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Comparative Performance Evaluation of Alternate and Convectional Furrow Irrigation under Different Water Application Level on Cabbage Water Use Efficiency and Economic Analysis

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Abstract: 0uit ble irrig tion metho! with pplic tion le/el is essenti l .or ! pt tion n! !option in the re s where w ter resources re limite!. ; here.ore(.iel! e2periment w s con!ucte! to test the per.orm nce o. ltern te .urrow irrig tion (%)' or))') n! con/ection l .urrow irrig tion (*)') with three w ter pplic tion le/el on crop(3iel! response(w ter use e..icienc3 n! cost bene.it n l3sis o. c bb ge. ; he e2periment h ! two . ctors(. ctori l !esign rr nge! in & n!omi?e! *omplete @loc: 1esign (&*@1) with nine tre tments o. three replic te. ; he tre tment n mel3 three .urrow 'rrig tion metho! ltern ti/e)urrow 'rrig tion (%)')( )i2e!)urrow 'rrig tion ())') n! *on/ection l)urrow 'rrig tion metho!s (*)') n! three pplic tion le/els .ull (100A)(three .orth 7BA n! h l. B0A o. .ull +;c (crop w ter reCuirement). ; he result shows * < 4+('< 4+ n! +<, were highl3 signi.ic ntl3 (, D0.01) ..ecte! b3 both '9s n! %=s. ; he highest n! the lowest me n crop n! irrig tion w ter use e..icienc3 (* < 4+ n! '< 4+)(n! economic w ter pro!ucti/it3 (+<,) were recor!e! b3 %)' n! *)' irrig tion. < here s(un!er %=s the highest n! the lowest me n * < 4+('< 4+ n! +<, were recor!e! b3 B0A n! 100A +;c %pplic tion !epth. 9 2imum w ter s /e! resulte! .rom %)' n!))'(with B0A(7BA n! 100A +;c pplic tion !epth w s eCu ll3 compute! s B#.33A(37.B0A n! 1"."7A which coul! irrig te !!ition l re o. 0.20(0."0 n! 1.40 h .or e ch tre tment respecti/el3. *ontr ril3 3iel! re!uction w s higher in))' .ollowe! b3 %)' n! *)' with the s me %=s. 7& (net return) pro!uce! per hect re w s higher in *)' .ollowe! b3 %)' n!))'. 'n c se o. @*&(%)' with 7BA n! B0A +;c w s higher th n))' .ollowe! n! the sm llest b3 *)' o. B0A n! 7BA +;c !e.icit le/el. - ence 3iel! re!uction n! 7& incurre! b3 ltern te (%)' n!))') were compens te! .rom !!ition l irrig ble re b3 !i/erting the w ter n! l bour s /e!. Eener ll3 .rom o/er ll in/estig tion o. * < 4+('< 4+(+<,(7& n! @*& ltern ti/e .urrow irrig tion metho! (%)') w s better th n))' n! *)' .or the w ter sc rce re .

Keywords: %ltern te)urrow 'rrig tion(1e.icit =e/els(* bb ge *rop(< ter 4se +..icienc3(+conomic %n l3sis

1. Introduction

'rrig te! griculture e2ten!s o/er 270 million hect res F1G. %lthough it represents onl3 17A o. the worl! culti/ te! re (it pro/i!es 40A to 4BA o. the worl! .oo! n! .iber suppl3 F2G. 'rrig te! griculture is the m jor consumer o. / il ble .resh w ter worl!wi!e n! its consumption is estim te! t H70A o. the e2isting .reshw ter supplies F2G. ; he competing uses .or w ter (!omestic(in!ustri l(n! en/ironment l) n! the incre sing !em n! .or .oo! !ue to r pi!l3 growing worl! popul tion reCuire n urgent impro/ement o. pro!ucti/it3 per unit o. w ter consume! in griculture F3G.

%bout I0A o. the irrig te! l n! o. the worl! is irrig te! using rel ti/el3 ine..icient sur. ce irrig tion metho!s F4G.

0imil rl3 in + ster +thiopi tr !ition l sur. ce irrig tion metho!s (b sin(bor!er n! .urrow) re wi!el3 use! to irrig te crops(though cute w ter short ge. 7ow ! 3 the mo!ern(high-tech n! e..icient micro irrig tion metho!s (!rip(bubbler(sprin:ler etc.) re !/oc te! worl!wi!e(howe/er; in !e/eloping countries li:e +thiopi is not ..or! ble(bec use o. high cost o. inst ll tion(oper tion n! m inten nce(n! reCuire! s:ille! m npower. ;hus see:ing .or e..icient irrig tion metho!s th t re economic l(e s3 to inst ll n! oper te(n! which re re !il3 ccept ble to the . rming communit3 is !em n!ing.

)urrow irrig tion(report32!w;8 6 (n) 6 (() - 3( ) - 1 00(r) - 5(e) - 2(p) - 6 or oic ois4(r) - 5(r 024) - oo t0 2ient wee - r7 - 5(

$$= 0."B\,810^{-3}\,8\,\sqrt{2g} \quad (1)$$

where; N is !isch rge .rom siphon tube (l s^{-1})(is re o. cross section(insi!e o. tube (cm^2)(g is cceler tion !ue to gr /it3 (cm sec^{-1}(I#1cm sec^{-2}) n! - is e..ecti/e he ! c using .low (cm).

;he e..ecti/e he ! w s c libr te! to be 12 cm n! hence the resulting !isch rge out o. the siphon tube w s 1.1B liters per secon!. ;his !isch rge w s selecte! in or!er to /oi! erosion(in ccor! nce e..ecti/e height n! llow ble m 2imum non erosi/e !isch rge s possible recommen!e! b3 F3G.

;he time reCuire! to !eli/er the !esire! !epth o. w ter in to e ch .urrow w s c lcul te! using the eCu tion recommen!e! b3 F1BG:

$$t = \frac{1_p 8 w 8 l}{3"08C} \quad (2)$$

where; 1_p is !epth o. w ter pplie! (cm)(t is pplic tion time (hr)(l is .low length (m) C is .low r te (l s^{-1}) n! w is .urrow sp cing (m).

