Effect of Fallow Frequency on Soil Water Conservation in the Semiarid Region of Saskatchewan

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Abstract

The effects of fallow frequency on soil water conservation were quantified for a 40 yr (1967-2006) field experiment conducted on a medium textured Orthic Brown Chernozem (aridic haploboroll) in semiarid southwestern Saskatchewan, in which soil water contents were measured each year in early spring, shortly after harvest, and again just prior to freeze-up in the fall. The three treatments examined were continuous wheat (*Triticum aestivum* L.) (Cont W) and fallow-wheat (F-W), each receiving N and P fertilizer and Cont W receiving only P. On average, 36 % of the precipitation received during the fall and winter months for Cont W (N+P) was conserved in the soil. In the summer fallow system (F-W (N+P)) a greater proportion (42 %) of the precipitation was conserved during the first fall and winter. During the second overwinter period, only 6 % of the precipitation received was conserved in the F-W system compared to 44 % in the first overwinter period. Compared to the 36% of fall and wither precipitation conserved in Cont W (N+P), inadequate N fertility (Cont W (+P)) resulted in only 27 % of the precipitation being conserved during this period. We developed equations that will allow estimation of water conserved as a function of precipitation received between harvest and seeding for F-W and Cont W (N+P. Trends in grain yield were fairly closely correlated with growing season precipitation and potential evapotranspiration.

INTRODUCTION

* In the northern Great Plains, especially the semiarid regions such as in the Brown and Dark Brown soil zones (aridic and typic borolls), water is the main factor influencing crop yields (Campbell et al. 1997).

* The efficiency of water storage from precipitation in the prairies is generally low and varies greatly with the type of cultural practice, soil texture, weed growth, the amount of standing stubble and crop residue left on the soil at harvest, and the amount and distribution of precipitation between harvest and the next seeding (Bauer 1972).

*Although the efficiency of soil water conservation from precipitation received during the non-cropping period is well established, there are few detailed long term studies that allow one to quantify how much water will be conserved in the soil as a function of precipitation received during this fallow period.

The objective of this poster is to quantify the relationship between water conserved in the soil and precipitation received during the non-cropping period for continuous wheat and summer fallow-wheat.

MATERIALS AND METHODS

The Swift Current crop rotation experiment was initiated in 1967 on a Swinton loam (Ayers et al. 1985), an Orthic Brown Chernozem (Canadian Soil Survey Committee, Subcommittee on Soil Classification 1978).

The treatments examined were summer fallow-wheat (F-W) and continuous wheat (Cont W) each receiving N and P fertilizer and Cont W receiving only P. Fertilizer N and P were applied in accordance with the soil NO_3-N (0- to 0.6-m depth) and soil P (0- to 0.15-m depth) levels in individual plots, measured the previous fall (mid-October) (Campbell et al. 2004).

Fertilizer N, as ammonium nitrate, was applied by broadcasting it in spring prior to seedbed preparation based on the recommendation of the soil-testing laboratory at the University of Saskatchewan (Saskatchewan Soil Testing Laboratory 1990). No fall tillage was performed on any of the plots. Seeding date of wheat ranged from April 28 to May 22 (average May 9) and harvest dates ranged from August 13 to September 29 (average September 3) (Campbell et al. 2007).

All plots were soil sampled in early spring, generally a week prior to seeding, shortly after harvest, and again just prior to freeze up in the fall (middle of October). Samples were taken with a Giddings soil corer (two cores per plot were bulked) from 0- to 0.15-, 0.15- to 0.3-, 0.3- to 0.6-, 0.6 to 0.9-, and 0.9- to 1.2-m depths. These samples were analyzed for gravimetric soil water content, which was converted to volumetric units using measured bulk densities of 1.20, 1.22, 1.26, 1.49 and 1.67 Mg m^{-3} for the five depths, respectively (Campbell et al. 1983a). Daily maximum and minimum air temperatures and precipitation were measured at a meteorological site located 1 km west of the experimental site. Potential evapotranspiration (PET) was estimated from a regression equation relating latent evaporation (i.e., evaporation from Bellani plate atmometers) to meteorological information (Baier and Robertson 1965).The precipitation deficit (PPTDEF) for the growing season was calculated as the difference between accumulated PET and growing season precipitation.

