ions h o gh s e of he s oil W a e eleas e c ve and an i a ive s oil W a e meas emen .

The ange of s oil W a e o en ial and vol me ic s oil W a e con en in he o a o oo zone a W hich ime i iga ion s ho ld occ o main ain ASW above 65 e cen is s hoW n in able 2. Thes e val es a e ob ained f om he gene ali zed s oil W a e eleas e c ves s hoW n in fig e 7 h o gh 10. Thes e val es a e no abs ol e, b s e ve as a gene al g ide fo effec ive i iga ion managemen .

An e am le of i iga ion s ched l- ing fo a cen e - ivo sy s em ove a nine day e iod in J ly is o lined in able 3. On he mo ning of 7/10, he ave age eading fo s eve al ens iom- e e loca ions aligned adially o W a d f om he cen e of a cen e - ivo i iga ed o a o field is -40 kPa. The edomina e s oil e e is s andy loam, W hich a -40 kPa has an ASW of 67 e cen and W a e

2.
65 A .

	( )	(%)
A A A	-25 -35	9-12
A ,	-35 -50	19-22
,	-50 -65	24-26
C , , C	-65 -75	29-31

3. - .

( )	( )	( )	( )	( )		
7/9	.29			0.91		
7/10	.31		0.5	0.62	0.81	AA . A . 0.8,
7/11	.27			0.89		
7/12	.25		0.5	0.64		
7/13	.22			0.86		
7/14	.18	.05	0.5	0.54		<0.1
7/15	.25			0.79	0.9	AA . A . 0.9,
7/16	.31		0.5	0.71		
7/17	.28		0.5	0.49		

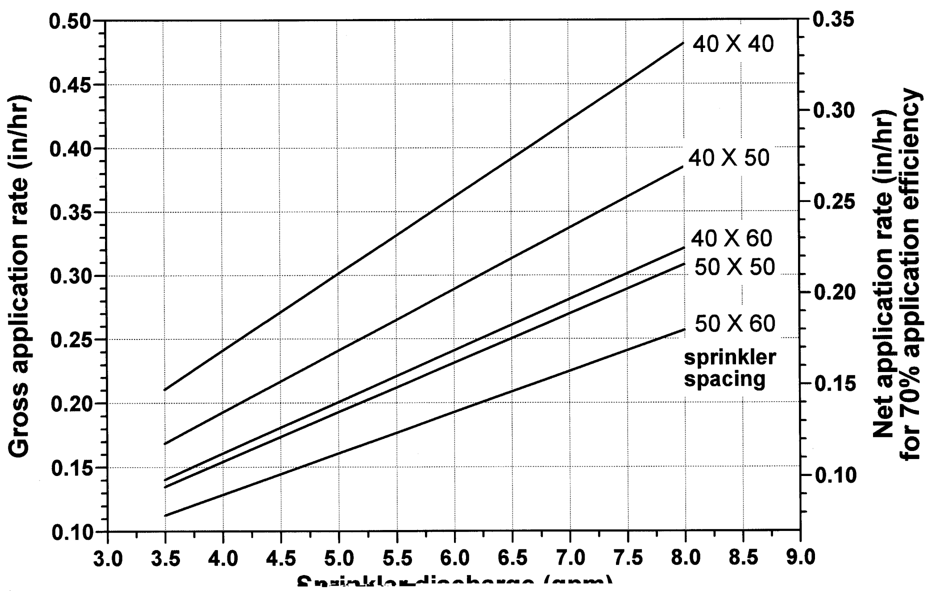
4. - .

( )	( )	( )	( )	( )		
7/9	.29			1.25		
7/10	.31		1.41	0	1.1	AA . A . 1.1 , 9.4
7/11	.27			0.27		
7/12	.25			0.52		
7/13	.22			0.71		
7/14	.18	.05		0.92		<0.1
7/15	.25			1.17		
7/16	.31		1.56	0	1.25	AA . A . 1.25 , 10.4
7/17	.28			0.28		

