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Lentil Water Use and Fallow Water Loss in a Semiarid Climate

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ABSTRACT

With renewed interest in legumes for green manures or as partial summer fallow replacement crops, it is important to know water requirements of these crops in semiarid agriculture. Our objective was to evaluate seasonal water use by black lentil (*Lens culinaris* Medikus cv. Indianhead), a potential fallow replacement crop, and to relate water use to parameters useful as soil water management tools. We measured evapotranspiration (ET) from two precision weighing lysimeters located on a Williams loam (fine-loamy, mixed Typic Argiboroll) near Sidney, MT. The lysimeters were in adjacent 180- by 180-m fields in a typical strip-crop environment of the semiarid northern Great Plains. Bowen ratio estimates of ET were also obtained. Lentil was seeded no-till into wheat (*Triticum aestivum* L.) stubble on one lysimeter field in 1993, and the other was left in chemical fallow. Seeded and fallow fields were rotated in 1994. Water loss by ET from lentil and fallow lysimeters was the same (≈25 mm) for 3 wk following seeding. Plant height was related to growing degree days (GDD) in both years. Cumulative ET was related to GDD for both years until about 800 GDD, corresponding to nearly 300 mm ET. Deciding how much water to sacrifice (with hopes of recovery during the noncrop period) becomes a matter of judgment about probable rainfall. At full bloom (≈2 Mg ha^{-1} dry matter production), the lentil crop used about 50 to 70 mm more water than fallow. Probably no more than 50 mm of water loss above that from fallow should be sacrificed if a grain crop is to be seeded the following year. From a practical standpoint, because plant height was closely related to both GDD and cumulative ET, it is plausible that a simple measure of lentil height (about 350 mm maximum) can give sufficient accuracy for determining when lentil growth, as a partial summer fallow replacement crop in a semiarid climate, should be terminated.

THERE HAS BEEN A RESURGENCE of interest in green manure and cover crops in recent years because of a renewed interest in developing sustainable agricultural systems. Some of the benefits of green manures and cover crops include improving soil organic matter, improving soil N status, reducing soil erosion from wind and water, enhancing water infiltration into the soil, and increasing soil productivity. Cover crops and green manures are more suited to subhumid and humid regions than to low-rainfall areas such as the semiarid northern Great Plains. In semiarid areas, it is often difficult to replace soil water used by a legume cover crop or green manure crop so that adequate soil water remains for a subsequent commercial crop.

In subhumid to humid areas, such as much of the eastern portions of the Great Plains, green manures and cover crops have been used with success. In eastern North Dakota, most green manure legumes grown full season depleted more soil water than fallow in the 0- to 1.2-m soil depth, but lentil was similar to summer fallow in water gain or loss to a depth of 2.2 m (Badaruddin and Meyer, 1989). They concluded that growing some legumes may not affect soil water content differently from summer fallow or from that of growing a continuous cereal crop, and that legumes grown for green manure in higher moisture areas should be considered in lieu of summer fallow (Badaruddin and Meyer, 1990). In the eastern Great Plains on a prairie soil, grain sorghum [*Sorghum bicolor* (L.) Moench] production was greater following legumes used as a green manure (Sweeney and Moyer, 1994). Power and Koerner (1994) listed several legume species suitable as cover crops in eastern Nebraska. Frye and Blevins (1989), working in Kentucky, found that a legume cover crop depleted more soil water in the spring as compared with a soil that had no cover crop. But, within about 2 wk following kill-down of the legume, soil water content under the legume mulch was greater than that of soil with no mulch.

Rice et al. (1993) concluded that green manures, including lentil, have a good potential as summer fallow substitutes in the Peace River region of Alberta and British Columbia. In a similar study, Townley-Smith et al. (1993) found that in the Dark Brown (Typic Borolls) soil zone of Saskatchewan, all legume systems used more water than was replenished. Their conclusion was that better methods of water conservation and improved snow trapping management were needed to replenish at least part of the water used by the green manure crop. However, information about performance and water use of green manures in the semiarid northern Great Plains is sparse. In drier regions, it becomes more important to manage green manures for soil water conservation.