Data were analyzed using the PROC MIXED of SAS (Version 9.1, SAS Institute, Cary, NC) with restricted maximum likelihood option and repeated measures with a first-order autoregressive covariance structure (Littell et al. 1998). Means were separated by Fisher's protected LSD test at $P<0.05$ (Steel and Torrie 1980), calculated from the standard errors for least squares means produced from the PROC MIXED analysis. Multiple regression was used. we used a stepwise regression with a backward elimination procedure to relate soil water conserved in the 0-1.2 m depth during the period between harvest and the next seeding date (Y) to precipitation during this period (X) for Cont W (N+P) and for F-W (N+P) (SYSTAT Software Inc. 2004).

RESULTS AND DISCUSSIONS

Soil Water Distribution Prior to Seeding

* Prior to spring seeding, wheat grown on fallow in the F-W (N+P) rotation had about 252 mm of water in the 0 - 1.2 m depth (Fig 1). This was equivalent to 138 mm of available water, based on the lower limit of available water for this depth being 114 mm.

*Cont W (N+P) at this time had 209 mm of water in the 1.2 m depth (i.e., 95 mm of available water) and Cont W (+P) had 204 mm of water (i.e., 90 mm of available water).

*Almost 90 % of the available water in the rooting depth (0-1.2 m) of the Cont W systems was located in the top 0.6 m, with 56 % in the 0 - 0.3 m depth and 32 % in the 0.3 - 0.6 m depth segments (Fig 1).

*In contrast, in the F-W system, because of the much more extended summer fallow period (approximately 20 mo), and with infiltration being derived from both snowfall and rainfall, water was able to move deeper into the root zone. Thus, only 68 % of the available water was located in the top 0 - 0.6 m depth (34 % in each of the 0 - 0.3 and 0.3 - 0.6 m segments); 18 % of the available water was found in the 0.6 - 0.9 m segment and 14 % into the 0.9 - 1.2 m segment.

*The difference in distribution in soil water between the fallow- (F-W) and stubble-cropping (Cont W) systems, with the much greater quantities and proportion of available water stored at depth in spring under the summer fallow system, reduces the dependency of fallow crops on growing season precipitation compared to the stubble crops.

Changes in Soil Water Content Between Seeding and Harvest

*The changes in soil water content (0 - 1.2 m) between spring, near seeding, and harvest (i.e., water used by the crop during the growing season) were proportional to the amount of water stored in the soil at spring (Fig 1). Thus, almost twice as much water was extracted from the fallow treatment than from Cont W (N+P), and 37 % more from Cont W (N+P) than from Cont W (+P). Most of the difference in water removal between the fallow system and Cont W (N+P) was observed in the 0.3 - 1.2 m depths, while the differences between Cont W (N+P) and Cont W (+P) was in the 0 - 0.6 m depths where the differences in stored water in spring were observed (Fig 1).

Soil Water Distribution at Harvest

*At harvest, F-W left 151 mm of water in the 0 - 1.2 m soil profile, Cont W (N+P) left 153 mm, and Cont W (+P) left 162 mm. Based on the lower limits of available water for this soil, this was equivalent to 38 mm of available water for F-W and Cont W (N+P) and 48 mm for Cont W (+P) (Fig 1).