2.4. Net and Gross Irrigation Water Requirement

* bb ge ( ) c n .lourish un!er irrig tion in the lower ltitu!es. 'rrig tion is st n! r! pr ctice in /eget ble crop li:e c bb ge. < ter nee!e! per irrig tion w s !etermine! s net !epth o. irrig tion w ter th t is reCuire! consumpti/el3 .or crop pro!uction. 't is the mount o. irrig tion w ter reCuire! to bring the soil moisture le/el in the e..ecti/e root ?one to .iel! c p cit3. ;hus it w s the !i..erence between the .iel! c p cit3 n! the soil moisture content in the root ?one be.ore st rting irrig tion. ;his is obt ine! b3 the rel tion gi/en below;

$$'_{net} = \frac{(0.c - 0i)P_b 8 1_r}{100} \quad (3)$$

where; $'_{net}$ is the net mount o. w ter to be pplie! !uring irrig tion (cm)($0_{.c}$ is the moisture content t .iel! c p cit3 in the root ?one b3 /olume (A)(0_i is .iel! moisture content be.ore irrig tion in the root ?one b3 /olume (A) i.e. 0-30 n! 30-"0 cm !epth(1_r is the !epth o. the root ?one (cm) rQ "0 cm n! bul: !ensit3 o. the soil in the root ?one (g cm^{-3}). Eross !epth o. irrig tion w ter ($'_{gr}$) eCu ls the net irrig tion !epth ($'_n$) !i/i!e! b3 the pplic tion e..icienc3 (+). ;he .ollowing eCu tion w s use! to compute gross irrig tion w ter reCuirement.

$$'_{gr} = \frac{'_n}{+} \quad (4)$$

;he .iel! w ter pplic tion e..icienc3 .or sur. ce .urrow irrig tion is norm ll3 t :en s "0A.

< ter s /ing with %)' n!))' comp re! to *)' w s c lcul te! s:

$$< 0(A) = \frac{(<_{*)'} - <_{)'/))'})}{<_{*)'}} 8100 \quad (B)$$

where < 0 is w ter s /e! $<_{*)'}$ is tot l w ter use! (mm) with the *)' metho! n! <% is tot l w ter use! (mm) with the %)' n!))' metho! n! mount o. w ter pplie! .or %)' n!))' w s eCu l.

,ercent o. 3iel! incre se/!ecre se in 3iel! (A) comp re! to the %)' or))' metho! w s compute! s

$$R_{'/1}(A) = \frac{(R_{*)'} - R_{\%)'/))})}{R_{*)'}} 8100 \quad (")$$

where $R_{'/1}$ is percent 3iel! incre se or !ecre se($R_{\%)'/))}$ n! $R_{)'*}$ re 3iel!s (:gh $^{-1}$) obt ine! with the %)'/))' n! *)' metho!s(respecti/el3.

2.5. Water Productivity

(1) *rop w ter use e..icienc3 (* < 4+): *rop w ter use e..icienc3 (* < 4+) or so-c lle! in other re.erences crop w ter pro!ucti/it3 (* < ,) w s compute! b3 !i/i!ing crop 3iel! b3 consumpti/e w ter use (net irrig tion).

$$* < 4+ = \frac{R}{*onsumti/e\ w\ ter\ pplie!\ to\ the\ .iel!\ (m^3)} \quad (7)$$

(2) 'rrig tion w ter use e..icienc3 (' < 4+): ' < 4+ (:g m^{-3}) w s !etermine! b3 !i/i!ing the 3iel! to se son l e/ potr nspir tion n! tot l se son l irrig tion w ter pplie!(n! c lcul te! b3 the .ollowing eCu tion:

$$' < 4+ = \frac{R}{;ot\ l\ \ w\ ter\ \ pplie!\ to\ the\ .iel!\ (m^3)} \quad (\#)$$

where < 4+ is w ter use e..icienc3 (:g m^{-3})(R is ctu l 3iel! (:g)(n! tot l (gross irrig tion) w ter pplie! to the .iel! (m^3) w s !etermine .rom +;c is se son l crop e/ potr nspir tion .rom the croppe! re .

(3) +conomic l w ter pro!ucti/it3: (+;@ m^{-3}) rel tes the economic bene.its per unit o. w ter use!. 't w s c lcul te! b3:

$$= \frac{\$utput\ (/\ lue)}{;ot\ l\ \ mount\ o.\ w\ ter\ consume!\ (m^3)} \quad (I)$$

where; <p is the economic w ter pro!ucti/it3 in +;@ m^{-3}(out-put is the pro!uct o. m r:et ble 3iel! n! m r:et price in +;@(n! w ter consume! in m^3. +;@ is +thopi n +;@

2.6. Cost Benefit Ratio and Net Return Analysis

;he cost n! bene.it o. e ch tre tment w s n l3?e! p rti ll3(3iel! n! economic ! t were compute! to comp re the !/ nt ge o. !i..erent .urrow irrig tion metho!s n! pplic tion le/els o. e ch tre tment. ;he tot l cost m inl3 inclu!es oper ting n! / ri ble costs. $per ting costs (l bor(l n! prep r tion(see!s(n! .ertili?ers n! implement costs) were b se! on the pl nte! re . > ri ble costs !epen!e! on the number o. irrig tion e/ents(l bour n! w ter unit price. ;he in!igenous . rmers in the stu!3 re !o not p 3 .or irrig tion w ter o. their . rms. ;here.ore ssumption w s

m !e .or the costs o. w ter unit price which w s estim te! to be 12.B +;@ m^{-3}. ;he m n-! 3 l bor cost w s B0 +;@ ! 3^{-1} to irrig te .iel!. ;ot l w ter cost .or se son w s c lcul te! b3 multipl3ing the w ter unit price b3 the tot l mount o. irrig tion w ter reCuire! .or c bb ge crop. Eross re/enue h s been c lcul te! b3 multipl3ing tot l 3iel! in :g h^{-1} o. c bb ge m r:et price per :ilogr m. ;he . rm-g te price .or c bb ge in this stu!3 w s 2.B +;@ :g^{-1} (/er ge! loc l price). 7et return (7&) n! bene.it-cost r tio (@*&) !ue to irrig tion were c lcul te! ccor!ing to F1"G s .ollows:

$$7\& = \text{Eross re/enue} - \text{;ot l cost} \quad (10)$$

;he bene.it cost r tio (@*&) in +;@ or +;@ me sures the incre se in net return (7&) which w s gener te! b3 tot l cost e2pen!iture (;*):

$$@*\& = \frac{7\&}{;*} \quad (11)$$

;he mount o. w ter s /e! (<0) per hect re o. l n! w s obt ine! b3 subtr cting con/ection l .urrow irrig tion with 100A +;c pplic tion le/els s control .or e ch tre tment. ;he net return .or !!ition l re (7&%) .or h r/este! m r:et ble 3iel! w s c lcul te! s the !i..erence between the sum o. the cost o. l bor .or inter ction o. irrig tion metho!s n! pplic tion le/els(the cost o. w ter th t w s s /e! .rom pplic tion le/els(n! the re/enue lost !ue to 3iel! !ecre ses resulting .rom this . ctor protocol is gi/en F17G s;

$$7\&\% = (E8=0\ S\ *8<0)M,8R= \quad (12)$$

where(7&% is 7et returns o. !!ition l re (+;@)(=0 is = bor s /e! .rom irrig tion s3stem (m n per ! 3)(<0 is >olume o. w ter s /e! ($m^3\ h^{-1}$)(R= is Riel! loss (:g h^{-1})(* is 4nit price per m^3 o. w ter(, is 4nit price per :ilogr m o. c bb ge 3iel! n! E is 4nit cost o. l bor per irrig tion per h