Biederbeck et al. (1993) set out some major criteria for annual legumes to be effective as fallow replacement in a semiarid environment. They were (i) fast emergence to provide early soil cover; (ii) high rate of N_2 fixation and phytomass production; (iii) high water use efficiency; (iv) insect and disease resistance; and (v) high potential as an emergency source of high protein forage. Biederbeck and Bouman (1994) studied four legumes, including black lentil, on an Orthic Brown Chernozem soil (Aridic Haploboroll) near Swift Current, SK, and reported results similar to those of Townley-Smith et al. (1993). Water use among the four legumes was similar, and their water extraction was limited to about a depth of 0.6 m when incorporated at full bloom. They emphasized the importance of early incorporation of legumes in a fallow replacement system to enhance soil water conservation. Welty et al. (1988), working in western Montana, stated that timely precipitation and winter water recharge are necessary for successful legume manure production. Sims and Slinkard (1991) suggested that a number of annual legumes may be successfully grown on dry lands,

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Abbreviations: ET, evapotranspiration; GDD, growing degree days.

but reemphasized the importance of managing annual legumes for fallow replacement in the semiarid northern Great Plains so that adequate soil water remains and/or can be replaced by subsequent precipitation. Power (1991) also suggested that a number of legumes might be successfully grown in a partial fallow replacement program on the northern Great Plains.

Our objectives were to evaluate seasonal water use by black lentil, a potential partial fallow replacement crop, and to relate water use to plant measurements or temperature related traits potentially useful as tools for soil water and cover crop management in a semiarid climate.

MATERIALS AND METHODS

The study was conducted on a Williams loam (fine-loamy, mixed Typic Argiboroll) 11 km northwest of Sidney, MT. Mean annual precipitation is 340 mm of which 20% comes as snow. We used two precision weighing lysimeters, 1.68 by 1.68 by 1.83 m deep, similar to that described by Ritchie and Burnett (1968). The lysimeters were installed in 1977. Rim width was 40 mm, resulting in a potential maximum 5% error in evaporating surface (Allen et al., 1991). The lysimeters were situated in the middle of adjacent 180- by 180-m fields in a typical strip-crop environment of the northern Great Plains. The fields were seeded to spring wheat in 1992, the year previous to the initiation of our study. There was about 3000 kg ha^{-1} wheat residue after harvest in 1992. The residue remained undisturbed and weeds were controlled with glyphosate [(*N*-phosphonomethyl) glycine] before seeding lentil.

Black lentil (cv. Indianhead) was no-till seeded on the north lysimeter field on 14 May 1993 with a disk opener no-till drill, 190-mm row spacing, and seeding rate of 59 kg ha^{-1}. The lysimeter and an area approximately 0.6 m wide surrounding the lysimeter were hand seeded to lentil, which successfully matched the open field in growth and production, as indicated by uniformity of growth inside and outside the lysimeter. The south lysimeter and surrounding field remained in chemical fallow in 1993. On 5 May 1994, lentil was no-till seeded on the south lysimeter field with the same equipment and approximate same seeding rate as in 1993. Again the lysimeter and immediate surrounding area were hand seeded to lentil, which successfully matched the open field in growth and production.

We used a field-calibrated Campbell Pacific Nuclear hydroprobe[1] to measure soil water content by neutron attenuation. Three neutron probe access tubes were located in a line about 14 m to the west, and three in a line about 14 m to the east of each lysimeter. The tubes in each line were about 15 m one from another. One access tube was located in the center of each lysimeter. Soil water content was measured in depth increments of 0.3 m in each lysimeter at the initiation of the study; thereafter, soil water contents of the lysimeters were determined by the water balance method. Periodically, soil water content profiles were measured to a depth of 1.8 m in the surrounding fields throughout both seasons.