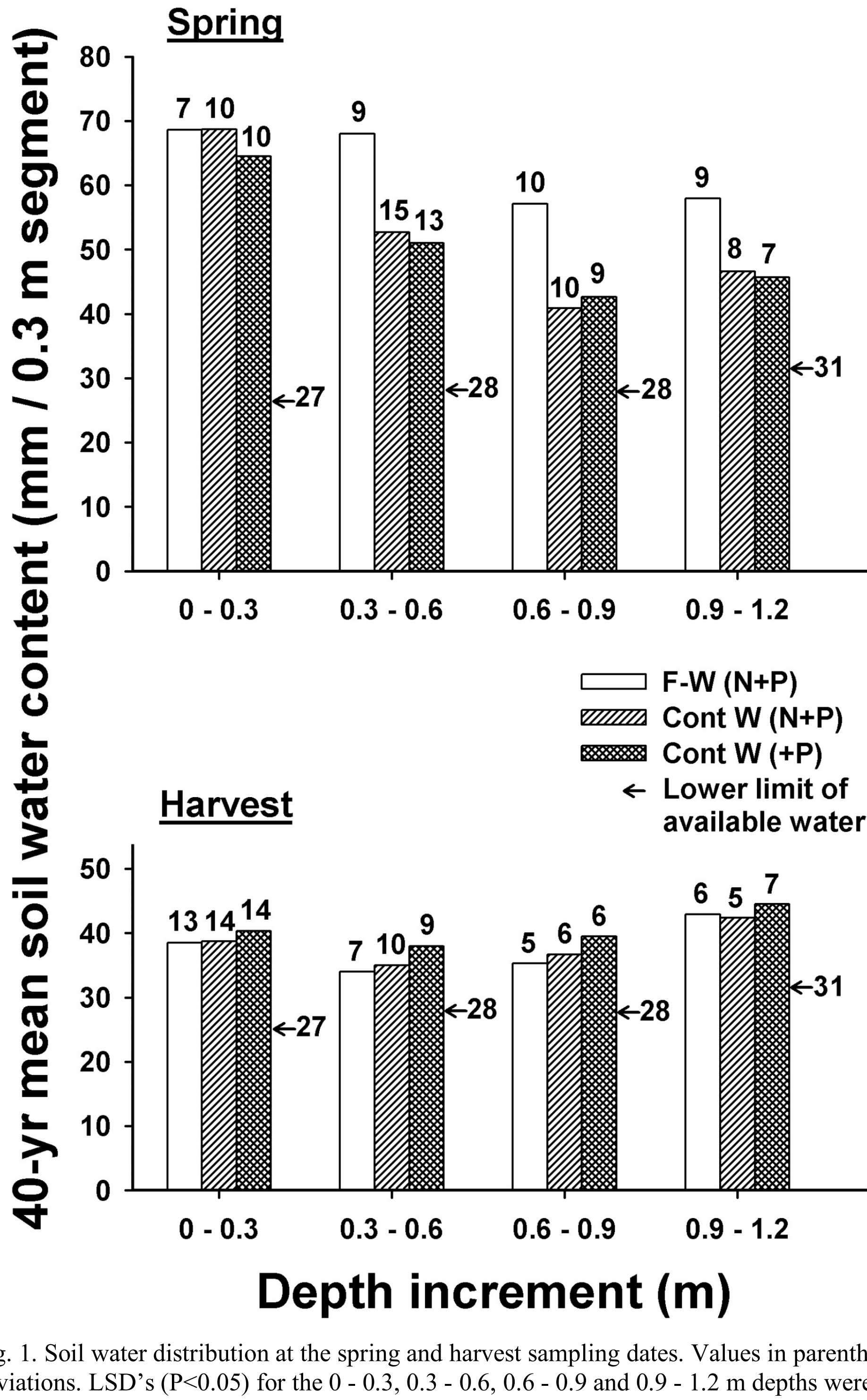

Fig. 1. Soil water distribution at the spring and harvest sampling dates. Values in parentheses are standard deviations. LSD's ($P<0.05$) for the 0 - 0.3, 0.3 - 0.6, 0.6 - 0.9 and 0.9 - 1.2 m depths were 3.2, 6.9, 3.0 and 2.8 mm, respectively in spring, and 1.2, 2.4, 2.9 and 4.3 mm at harvest.

*There was 8 mm more water left by Cont W (+P) in the 0 - 1.2 m depth than under Cont W (N+P), probably because of weaker crop growth in Cont W (+P). However, by the following spring the greater amount of crop residues produced under Cont W (N+P) resulted in greater amounts of snow trap and thus greater replenishment of water in the soil under Cont W (N+P).