;he e2tr irrig ble l n! re which coul! be ser/e! b3 the irrig tion w ter s /e! per hect re w s !etermine! b3 !i/i!ing the tot l s /e! w ter per hect res o. l n! to be irrig te!(the e2tr l n! w s obt ine! b3 multipl3ing the ch nge in net income b3 the re s /e! F17G.

2.7. Statistical Analysis

%ll me sure! / ri bles were subjecte! to n l3sis o. / ri nce ppropri te .or &*@1. ;he ! t were n l3?e! using Eenst t $1B^{th}$ e!ition st tistic l so.tw re. ;he me n sep r tion w s m !e using .isher protecte! list signi.ic nt !i..erence (=01) metho!.

3. Result and Discussion

3.1. Water Productivity

3.1.1. Crop Water Use Efficiency (CWUE)

;he outcome o. st tistic l n l3sis in!ic tes th t *<4+ / rie! highl3 signi.ic ntl3 (,D0.01) in.luence! b3 both irrig tion metho!s ('9s) n! pplic tion le/els (%=s). ;he highest / lue pro!uce! w s 2I.B3 :g m^{-3} b3 %)'(n! the lowest w s recor!e! b3 *)' s 2".4# :g m^{-3}(but when comp re! %)' with))' there were no signi.ic nt !i..erence between them. %pplic tion le/els show th t(*<4+ signi.ic ntl3 incre se! when irrig tion mount or !epth !ecre se!. 0imil rl3 the result .or %=s shows th t(the highest / lue o. crop w ter use e..icienc3 o. 3B.I3 :g m^{-3} w s obt ine! b3 %=s o. B0A +;c .ollowe! b3 7BA +;c s 2".I0 :g m^{-3} n! 22.07 :g m^{-3} t 100A +;c correspon!ingl3 (; ble 1).

't is lso e/i!ent th t(t e ch irrig tion metho!s(the *<4+ incre se! with !ecre sing the w ter pplic tion le/el(comp r ti/el3(when goes .rom 100A +;c to B0A o. +;c %=s the / lue obser/e! s 13.#" :g m^{-3} !i..erence (; ble 1).

Table 1. . . .

Irrigation method	CWUE	Application level	CWUE
%)'	2I.B3	100 A +;c	22.07[c]
))'	2#.I0	7B A +;c	2".I0[b]
*)'	2".4#[b]	B0 A +;c	3B.I3
=01 (BA)	1.232		1.232

*<4+ (:g m^{-3}): *rop w ter use e..icienc3(=01: =e st signi.ic nce !i..erence(7ote: me ns .ollowe! b3 the s me in column h /e not signi.ic nt !i..erence

3.1.2. Irrigation Water Use Efficiency (IWUE)

;he n l3sis o. / ri nce(showe! th t '<4+ were highl3 signi.ic ntl3 (,D0.01) in.luence! b3 both '9s n! %=s. ;he obser/ tion .rom ; ble 2 opine! th t irrig tion w ter use e..icienc3 w s !ecre se! signi.ic ntl3 .rom 17.72 to 1B.#I :g m^{-3}(.or %)' n! *)' respecti/el3(but st tistic ll3 me n o. '<4+ pro!uce! b3 %)' n!))' were not signi.ic ntl3 !i..erent. '<4+ w s lso ..ecte! b3 pplic tion le/els(n! the highest / lue w s recor!e! s 21.B" :g m^{-3} b3 B0A +;c .ollowe! b3 7BA +;c (1".14 :g m^{-3})(where s 13.24 :g m^{-3} t 100A +;c !e.icit le/els in !ecre sing or!er.

;his result in!ic tes *<4+ n! '<4+ rel te! to the mount o. w ter supplie! h s in/erse rel tion with 3iel! obt ine! s .ormul te! pre/iousl3 in eCu tion 7 n! #.

Table 2. . . .

Irrigation method	IWUE	Application level	IWUE
%)'	17.72	100 A +;c	13.24[c]
))'	17.34	7B A +;c	1".14[b]
*)'	1B.#I[b]	B0 A +;c	21.B"
=01 (BA)	0.73I		0.73I

'<4+: (:g m^{-3}) 'rrig tion w ter use e..icienc3(+;c: +/ potr nspir tion o. crop(=01: =e st signi.ic nce !i..erence(7ote: me ns .ollowe! b3 the s me in column re not signi.ic ntl3 !i..erent

3.1.3. Economic Water Productivity (EWP)

;he n l3sis o. / ri nce re/e le! th t economic w ter pro!ucti/it3 w s highl3 signi.ic ntl3 (,D0.01) in.luence! b3 both irrig tion metho!s ('9s) n! pplic tion le/els (%=s). ;he result in!ic tes th t me n m 2imum economic w ter pro!ucti/it3 / lue .or %)' obt ine! s "4.2" +;@ m^{-3}(which h ! no signi.ic nt !i..erent .rom .i2e! .urrow irrig tion metho!s n! the me n minimum +<, w s recor!e! b3 *)' s B7."B +;@ m^{-3} (; ble 3).

127 5em l 7ur - ssene n! 9u:erem ; h 0ei!: *omp r ti/e ,er.orm nce +/ lu tion o.%ltern te n! *on/ection l)urrow 'rrig tion un!er 1i..erent < ter%pplic tion =e/el on * bb ge < ter 4se +..icienc3 n! +conomic%n l3sis

Table 3. . *EI R P P*

3.2.2. Effect of Irrigation Methods and Application Levels on Water and Land Productivity

;he result in!ic te! th t w ter s /e! .rom tre tment combin tion o. %)' n!))' with 100A +;c(7BA n! B0A +;c le/els were 1"."7 A(37.BA n! B#.33A o. tot l net /olume o. irrig tion w ter pplie!. <here s *)' with 7BA n! B0A pplic tion obt ine! 2BA n! B0A respecti/el3.