Bowen ratio equipment was located near the cropped lysimeter in each year and was installed after the lentil had emerged, to ensure that the instrumentation was placed over a representative, uniform canopy. Supports for the equipment consisted of one vertical main mast anchored in the soil and guyed with three wires. A cross arm, to be adjustable up or down, was attached to the main mast so that a constant height above the crop canopy could be maintained as the growing season progressed. At each end of the cross arm, a vertical arm was attached for mounting anemometers and psychrometers. Two R.M. Young photochopper anemometers were mounted on the west vertical arm, with the middle of the lower anemometer cup maintained 0.25 m above the crop canopy and the middle of the upper anemometer cup 1.0 m above the middle of the lower cup. Two aspirated psychrometers were mounted in insulated shields on the east vertical arm at the same distances above crop canopy as the anemometers. Each psychrometer consisted of 20-gauge copper-constantan thermocouples to measure wet and dry bulb temperatures; the wet bulbs had ceramic wicks that were fed with distilled water from an insulated water reservoir. The psychrometers were directed to the north and were aspirated with electric Howard Industries fans. Net radiation was measured with a Radiation & Energy Balance Systems model Q*6 net radiometer and soil heat flux with a model HFT-3 flux plate.

Data from lysimeters and Bowen ratio equipment were logged on Campbell Scientific CR21X portable data loggers every 60 s, averaged every 30 min, and summed every 24 h. Data were collected continuously until harvest. Routine weather station data were obtained at the same frequency as the field data from an automated weather station located in the southeast corner of the north lysimeter field (adjacent to the northeast corner of the south lysimeter field). Air temperature was measured at 2.0 m; precipitation was measured with a tipping bucket rain gauge.

Growing degree days (GDD) were accumulated from day of seeding in both years using a base temperature (T_b) of 5°C (Everson et al., 1976; Selirio and Brown, 1979; Strand, 1987)

$$\mathrm{GDD} = \sum \left[\frac{(T_{max} + T_{min})}{2} - T_b \right] \quad [1]$$

where T_{max} is maximum air temperature in °C and T_{min} is minimum air temperature in °C.

The Bowen ratio can be expressed as

$$\beta = H/\mathrm{LE} = (R_n - \mathrm{LE} - S)/\mathrm{LE} \quad [2]$$

with LE solved as

$$\mathrm{LE} = (R_n - S)/(1 + \beta) \quad [3]$$

where β is the Bowen ratio, H is sensible heat flux to the air (MJ m^{-2} h^{-1}), LE is latent heat flux (MJ m^{-2} h^{-1}), R_n is net radiation (MJ m^{-2} h^{-1}), and S is soil heat flux (MJ m^{-2} h^{-1}) (Suomi and Tanner, 1958).

At approximately weekly intervals, plant samples from 10 row segments, 0.5 m long and separated by at least 15 m, were cut from the field at soil level. Number of plants from each sample segment were counted. Ten random plants from each segment were selected for upstretched plant height measurements prior to oven drying the whole sample at 57°C for dry matter determination. Total field aboveground dry matter production was estimated from plant count and plant dry matter determinations. Rainfall in the summer of 1993 was 176 mm above the long-term average, providing a longer growth period than usual. The lentil plants set enough seed and ripened sufficiently to be swathed on 14 September. They were left in windrows for about 2 wk prior to combining. The summer of 1994 was drier than 1993, and seedset and ripening proceeded at a more rapid pace, and the lentil crop could be direct combined on 23 August (Fig. 1). The Bowen ratio equipment was re-

[1] Trade and company names are included for the benefit of the reader and imply no endorsement or preferential treatment by the USDA of the product listed, nor does mention of specific pesticides imply registration under FIFRA as amended.