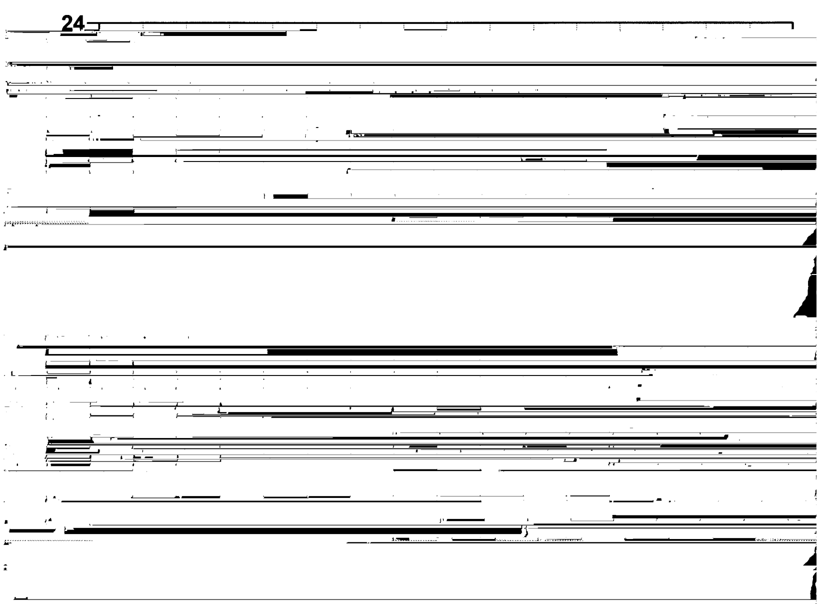
G oss Wa e a lica ion a es fo se-move and solid-se s inkle sys ems, as a f nc ion of s inkle flow a e and s acing, a e esen ed in fig e 12. S inkle flow a e can be ob ained f om fig e 13 fo s aigh -bo e no zzles, as a f nc ion of no zzle si ze and ess e. Ne a lica ion a es fo 70 e cen a lica ion efficiency a e given in fig e 12 (igh -side a is). Ne a lica ion a e fo any a lica ion efficiency can be calc la ed as:

E :

(fig e 5). Howeve , a f ll soil wa e ese voi was no necessay in 1993, since eak ET seldom e ceeded 0.28 in/day (fig e 5). Fig e 14 de ic s available soil wa e h o gh- o he i iga ion season fo a cen e - ivo sys em ha is managed so ha soil wa e is e lenished o field ca aciy (100 e cen ASW) ea ly in he season (fig e 14a), com a ed o only 85 e cen ASW (fig e 14b). Unde bo h scena ios, he cha ac e - is ic g ad al d awdown of ASW occ s d ing he eak- se e iod.



12. -
(-) ( ).



13. (-)
( ).

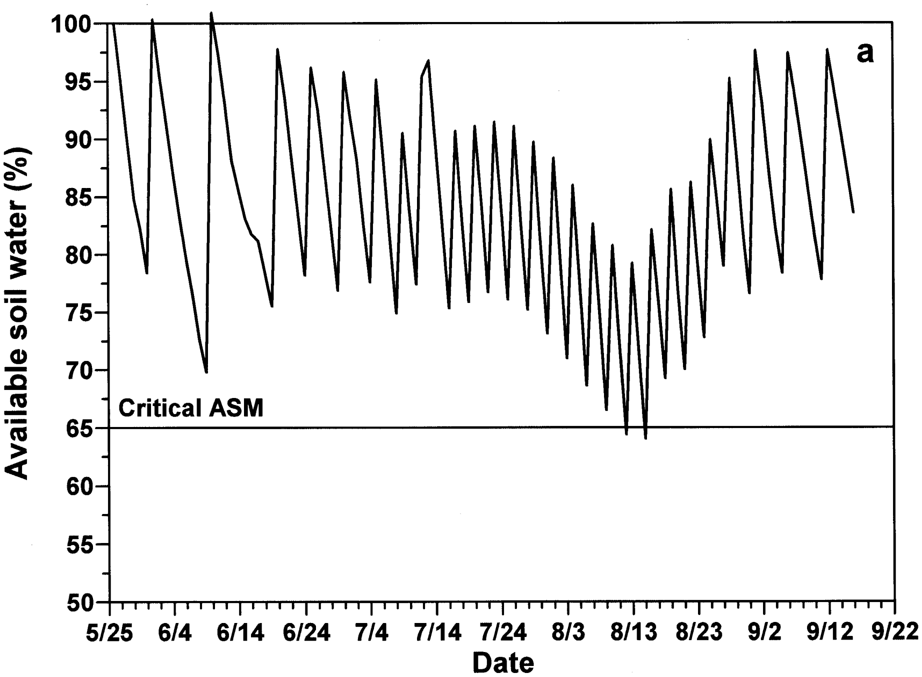
Howeve , in he second case, low ASW val es fall below ecom- mended limi s, es l ing in e iodic lan wa e s ess. When his occ s he e is no co ec ive co se of ac ion as sys em ca aciy is fi ed. The l ima e be y ield and aliy de end on he seasons clima ic condi ions as hey d ive daily ET.