*)' with 100A +;c pplic tion !epth recor!e! m 2imum 3iel! bec use this tre tment recei/e! .ull crop w ter reCuirement(hence no 3iel! re!uction obser/e!. <here s %)' n!))' with 100A +;c 3iel! re!uction w s less th n 10A(which w s in!ic te! s I.4 n! 7.BA(respecti/el3 when comp re! with no w ter stresse! (*)' with 100A +;c). -owe/er %)' n!))' with 100A %=s were s /e! 1"."7A w ter .rom e ch tre tment (; ble B)(which coul! irrig te bout 0.2 h (; ble ").

@ut un!er plot o. 7BA +;c pplic tion !epth or 2BA stresse! tre tment o. %)'( ))' n! *)' were in!ic te! th t signi.ic nt 3iel! re!uction s 1".3A(21.2A n! I.7A respecti/el3. %s presente! in ; ble B tot l mount o. net /olume o. irrig tion w ter s 37.BA (1BB3.40 m^3) .rom %)'( ))' o. e ch tre tment n! 2BA (103B."0 m^3) .rom *)' w s s /e!. -ence w ter s /e! .rom %)'( ))' n! *)' with 7BA %=s coul! irrig te 27A (1.B3 h) o. tot l !!ition l re (; ble "). ;he result in!ic tes c bb ge per.orm nce un!er this !e.icit le/el w s better in con/ection l .urrow irrig tion (*)') .ollowe! b3 %)' n!))' with 7BA %=s correspon!ingl3.

%ccor!ingl3 .or tre tments with B0A +;c pplic tion le/el(3iel! re!uction w s higher when comp re! to 7BA +;c s presente! in (; ble B). ;he 3iel! re!uction in ccor! nce to pplic tion le/el w s incre se! s 22.0(24.3 n! 2".1A b3 *)'(%)' n!))' with B0A +;c respecti/el3. ;his is bec use the c bb ge stresse! b3 h l. (B0A) net crop w ter reCuirement which resulte! in m 2imum 3iel! re!uction comp re! to norm l or .ull w ter pplic tion. -owe/er "" A o. w ter s /e! coul! irrig te tot l !!ition l re o. 3.# h . ;his cle rl3 shows th t 3iel! re!uction resulte! .rom both irrig tion metho!s n! pplic tion le/els coul! be compens te! b3 !!ition l irrig ble re to be culti/ te!.)rom economic point o. /iew 3iel! obt ine! .rom tot l !!ition l irrig ble re (B.73 h) coul! pro!uce 32B.I tons o. m r:et ble c bb ge 3iel! (; ble ").

Table 5. . . . . .

Treatment combination	Marketable yield (kg ha^{-1})	Yield reduction (kg ha^{-1})	Yield eduction (%)	I_n (m^3 ha^{-1})	Water saved from I_n (m^3 ha^{-1})	Water save in (%)
%)' 100A +;c	"B304.4	"7"2.2	I.4	34B2.0	"I0.40	1"."7
%)' 7BA +;c	"0333.3	11733.3	1".3	2B#I.0	1BB3.40	37.B0
%)' B0A +;c	B4BBB."	17B11.1	24.3	172".0	241".40	B#.33
))' 100A +;c	"""BB."	B411.1	7.B	34B2.0	"I0.40	1"."7
))' 7BA +;c	B"#11.1	1B2BB."	21.2	2B#I.0	1BB3.40	37.B0
))' B0A +;c	B32BB."	1##11.1	2".1	172".0	241".40	B#.33
*)' 100A +;c	720"".7	0.0	0.0	4142.4	0.00	0.00
*)' 7BA +;c	""377.#	B"##.I	7.I	310".#	103B."0	2B.00
*)' B0A +;c	B"200.0	1B#"".7	22.0	2071.2	2071.20	B0.00

3.3. Cost Benefit and Economic Analysis

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7et return .rom !!ition l irrig ble re !ue to w ter s /e! .rom irrig tion metho!s n! pplic tion le/els o. c bb ge pro!uction estim te! ccor!ing to w ter pplie! .or e ch tre tment. ; ble " in!ic tes th t the net return (7&) compute! .rom the w ter n! l bor s /e! o. e ch tre tment n! !et il c lcul tion o. net income or return g ine! .rom !!ition l irrig ble re o. e ch tre tment re presente!. ;he result in!ic tes th t the highest net return obser/e! in ltern ti/e irrig tion metho! with B0A +;c pplic tion le/el n! the lowest net return w s obt ine! .rom *)' with 7BA +;c pplic tion le/el. <ith the s me /ein(*)' with 7BA +;c pplic tion le/el resulte! in lowest w ter s /e! n! irrig ble re comp re! to %)' n!))' o. the s me %=s. 't cle rl3 seen th t the / lue o. net return gener te! w s in.luence! not onl3 b3 w ter pplie! but lso .urrow irrig tion metho!s.

$n the other h n!(*)' with 100A +;c w s use! s control .or ll tre tment. ;he result shows the w ter s /e! .rom %)' n!))' with 100A +;c or with .ull irrig tion onl3 .oun! out .rom the two other .urrows rem in !r3 until the ne2t irrig tion sche!ule .or %)' n!))' with their pplic tion. %ccor!ingl3 the !!ition l re to be irrig te! o. e ch tre tment w s c lcul te! b se! on the mount o. w ter pplie! n! the r tio o. tot l w ter pplie! .or non-stresse! tre tment (*)' with 100A +;c) to stresse! tre tments. =i:ewise(the tot l !!ition l re obt ine! w s con/erte! to hect re .rom e ch tre tment s bout B.73 h (which coul! be irrig te! b3 tot l w ter s /e! o. 20712.02 m^3 per hect re with tot l l bor s /e! show in ; ble ".

Table 6. . . . .