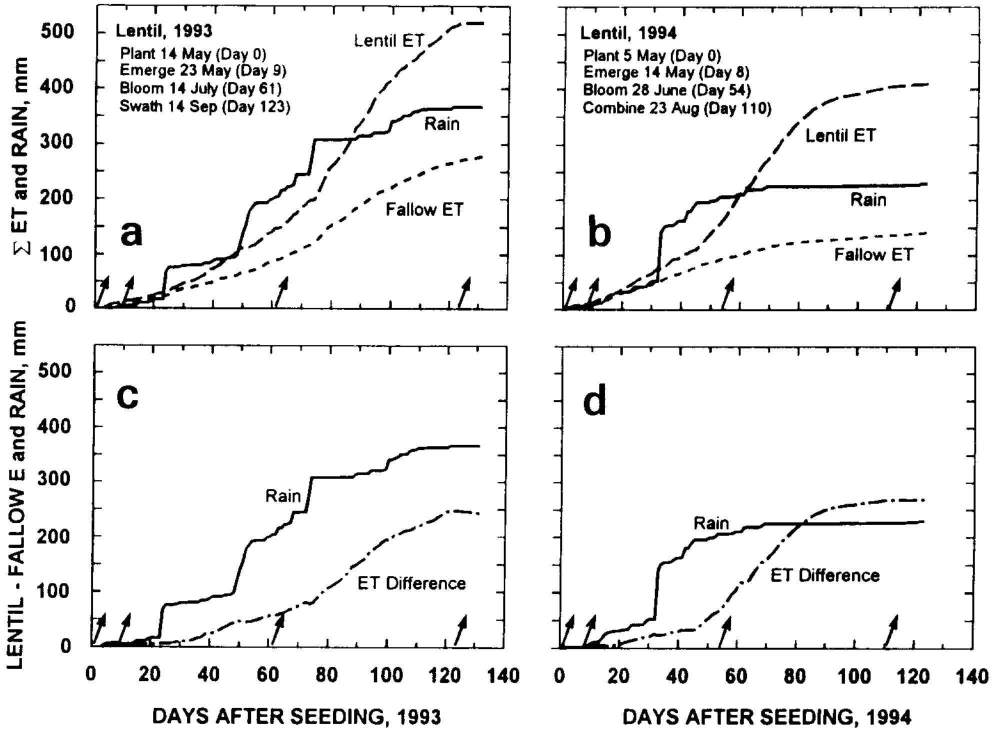

Fig. 1. Cumulative lentil lysimeter evapotranspiration (Lentil ET), fallow lysimeter evapotranspiration (Fallow ET), rain, and cumulative ET difference between the lentil and fallow lysimeters during 1993 (a and c) and 1994 (b and d). Arrows indicate the sequence of events described in the legend.

moved from the field before swathing and combining; the lysimeters remained in operation for a few days longer, for comparing evaporative loss of water following swathing and combining.

RESULTS AND DISCUSSION

Growing conditions for the two years of the study differed, as shown by total rain and its temporal distribution. Total rain was 367 mm (192% of average) between planting and swathing in 1993 and 227 mm (119% of average) between planting and combining in 1994 (Fig. 1a,b).

The field estimated drained soil water upper limit is about 600 mm in a 1.8-m soil profile, and the lower limit is about 345 mm. Both lysimeter and field seeded to lentil in 1993 had adequate soil water at the beginning of the growing season. Soil water content in the field remained constant during the season, meaning that rain supplied all water required for crop growth. The lentil lysimeter lost about 130 mm more water than that supplied by rain, and soil water was depleted to near the lower plant available soil water limit (Table 1). The fallow lysimeter began the 1993 season with a greater soil water content than the surrounding fallow field and also gained more water, emphasizing that the field, as opposed to the lysimeter, provided both surface and internal drainage. Both fallow field and lysimeter lost water over the winter, and soil water contents in field and lysimeter at planting in 1994 were similar to those at planting in 1993. As in 1993, in 1994 the lentil lysimeter lost more water than the lentil field; however, field soil water content remained less than lysimeter soil water content during the whole season.