Amount of Soil Water Conserved Between Harvest and Seeding

*During the 20 mo summer fallow period 101 mm of water on average was conserved in the 0 - 1.2 m depth of the F-W (N+P) rotation. Of this, 17 mm was stored during 1.5 mo between harvest and the first fall, 47 mm during the 6.5 mo between the first fall and second spring, 31 mm during the 5.5 mo between the second spring and second fall, and only 6 mm during the 6.5 mo between the second fall and third spring, i.e., just prior to the next seeding.

*At the end of the first winter (i.e., after about 8 mo), 64 mm of water was conserved in the F-W system (17 mm between harvest and the first fall and an additional 47 mm between the first fall and the second spring). This was 9 mm more than conserved by Cont W (N+P) and 24 mm more than conserved by Cont W (+P).

*In the two Cont W systems, most of the precipitation between harvest and the next spring was conserved in the 0 - 0.6 m depths (e.g., 56 %, 31 %, and 13 % in the 0 - 0.3 m, 0.3 - 0.6 m and 0.6 - 1.2 m depths, respectively, for Cont W (N+P); for Cont W (+P) the corresponding values were 61 %, 32 % and 7 %.

Proportion of Precipitation Conserved Between Harvest and Seeding

*Over the 40 yr study period, the average amount of precipitation between harvest and fall was 45 mm; between fall and spring 107 mm, for a total of 152 mm for the period from harvest to seeding of the Cont W treatments.

*During the first 22 yr of this study, when growing season conditions were generally drier than average, precipitation was lower in the harvest to fall period than during the more humid 1989 - 2006 period; however, there was no difference in total precipitation received between fall to spring (107 mm).

*On average, 16 of the 45 mm precipitation received in the harvest to fall period was conserved in the soil under Cont W (N+P) (i.e., about 36 % conserved).

*In the summer fallow system (F-W) water conservation in amounts and proportion of precipitation received were similar to those for Cont W (N+P) during the harvest to first fall period. However, more water was conserved in F-W (N+P) between the first fall and the second spring (47 mm) than in Cont W (N+P) (40 mm). This resulted in a greater amount of water conserved (40 yr mean is 64 mm) and higher proportion of precipitation conserved (42 %) between harvest and the second spring in the summer fallow system than in the Cont W (N+P) system (55 mm and 36 %).

*In the F-W (N+P) system, although precipitation between the second spring and second fall (243 mm) was 60 % greater than that received between harvest and the second spring (152 mm), the amount (31 mm) and proportion of precipitation conserved (13 %) during the second spring to second fall was much less than during the harvest to second spring (64 mm or 42 %).

*During the second fall to third spring (seeding), only 6 of the 107 mm precipitation was conserved in the summer fallow system (i.e., 6 % compared to 44 % of the precipitation that was conserved in the first winter period.

Estimating Soil Water Conserved from Precipitation Between Harvest and Seeding

*The result of regression analysis to relate the water conserved in soil to precipitation received between harvest and seeding (Fig. 2).