Treatment	MHY *100	I_g (*100)	WS (m^3) *100	A. A irrig. by WS	YG of A. A (*100)	G* LS (*100)	C*W S (*100)	TC(*100)	TR(*100)	NR due to AA *100
;$_1$	"B.30	B7.B3	11.B1	0.20	130."1	B.#	143.#	1"7.7	32".B	1B#.#
;$_2$	"0.33	43.1B	2B.#I	0."0	3"2.00	13.1	323."	3I1.0	I0B.0	B14.0
;$_3$	B4.B"	2#.77	40.27	1.40	7"3.7#	20.4	B03.4	"B0.4	1I0I.4	12BI.1
;$_4$	"."."	B7.B3	11.B1	0.20	133.31	B.#	143.#	1"7.7	333.3	1"B.B
;$_B$	B".#1	43.1B	2B.#I	0."0	340.#7	13.1	323."	3I1.0	#B2.2	4"1.2
;$_"$	B3.2"	2#.77	40.27	1.40	74B.B#	20.4	B03.4	"B0.4	1#"3.I	1213."

Treatment	MHY *100	I_g (*100)	WS (m^3) *100	A. A irrig. by WS	YG of A. A (*100)	G* LS (*100)	C*W S (*100)	TC(*100)	TR(*100)	NR due to AA *100
;7	72.07	"I.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
;#	"".3#	B1.7#	17.2"	0.33	221.2"	#.7	21B.#	2B4."	BB3.1	21#.B
;I	B".20	34.B2	34.B2	1.00	B"2.00	17.B	431.B	B3I.4	140B.0	#"B."
;ot l			207.12	B.73	32BI.40	104.I	2B#I.0	3212.2	#14#.B	413".3

7ote: '$_g$: Eross irrig tion per h in m^3(%.%: %!!ition l re irrig te!(9 -R: 9 r:et ble he ! 3iel! in ton h^{-1}(=0: = bor s /e! .rom irrig tion s3stem(<0: >olume o. w ter s /e! in m^3 per h (RE: Riel! g ine! .rom %.% in :g h^{-1}(*: 4nit price per m^3 o. w ter (*Q12.B +;@) n! ,: 4nit price per :g o. c bb ge he ! (,Q2.B +;@ :g^{-1})(E: = bor per irrig tion per h (EQB0 +;@ ! 3^{-1})(;&: ;ot l return in +;@ h^{-1}(;*: ;ot l cost in +;@ h^{-1} n! 7&: 7et return in +;@ per hect re o. !!ition l re . (- int: ll / lues re multiple o. 100 e2cept !!ition l re to be irrig te!)

)in ll3 ; ble 7 in!ic te! th t @*& (bene.it cost r tio) o. c bb ge w s compute! .or e ch tre tment combin tion s the r tio o. 3iel! e rne! to the cost e2pen!e!. %ccor!ingl3(tre tments))'(%)' n! *)' with 100A +;c w ter pplic tion le/el h ! the lowest @*& s 0.II(0.I n! 0.#2 respecti/el3. @ec use those tre tments cost o. pro!uction higher s comp re! to 3iel! obt ine!.

9oreo/er tre tment combin tion o. 7BA %=s(the highest @*& w s tt ine! b3 %)' n! the lowest w s recor!e! un!er *)'(s presente! in ; ble 7. ;he other rem ining tre tments were occupie! in between l rgest n! the sm llest / lue o. @*&. ;his implie! th t the w ter s /e! with incorpor tion o. both combine! . ctor o. ('9s n! %=s) h ! n in!ic tor .or n l3sis o. @*& .rom !!ition ll n! / il ble.

;here.ore the net re!uction in bene.it !ue to 3iel! re!uction o. e ch tre tment w s compens te! b3 net bene.it g ine! .rom 3iel! obt ine! b3 !!ition l re culti/ te! with l bour n! w ter s /e! with the s me criteri n! con!ition !etermine!. %mong !i..erent irrig tion tre tments(ltern te .urrow irrig tion (%)' with 7BA) h ! the better 3iel! n! the optimum @*& when comp re! with))' n! *)' with the s me pplic tion.

Table 7.

Treatment	Water applied m^3 ha^{-1}	Cost of labor and water (VC)	Operation cost (FC)	Total cost (TC) in ETB ha^{-1}	Marketable yield(kg ha^{-1})	Gross Revenues (GR) in ETB	Net Return (NR) in ETB	BCR
;1	B7B3.3	74#30.03	I040.0	#3#70.0	"B304.44	1"32"1.1	7I3I1.1	0.I4
;2	431B.0	B"122.B2	I040.0	"B1"2.B	"0333.33	1B0#33.3	#B"70.#	1.31
;3	2#7".7	3741B.01	I040.0	4"4BB.0	B4BBB.B"	13"3##.I	#II33.I	1.I4
;4	B7B3.3	74#30.03	I040.0	#3#70.0	"""BB.B"	1"""3#.I	#27"#.I	0.II
;B	431B.0	B"122.B2	I040.0	"B1"2.B	B"#11.11	142027.#	7"#"B.3	1.1#
;"	2#7".7	3741B.01	I040.0	4"4BB.0	B32BB.B"	13313#.I	#""#3.I	1.#7
;7	"I04.0	#I7I".04	I040.0	I##3".0	720"."7	1#01"".7	#1330."	0.#2
;#	B17#.0	"7347.03	I040.0	7"3#7.0	""377.7#	1"BI44.4	#IBB7.4	1.17
;I	34B2.0	44#I#.02	I040.0	B3I3#.0	B"200.00	140B00	#"B"2.0	1."0

@*&: @ene.it cost r tio(>*: > ri ble cost (+;@ h^{-1}) n!)*:)i2e! cost (+;@ h^{-1})(;1(;2 n! ;3 .or pplic tion le/el o. (%)') with 100A(7BA n! B0A +;c respecti/el3(;4(;B n! ;" .or pplic tion le/el o. ())') with 100A(7BA n! B0A +;c respecti/el3: ;7(;# n! ;I .or pplic tion le/el o. (*)') with 100A(7BA n! B0 A +;c respecti/el3(+;@: +thiopi n @irr (- int the home currenc3 up to the p per o. completion is 1 +;@ Q 0.04B 40 T)

4. Discussion

4.1. Water Productivity

rop w ter use e..icienc3 (< 4+): *omp ring the results o. the three irrig tion metho!s .rom the point o. crop w ter use e..icienc3(it cle rl3 con.irme! th t(ltern te .urrow irrig tion .ollowe! b3 .i2e! .urrow irrig tion n! con/ention l .urrow irrig tion h ! more bene.ici l use o. w ter respecti/el3. ;his result re/e le! th t incre sing w ter pplic tion !ecre ses w ter use e..icienc3 o. crop. ;he results gree with F1#G F1IG who reporte! th t * < 4+ / lues !ecre se! with incre sing w ter use. $n the other h n!(.or ll irrig tion metho!s(s pplic tion le/els incre se! the * < 4+ !ecre ses(this pro/e th t s !epth o. pplic tion incre se w ter lose b3 1ee percol tion(sur. ce runo.. n! e/ por tion incre se r ther th n w ter utili?e! b3 crop. %ccor!ingl3 F20G reporte!(th t crop w ter use e..icienc3 .or ltern te .urrow irrig tion subst nti ll3 incre se! s comp re! with con/ention l .urrow irrig tion .or corn.