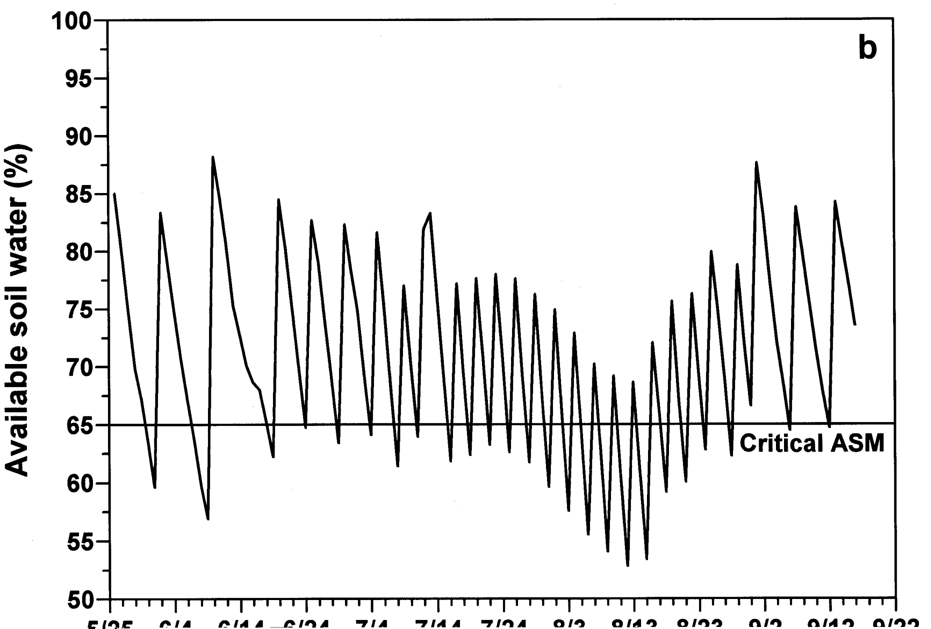
The na al endency is o s eed he cen e - ivo sys em when co wa e defici s (s ess) develo s. This ac ion only se ves o ed ce a lica ion efficiency beca se ET is inc eased by eva o a ion f om we soil and vege a ion. Inc easing he s eed of a cen e - ivo od ces ligh e a lica ions and mo e f e- en we ing of he soil and lan cano y, he eby inc easing he o al amo n of wa e los o eva o a ion and dec easing he amo n s o ed in he soil. Th s, sys em s eeds ho ld emain he same o be ed ced when co wa e defici s (s ess) develo . This will inc ease i iga ion efficiency by s o ing a g ea e e cen age of wa e a lied in he soil.

Mino changes in a lica ion efficiency can es l in a significan diffe ence in cen e - ivo sys em e fo mance. A 3 o 8 e cen diffe ence in a lica ion efficiency will occ be ween nigh ime and day ime i iga ion, es l ing in diffe ences in soil wa e s o age. As a es l , cen e - ivo s eed sho ld be adj s ed so ha o a ion ime is no a m l i le of 24 ho s. O he - wise, a eas of he field consis en ly wa e ed d ing he day ime will have 3 o 8 e cen less wa e s o ed in he soil fo co se. This small diffe ence acc m la ed ove ime can es l in wa e s essed a eas wi hin he field.

Conse va ion illage ac ices, s ch as basin o ese voi illage, a e e i ed o achieve o im m infil a- ion nifo miy wi h o a oes nde

cen e - ivo i iga ion. The hilling of
o a o lans ca ses Wa e o
concen a e in he f oW nde high





14. A

- **: ( ) 100% ( ) 85%**

- .

a lica ions o individ al lan s anging f om half o wice he field ave age (T o e al., 1994). Th s, f ow i iga ion canno achieve he deg ee of nifo m wa e a lica ion needed o od ce cons is en ly high q aliy be s on a comme cial field-s cale bas is .

A common f ow i iga ion ac ice fo o a oes is o i iga e al e na e f ows on each s cces-s ive i iga ion in an a em o ove come s ome of he diffic ly in a ly ing s mall i iga ion de hs . Cons eq en ly , only abo 15 e cen of he s oil s face is we ed and wa e is e ec ed o move wa d la e ally o we he whole oo zone. In he abs ence of a clay s oil o dens e s oil lay e s , g aviy ca s es wa e o move fas e down wa d han la e ally . Th s , a em s o com-le ely we he oo zone o he o of he hill a e s ally ns cces s f l and es l in e ces s ive dee e cola ion los s es . The la e al wa e dis ib ion oblem es l s in s ignifican va ia-ion in s oil wa e con en s , va y ing widely nea he f ow and emaining d y on hill o s .

A cons eq ence of he non-nifo m wa e dis ib ion be ween and along f ows is he wide va ia ion in ni ogen availabiliy d e o bo h d y s oil egions and leaching los s es . This ends o f he ed ce be q aliy nde f ow i iga ion and als o ed ces n ien s e efficiency .

Thes e limi a ions have ca s ed many od ce s o abandon f ow i iga ion in favo of s inkle i iga-ion. A common a oach is o ili ze a com le ely o able s inkle i iga ion sy s em fo o a oes , which can be moved a o nd he fa m acco ding o c o o a ion, and s ing f ow i iga ion fo he o he ow c o s . The advan ages of highe g os s income and ed ced is k wi h be e be q aliy , and highe wa e