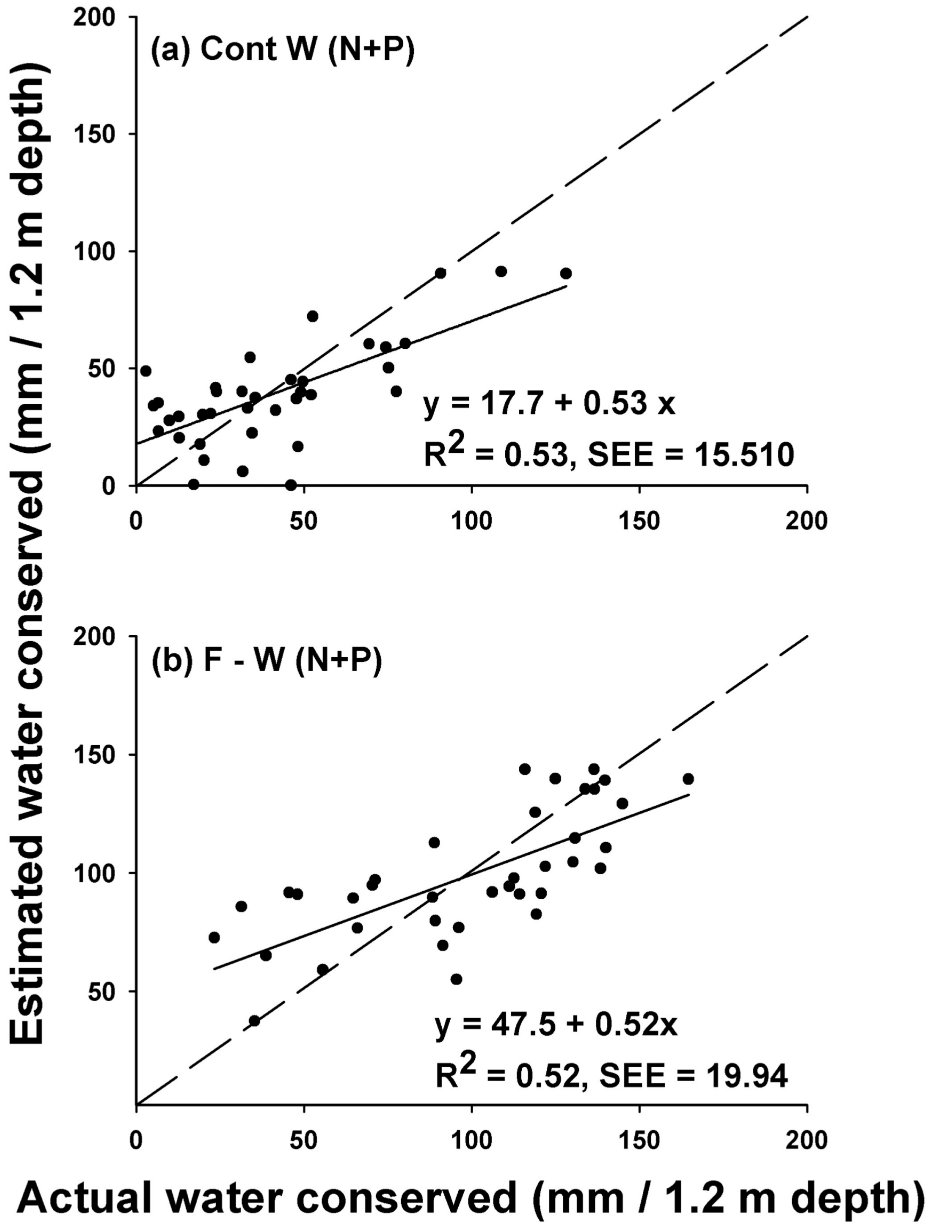

Fig. 2. Relationship between measured soil water conserved in the fallow period and the estimated one from precipitation received during the fallow period for (a) Cont W (N+P) and (b) F-W (N+P).

*We accounted for 52 % of the variability in water conserved as a function of precipitation between harvest and seeding in both the Cont W (N+P) and F-W (N+P) systems.

*The estimates from the regression equations had a significant bias with intercepts of 17.7 mm for the Cont W (N+P) treatment and 47.5 mm for the F-W (N+P) treatment (Fig 2a and 2b).

*The equations should prove useful for estimating the amount of soil water conserved from precipitation in medium textured soils under conventional tillage in the semiarid prairies of the Northern Great Plains. This could therefore save time and expense in soil sampling in early spring, and facilitate cropping decisions.

Relating Yield and Yield Trends to Weather Variables and Conserved Water

*Grain yields of Cont W (N+P) averaged 1637 kg ha^{-1} and yields varied between zero in the severe drought year (1988) and 3144 kg ha^{-1} in a year (2004) with 47% above average growing season precipitation.

*Yields of F-W (N+P) averaged 2263 kg ha^{-1} and varied between 764 kg ha^{-1} in a drought year (1985) and 3645 kg ha^{-1} in 1997 when PPT was near average, but evenly distributed throughout the growing season and the spring soil water content was 62 mm (i.e., 25 % above average). The average growing season precipitation was 197 mm, with 20 yr below average; 13 of these were prior to 1988.