'rrig tion w ter use e..icienc3 (' < 4+): ;he result reporte! b3 F21G un!er controlle! en/ironment stu!3 with m i?e(p rti l root ?one irrig tion pplie! t the jointing st ge re!uce! w ter consumption b3 12A n! enh nce! < 4+ b3 12A. 0ome uthor con.irme! th t signi.ic nt impro/ements in ' < 4+ h /e been ssoci te! with %)' F22G n! F23G. 0imil rl3 F24G !emonstr te! th t ' < 4+ incre se! with !ecre se in irrig tion w ter. 9oreo/er F2BG .or Uel! grown pot to showe! th t comp re! with)' (.ull irrig tion)(,&1 (p rti l root !r3ing) tre tment s /e! 30A o. w ter n! incre se! w ter use e..icienc3. 'n contr st to this stu!3 F2"G .oun! th t ' < 4+ w s highest in the .ull irrig te! tre tment. 'n gener l(!i..erences between this stu!3 n! bo/e cite! stu!ies m 3 be !ue to !i..erences in the pl nt / riet3 use!(gro-clim tic con!itions o. the region n! culti/ tion perio!s.

+conomic w ter pro!ucti/it3 (+<,): ;he re son behin! this result is th t(economic w ter pro!ucti/it3 relies on the r tio o. 3iel! con/erte! to / lue (c sh) o. m r:et ble 3iel! obt ine! b3 the mount o. w ter pplie! on /olume b sis. ;hus B0A +;c h ! le st w ter pplic tion !epth n! lso rel ti/el3 lower 3iel! pro!uce!(this resulte! in superior

economic w ter pro!ucti/it3. ;he re/iewe! liter ture lso con.irme! the s me i!e o. w ter pro!ucti/it3 is consi!er bl3 incre se! b3 using %,&1 (ltern ti/e p rti l root !r3ing) on !i..erent crops F2BG F27G. F2#G lso reporte! th t ,&1 signi.ic ntl3 re!uce! 3iel! b3 24A(while <, (w ter pro!ucti/it3) incre se! b3 B2A comp re! with the)' (.ull irrig tion). F2IG reporte! th t <, un!er !e.icit irrig tion r nge! .rom minimum o. 1" :g m^{-3} in)' to m 2imum o. 21.B :g m^{-3} in ,&1 with B0A pplic tion le/el tre tments.

4.2. Significance of Irrigation Method and Application Levels on Cabbage Yield Optimization and Net Return

0igniUc nce o. &esults: ;his stu!3 presents e2plicitl3 in/estig te! w ter pro!ucti/it3 o. c bb ge un!er !i..erent .urrow irrig tion metho!s n! pplic tion le/els. -ence(this le !s or !/ nces to Cu li.3 best .urrow irrig tion s3stems(while pro/i!ing .r mewor: .or ssessing potenti l .uture tr nsitions o. .urrow irrig tion metho!s(s li:el3 re!ucing w ter reCuirement in /iew o. pro!ucing optimum 3iel! to meet incre sing in .oo! !em n! t w ter sc rce re especi ll3 .or !e/eloping countr3. Eener ll3(it h s been ssume! th t economic n! gronomic control or w ter m n gements b3 impro/ing e2isting sur. ce irrig tion metho!s inclu!ing optimum pplic tion le/els with mo!est 3iel! re!uction c n impro/e net returns .rom !!ition l irrig ble re .

)rom sust in bilit3 perspecti/e(the prim r3 objecti/e o. this stu!3 whether .urrow irrig tion o/er!r .t the re!uction o. irrig tion w ter consumption to m 2imi?e culti/ tion l n! with little 3iel! loses when comp re! with cultur l or norm l pr ctice n! optimi?e w ter pro!ucti/it3. < ter s /e! through impro/e! irrig tion s3stems coul! llow .or n e2p nsion o. culti/ tion l n! n! incre se crop pro!uction in w ter limite! re .) rmersV !ecisions re o.ten !ri/en b3 m 2imi?ing their return n! r rel3 b3 en/ironment l concerns; i. the3 pursue e..orts to s /e w ter(!o the3 o.ten use it to e2p n! their irrig te! re s or shi.t to higher / lue crops(r ther th n losing w ter lloc tion F30G F31G.

ost bene.it n! +conomic n l3sis: -ence b3 using o. ppropri te irrig tion metho!s n! pplic tion le/els were better .or higher 3iel! n! coul! be economic ll3 ttr cti/e to incre se crop pro!uction n! pro!ucti/it3 t w ter sc rce or limite! w ter n! !rought susceptible re s. 0umming up in terms o. 7& n! @& ltern ti/e .urrow irrig tion show better when comp re! with))' n! *)' with s3non3mous pplic tion le/el. ;he report gree! n! sh re! with F3"G F37G F3#G whom recommen! th t mongst the &1' (regul te! !e.icit irrig tion) ppro ches(ltern te p rti l root-?one irrig tion h s been .oun! to be most e..ecti/e n! e..icient in s /ing w ter n! impro/ing <4+ while m int ining crop pro!ucti/it3.

5. Conclusion

;his stu!3 !/oc tes th t the techniCue o. ltern te .urrow irrig tions were subst nti ll3 s /e! w ter th n con/ection l .urrow irrig tion metho! in .iel! con!itions un!er w ter pplic tion le/el.)rom the result w ter s /e! ltern te .urrow (%)' n!))') irrig tion with B0A +;c %=s coul! s /e B#.33A o. tot l net /olume o. irrig tion w ter pplie!. <ith respect to ph3sic l w ter use e..icienc3 n! economic w ter pro!ucti/it3(summ ri?e! s .ollow: 9e n m 2imum n! minimum *<4+('<4+ n! +,< were recor!e! b3 %)' n! *)' respecti/el3.)or %=s crop n! irrig tion w ter use e..icienc3 n! +<, were incre sing .rom 100A +;c (.ull irrig tion) to B0A +;c. 'n the c se o. net return (7&) n! bene.it cost r tio (@*&) inter ction o. (n! *)')(un!er 100A +;c(the highest w s pro!uce! b3 ltern te .urrow (%)' n!))') irrig tion higher th n *)'(un!er ll w ter pplic tion !epth.)in ll3 the .in!ing in!orses th t . rmers c n pr ctice either ltern te .urrow irrig tion (%)' n!))') with o. 100A pplic tion le/el or *)' with 7BA +;c s best option(this w s i!enti.ie! s negligible 3iel! re!uction o. less th n 10A s comp re! to e/er3 or con/ection l .urrow irrig tion with .ull w ter pplic tion. %nother ltern ti/e option w s obser/e! %)' metho! in!ic tes best @*& which pre.erenti ll3 selecte! t 100A n! 7BA !e.icit le/el o/er))' with the s me !e.icit le/el.