Total lentil ET through 13 Sept. 1993 was 515 mm (Fig. 1a); during the lower-rainfall year of 1994, it was 404 mm (Fig. 1b). Comparison of ET from the chemically fallowed lysimeter with the lentil lysimeter showed that in both years there was essentially no difference in ET between the two lysimeters for about 3 wk following seeding (Fig. 1c,d). About 25 mm of soil water was lost whether a crop was grown or not (Fig. 1a,b). These results are similar to those reported by Aase and Siddoway (1982) for wheat grown on the same fields and on the same lysimeters, where there was no difference in water use between fallow and crop until tillering was complete.

Table 1. Total profile soil water contents in the spring and fall inside (Lysimeter) and outside (Field) two lysimeters located in adjacent fields (North and South), with growing-season precipitation.

	Soil water content†					
	North			South		
Date	Crop	Lysimeter	Field	Crop	Lysimeter	Field
	mm					
1993 (growing season precipitation: 367 mm)						
spring	lentil	476	401 ± 24‡	fallow	520	243 ± 31
fall		346	339 ± 17		604	492 ± 20
1994 (growing season precipitation: 227 mm)						
spring	fallow	515	394 ± 11	lentil	531	436 ± 14
fall		609	433 ± 8		377	367 ± 25

† To the 1.8-m depth.
‡ ± 1 SD.

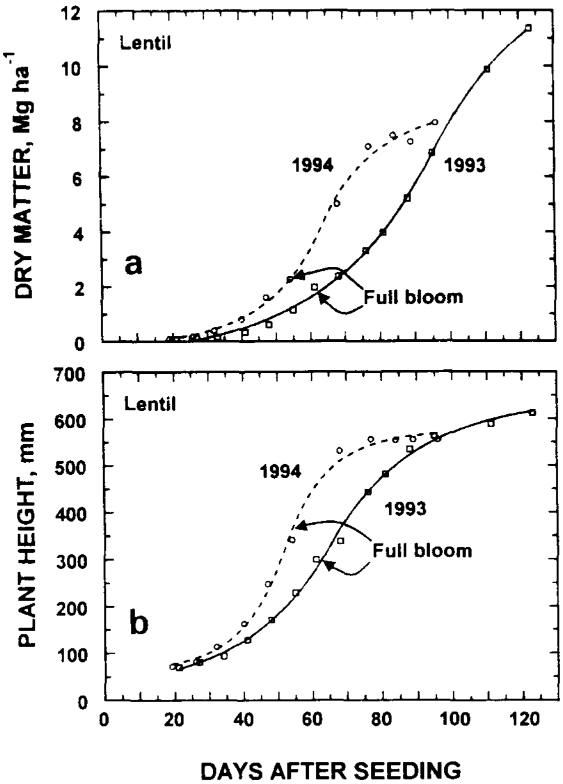

Fig. 2. Black lentil dry matter production and upstretched plant height vs. days after seeding for 1993 and 1994.