*The trends in grain yield of Cont W (N+P) during the experimental period (1967 - 2006) were assessed by determining the accumulated deviations from the long-term mean yield (Fig 3a).

*The yield trends for Cont W (N+P) were related to growing season precipitation (PPT) (Fig 4a), potential evapotranspiration (PET) (Fig 4b), precipitation deficit (PPTDEF) (Fig 4c), and soil water conserved from precipitation received between harvest and seeding (SWC) (Fig 4d) for the period 1967 - 2006.

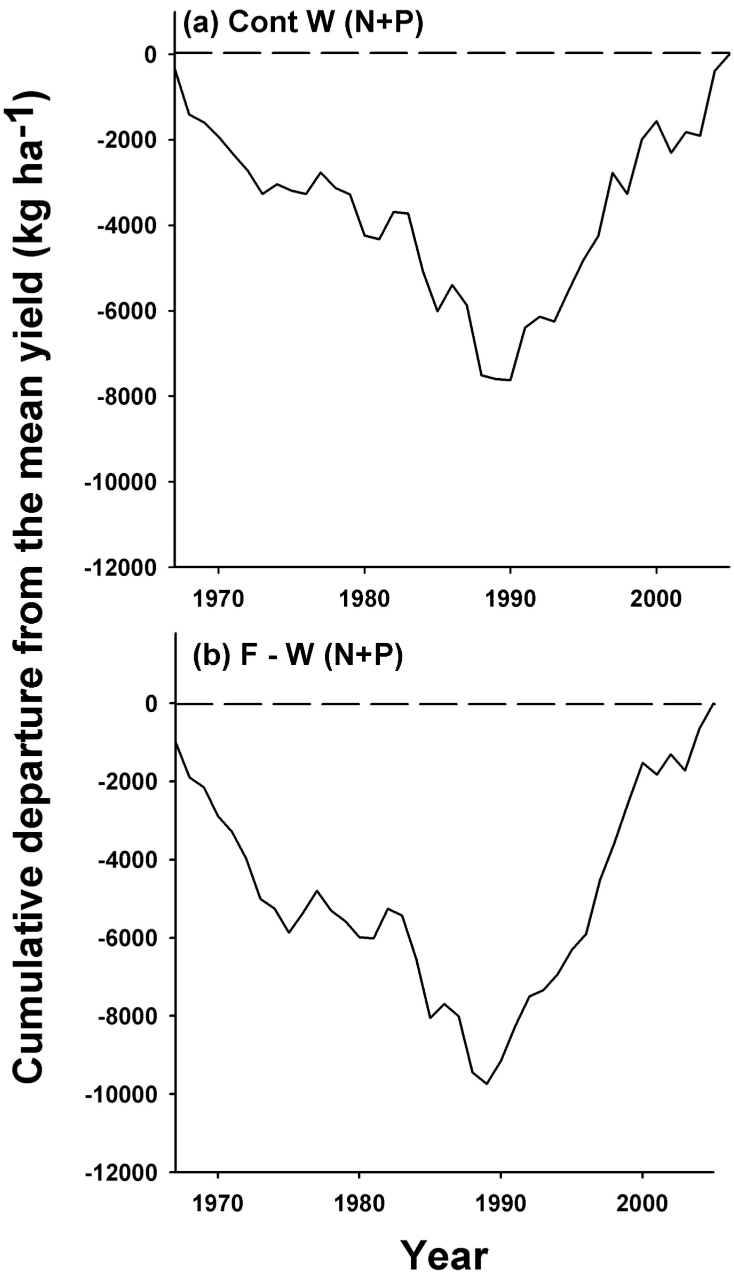

Fig. 3. Trends in grain yield of (a) Cont W (N+P) and (b) F-W (N+P) (1967-2006).