References

F1G 9orison(5. '. =.(7. &. @ :er(,. 9. 9ulline u2(n! <. 5. 1 /ies. 200#. 'mpro/ing w ter use in crop pro!uction. ,hil. ;r ns. &o3 l 0oc. @ 3"3: "3IM"B#.

F2G +/ ns(&. E. n! +. 5. 0 !ler. 200#. 9etho!s n! technologies to impro/e e..icienc3 o. w ter use. < ter &esources &es. 44: 1M1B.

F3G)oo! n! %griculture $rg ni? tion o. the 4nite! 7 tions. 2002. *rops n! !rops: 9 :ing the best use o. w ter .or griculture 7 tur l &esources +n/iron. 1ept.( )%$(&om.

F4G ;iercelin(5. &.(>i! l(%.(200". ;r iteW!V'rrig tion(X 2n! +!. , ris( )r nce.

FBG @urt(*. 9.(*lemmens(%. 5.(0trel:o..(;. 0.(0olomon(J. -.(@liesner(&. 1.(- r!3(=. %.(-owell(;. %.(+isenh uer(1. +.(1II7. 'rrig tion per.orm nce me sures: e..icienc3 n! uni.ormit3. 5. 'rrig. 1r in. +ng. 123(423M442.

F"G %mp s(>.(@ lt s(+.(200I. $ptimi? tion o. the .urrow irrig tion e..icienc3. Elob. 7+0; 5. 11 (4)(B""MB74.

F7G 1u(;. 0.(J ng(0. Y.(0un(5. 0.(Yh ng(Z. R.(Yh ng(5. -.(2010. %n impro/e! w ter use e..icienc3 o. cere ls un!er tempor l n! sp ti l !e.icit irrig tion in north *hin . %gric. < ter 9 n g. I7 (1)(""M74.

F#G -orst(9. E.(0h mut lo/(0. 0.(,ereir (=. 0.(Eonc l/es(5. 9.(200B.)iel! ssessment o. the w ter s /ing potenti l with .urrow irrig tion in)erg n (%r l 0e b sin. %gric. < ter 9 n g. 77 (1M3)(210M231.

FIG 9 shori(%. 0.(2013. +/ lu tion o. the per.orm nce o. the ltern te .urrow irrig tion un!er clim tic con!itions o. 0in!h. 'n: 9. +. ;hesis. 0in!h %griculture 4ni/ersit3(; n!oj m(, :ist n 9itchell(5. ,.(0henn n(*.(Er tt n(0. &. [9 3(1. 9.(;om to .ruit 3iel!s n! Cu lit3 un!er w ter !e.icit n! s linit3. 5 %mer 0oc -ort 0ci(11"(pp. 21B-221(1II1.

F10G 9itchell(5. ,.(0henn n(*.(Er tt n(0. &. [9 3(1. 9.(;om to .ruit 3iel!s n! Cu lit3 un!er w ter !e.icit n! s linit3. 5 %mer 0oc -ort 0ci(11"(pp. 21B-221(1II1.

F11G @ehbou!i n(9. -. [9ills(;. 9.(1e.icit irrig tion in !eci!uous orch r!s. -ort &e/(21(pp. 10B-131(1II7.

F12G 0l tni(%.(Y 3 nib(J.(Y iri (%.(R coubi (0.(0 l/ !orc(&. [,l 3\nc(+.(%ssessing ltern te .urrow str tegies .or pot to t the *her.ech irrig tion !istrict o. ;unisi . @ios3stems +ngineering(10#(2)(pp. 1B4-1"3(2011.

F13G 7elson(1. 5. [%l-J isi(9. 9.(%gronomic n! economic e/ lu tion o. / rious .urrow irrig tion str tegies .or corn pro!uction un!er limite! w ter suppl3. 5ourn l o. 0oil n! < ter *onser/ tion(""(2)(pp. 114-120(2011.

F14G 9ich el(%. 9. 1II7. 'rrig tion ;heor3 n! ,r ctice. , shur ti ,rinters(1elhi.

F1BG 'sr elsen($. <.(n! >. +. - nsen. 1I#0. 'rrig tion ,rinciples n! ,r ctices. 5onsen <ile3 n! 0ons('nc. 7ew Ror:(=on!on

F1"G =i(%.(+. +neji(=. 1u n(0. 'n n g (n! Y. =i. 200B. 0 /ing irrig tion w ter .or winter whe t.

F17G -orton 1.(1I#2. , rti l bu!get n l3sis .or on . rm pot to rese rch. ;echnic l in.orm tion bulletin 1". 'ntern tion l pot to center. =im (,eru with phosphorus pplic tion the north *hin pl in. 5ourn l o. ,l nt 7utrition 2#: 2001-2010.

F1#G Een]ogl n(*.(n! %. R ? r. 1III. ;he e..ects o. !e.icit irrig tions on corn 3iel! n! w ter use e..icienc3. ;ur:ish 5. %gric.)orest. 23: pp 233M241.

F1IG Yel lem shelemew. 201B. &esponse o. m i?e to !e.icit irrig tion un!er three .urrow irrig tion s3stems in ! mi tulu ri.t / lle3 *entr l +thiopi . 9. 0*. ;hesis. %lem 3 4ni/ersit3(+thiopi .

F20G %w ! %b! +l-- lim. 2013. 'mp ct o. ltern te .urrow irrig tion with !i..erent irrig tion inter/ ls on 3iel!(w ter use e..icienc3(n! economic return o. corn. *hile n 5ourn l o. %gricultur l &ese rch 73(2) %pril-5une 2013. ; nt 4ni/ersit3( ) cult3 o. %griculture(; nt (+g3pt.