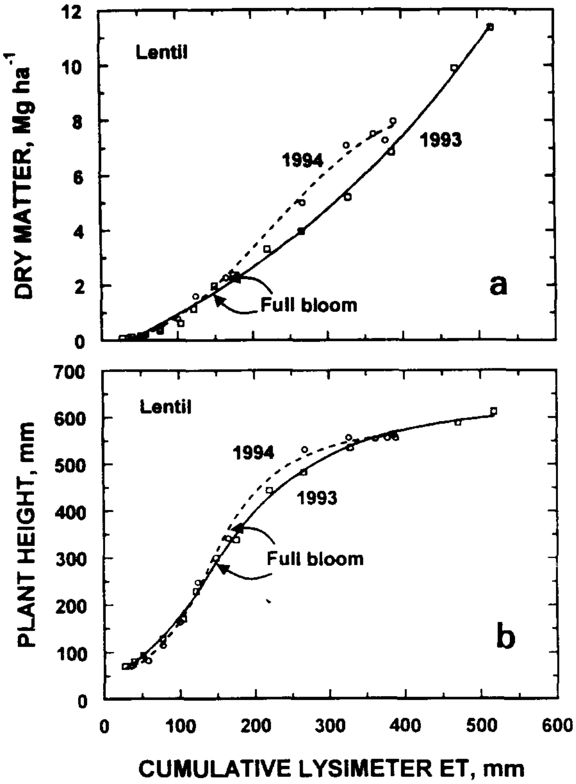

Fig. 3. Black lentil dry matter production and upstretched plant height vs. cumulative black lentil lysimeter evapotranspiration (ET) for 1993 and 1994.

The 3-wk period of similar ET from cropped and noncropped lysimeters coincided closely with the first practical plant sampling opportunity (Fig. 2). At that time, in both years, plant dry matter was less than 0.1 Mg ha^{-1} and upstretched plant height was 70 mm. From a common point of origin in each year, both the dry matter curves and plant height curves diverged in response to the different growing conditions in the two years. The wetter weather of 1993 resulted in a prolonged growing season, with dry matter production reaching 11.4 Mg ha^{-1} and plant height reaching 625 mm. Weather conditions in 1994 resulted in a shorter growing season and more rapid plant development as determined by dry matter production and plant height, both of which were less than in 1993. Dry matter production reached 8 Mg ha^{-1} and plant height reached 555 mm in 1994.

For lentil to be grown as a green manure crop in a partial summer fallow replacement cropping program, lentil growth would need to be terminated well before reaching maturity. Townley-Smith et al. (1993), Biederbeck et al. (1993), and Biederbeck and Bouman (1994) desiccated legume green manures at full bloom when using them as green manure substitutes for summer fallow. Sims and Slinkard (1991) suggested that a certain amount of soil water be allocated for a green manure crop before desiccating. In our instance, lentil produced about 2 Mg ha^{-1} near full bloom (Fig. 2) and used about 150 to 170 mm of water (Fig. 3); that equates to about 50 to 70 mm more water than that lost from fallow during the same time period.

Bowen ratio measurements of ET resulted in similar relationships to dry matter production and plant height, as did lysimeter measurements of ET (Fig. 4); however, Bowen ratio measurements of ET were greater than lysimeter ET measurements and resulted in greater water use for a given dry matter production or plant height.

Growing degree days summed across the growing seasons for the two years illustrate that the 1994 season was warmer than the 1993 season (Fig. 5). The relationship between cumulative GDD and days after seeding was nearly linear with a slope of 10.8 GDD d^{-1} in 1993 and 13.5 GDD d^{-1} in 1994. Thus, the implication is that the hastening of growth and early maturity in 1994 as compared with 1993 was due to the drier and warmer growing conditions. Nevertheless, bloom in both years occurred at about 550 GDD, or 61 d after seeding in 1993 and 54 d after seeding in 1994, corresponding to the suggested latest cut-off point for terminating lentil growth in a partial summer fallow replacement program.

Dry matter production and plant height compared well between years with cumulative GDD, particularly during the early growth stages (Fig. 6). Of the two, plant height is easier to measure. The early part of the season is of particular importance, since we are interested in early-season growth as it may relate to water use compared with ET from fallow soil. On the semiarid northern Great Plains, in a partial summer fallow replacement program, it is important to determine how much water to allow a green manure crop to use before terminating crop growth. Cumulative ET for both years, as measured by lysimeters, exhibited a common relationship to cumu-

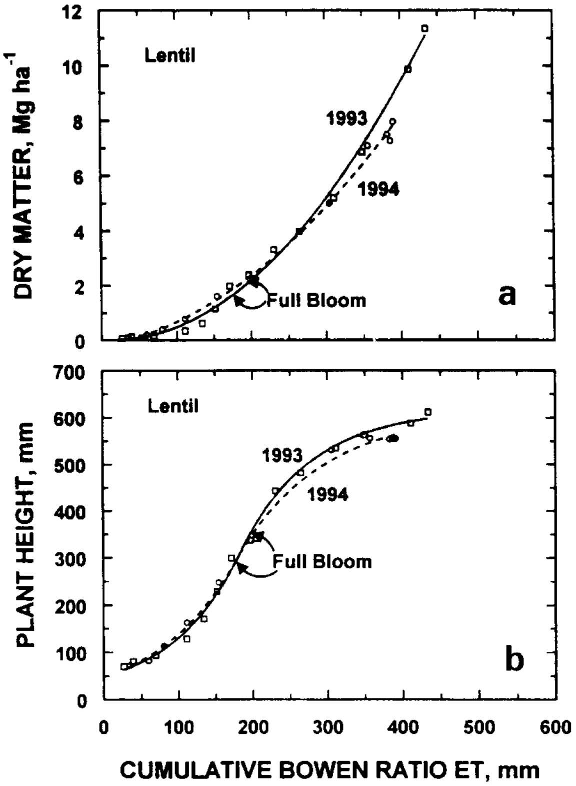

Fig. 4. Black lentil dry matter production and upstretched plant height vs. cumulative Bowen ratio evapotranspiration (ET) estimates.

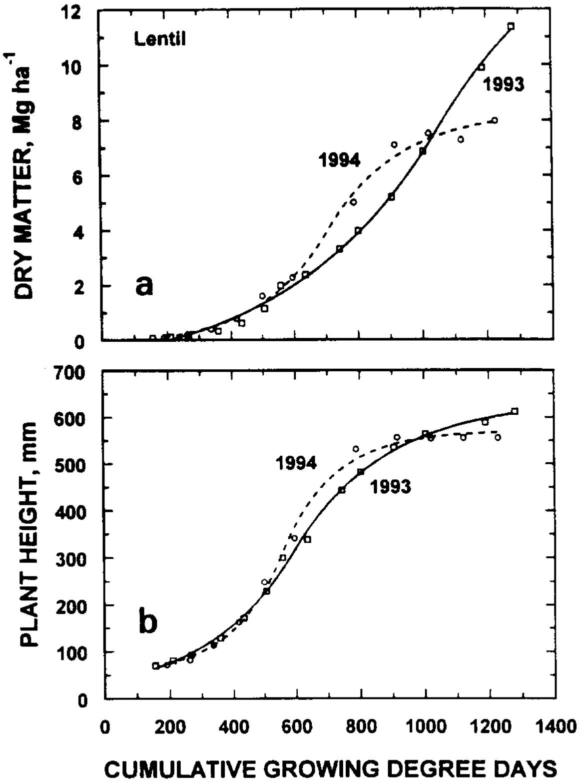

Fig. 6. Black lentil dry matter production and upstretched plant height vs. cumulative growing degree days (base 5°C) for 1993 and 1994.

lative GDD until about 800 GDD, corresponding to nearly 300 mm ET (Fig. 7). Past that point, the relationship diverged for the two years, primarily because the rains ceased at about that time in 1994. As a result the plants began to mature and ET decreased thereafter.

How much water to allow a crop to use in a partial fallow replacement system depends on antecedent soil water content and on expected precipitation to replenish the soil water reservoir for the following commercial crop. In the semiarid northern Great Plains, precipitation cannot be relied on to be consistent and timely. Fallow efficiency has typically been about 25% of annual precipitation, which ranges from about 300 to 360 mm in a late spring–early summer precipitation pattern. Fallow efficiency can range from a loss of water during the summer portion of fallow to an overall efficiency approaching 50% with good management practices and timely precipitation (Black et al., 1974; Aase and Siddoway, 1982; Tanaka and Aase, 1987; Aase and Reitz, 1989). Therefore, determining how much water to sacrifice becomes a matter of judgment and weighing the probabilities. Procedures, soil water guidelines, and rain probabilities such as those suggested and outlined by Brown et al. (1981) and Brown and Carlson (1990) may be used to aid in decision making. In any given situation, probably no more than 50 mm of water, above that lost to fallow, should be sacrificed (Sims, 1989).