F21G =i)(*. <ei( ). Yh ng(5. Yh ng(9. 7ong(0. J ng. 2010 . < ter-use e..icienc3 n! ph3siologic l responses o. m i?e un!er p rti l root-?one irrig tion. %grc(< ter 9 n g I7: 11B"M11"4. !oi:10.101"/j. gw t.2010.01.024.

F22G Yh ng(5.(0. J ng(Y. =i ng.(R. Y. , n(,. 0hi(R. -. , n(Y. 0. =i ng(Z. ;. -u(2000. 0oil w ter !istribution(uni.ormit3 n! w ter use e..icienc3 un!er ltern te .urrow irrig tion in ri! re s. 'rrig. 0ci. 1I: 1#1-1I0.

F23G J ss w @esh w. 2011. +/ lu tion o. ltern te n! surge .low .urrow irrig tion metho!s .or onion pro!uction t humbo(southern +thiopi . 9sc.thesis(- r m 3 4ni/ersit3(- r m 3

F24G Jirn : -.(0. 1emir('. ; s(9. * :m :li. 2002. &esponse o. !i..erent irrig tion w ter pplic tions on 3iel! n! growth o. lettuce grown in greenhouse. 5 %gric) c - rr n 4ni. "(1-2)(47-B4.

F2BG 0h hn ? ri(%.(=iu( ).(%n!ersen(9. 7.(5 cobsen(0. +.(5ensen(*. &.(2007. +..ects o. p rti l root-?one !r3ing on 3iel!(tuber si?e n! w ter use e..icienc3 in pot to un!er .iel! con!itions.)iel! *rops &ese rch(100: 117-124.

F2"G J ! 3W.cW %(E'. ;u3lu(R. 4] r(@. ^ :m :. 2004. +..ects o. mulch n! irrig tion w ter mounts on lettuce s 3iel!(e/ potr nspir tion(tr nspir tion n! soil e/ por tion in 'sp rt loc tion(;ur:e3. 5ourn l o. @iologic l 0cience 4("): 7B1-7BB.

F27G %hm !i(0. -.(9. 7(%n!ersen( ).(,l uborg(&. ;.(,oulsen(*. &.(%. &.(5ensen(0ep s:h h(0.(- nsen(2010b. +..ects o. irrig tion str tegies n! soils on .iel! grown pot toes: Riel! n! < ter ,ro!ucti/it3. %gricultur l < ter 9 n gement(1$' 10.1`01"/j. gw t.2010.07.007.

F2#G Eu ng-*heng(0.(Yh n-Ru (Y.(7 c(=.(0hu ng-+n (R.(<eng-E ng (Z.(200#. *omp r ti/e e..ects o. !e.icit irrig tion (1') n! p rti l root ?one !r3ing (,&1) on soil w ter !istribution(w ter use(growth n! 3iel! in greenhouse grown hot pepper. 0cienti -orticultur e(11I: 11-1".

F2IG 9 n!e.ro *h l n! Jo:obe </Roh nnes. 201B. +..ect o. irrig tion pplic tion le/els on 3iel! n! w ter pro!ucti/it3 o. !rip irrig te! lettuce (= ctuc s ti/ l.)(Ee!io ?one(southern +thiopi . 'ntern tion l journ l o. b sic n! pplie! sciences /ol. 4. 7o. 4 201B. ,p. 22I-234 (online /ersion / il ble t: www.cr!eep.com)

F30G ,.ei..er =. n! R. *. =in. 2014. 1oes e..icient irrig tion technolog3 le ! to re!uce! groun!w ter e2tr ctiona +mpiric l e/i!ence(5. +n/iron. +con. 9 n g. "7(1#IM20#(&oi: 10.101"/j.jeem.2013.12.002(3BI"(3"1B.

F31G 0h h(;. 2014. Eroun!w ter go/ern nce n! irrig te! griculture(;+* b c:groun! p pers no. 1I(;ech. &ep. 1I(Elob l < ter , rtnership ;echnic l *ommittee(0toc:holm(0we!en. ,p. 3"1B.

F32G =i-0ong ; ng(R n =i(5i nhu Yh ng. 200B. ,h3siologic l n! 3iel! responses o. cotton un!er p rti l root ?one irrig tion.)iel! crop rese rch rticle in press. www.else/ier.com/loc te/.cr.)u: ng 0t tion o. 1esert +colog3(Zinji ng 'nstitute o. +colog3 n! Eeogr ph3(*hinese %c !em3 o. 0ciences(40-3 0outh @eijing &o !(4rumCi(Zinji ng #30011(*hin .

F33G ,r /u: l3 n , nigr hi(7 ren!r 7 th 0 hu. 0 n t n ,r !h n. (2011). +/ lu ting p rti l root-?one irrig tion n! mulching in o:r (%belmoschus esculentus =.) un!er sub-humi! tropic l clim te. 5ourn l o. %griculture n! &ur l 1e/elopment in the ;ropics n! 0ubtropics. >ol. 112 7o. 2 (2011) 1"IM17B.

F34G 0i3 l %. %.(9 shori %. 0(@ristow(J. =.(> n Eenuchten 9. ;h. 201". %ltern te .urrow irrig tion c n r !ic ll3 impro/e w ter pro!ucti/it3 o. o:r . %gricultur l < ter 9 n gement. 5ourn l homep ge: www.else/ier.com/loc te/ gw t

F3BG 1oorenbos(5. n! %. -. J ss m(1I7I. Riel! response to w ter. 'rrig tion n! 1r in ge p per 33( )%$(&ome.

F3"G -utton &5(=o/e3s @& (2011). % p rti l root ?one !r3ing irrig tion str teg3 .or citrus b e..ects on w ter use e..icienc3 n! .ruit ch r cteristics. %grc < ter 9 n g. I#: 14#BM14I". !oi:10.101"/j. gw t.2011.04.010.

F37G R ct 3o <(1. %.(& mcre?(&.(Eutidrre?(>.(9 res(%.(,os ! s(&.(Nuiro?.((2013) +..ect o. p rti l root-?one !r3ing irrig tion timing on pot to tuber 3iel! n! w ter use e..icienc3. %grc. < ter 9 n g. 123: "BM70. !oi:10.101"/j. gw t.2013.03.00I.

F3#G R ng N=( ). *.(Yh ng(Z. E.(=iu(Y. R.(Ee. (2012b). +..ects o. controlle! ltern te p rti l root-?one !rip irrig tion on pple see!ling morphologic l ch r cteristics n! root h3!r ulic con!ucti/it3. *hin 5 %ppl +co 23: 1233M123I.