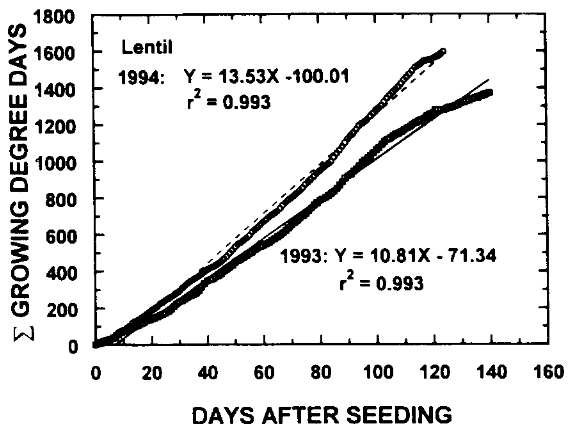

Fig. 5. Cumulative growing degree days (base 5°C) vs. days from day of seeding black lentil for 1993 and 1994. Solid and dotted lines represent regression lines.

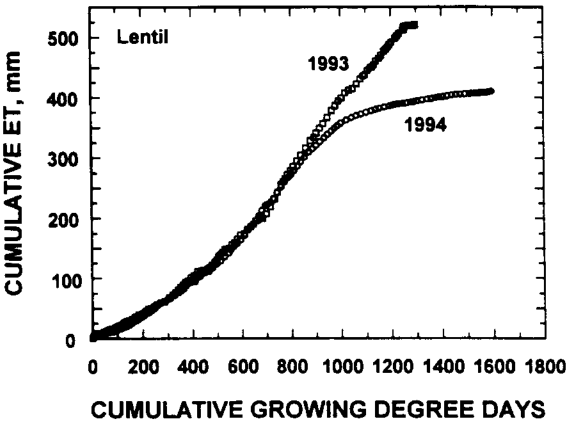

Fig. 7. Cumulative black lentil lysimeter evapotranspiration (ET) vs. cumulative growing degree days (base 5°C) for 1993 and 1994.

If we assume that total maximum allowable ET is limited to 150 mm, which occurs near full bloom or near dry matter production of about 2 Mg ha^{-1}, then we are well within the common relationship discussed earlier, between ET, dry matter production, or plant height vs. GDD; or plant height vs. ET. For a rough estimate of water use as related to plant growth, days after seeding may be used. However, a more nearly accurate estimate of water use as related to plant growth is cumulative GDD, and persons who have access to a climatological network where GDD are routinely accumulated may wish to use GDD as a measure. Also, possibly from a more practical point of view, because plant height is closely related to both GDD and cumulative ET, and because plant height vs. cumulative ET was consistent between the two divergent crop production years, it seems plausible that a simple measure of plant height can give sufficient accuracy and flexibility to decide when a partial summer fallow replacement crop should be terminated. For example, the decision is made, based on soil water conditions and rainfall probabilities, that 100 mm of water will be allocated for lentil growth. One can use a relationship such as the one shown in Fig. 3 and decide that lentil growth will be terminated when the plants reach a height of 175 mm. Then it is simply a matter of walking the field and measuring plant height. Alternatively, one can use a relationship such as the one shown in Fig. 7 and decide that when cumulative GDD reach 400 it is time to terminate lentil growth. Relationships such as the ones discussed should also be appropriate for semiarid areas other than that of the northern Great Plains of the United States.

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