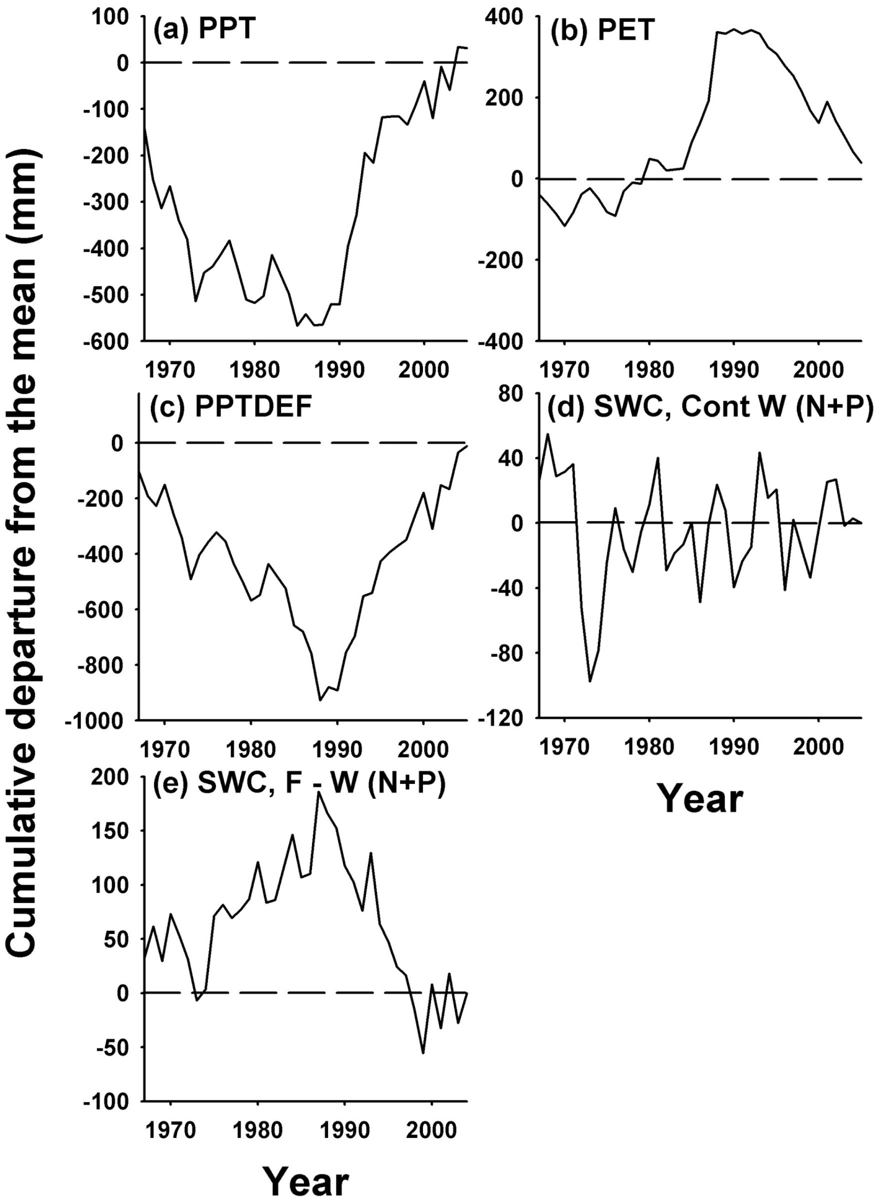

Fig. 4. Trends in (a) growing season precipitation (PPT), (b) growing season potential evapotranspiration (PET), (c), gowing season precipitation deficit (PPTDEF), (d) soil water conserved, 0 - 1.2 m (SWC) from harvest to seeding, Cont W (N+P), and (e) soil water conserved, 0 - 1.2 m (SWC) from harvest to seeding, F-W (N+P).

*During the 40-yr study period, there were two main trends in Cont W (N+P) yields: one trend between 1967 and the late 1980s when yields were generally below average for this semiarid region, and the second after 1990 when yields were mostly above average (Fig 3a).

*The trends in growing season precipitation (Fig 4a) partly explained the yield trends: from 1967 to the early 1970s, precipitation was generally below average (1967 - 1973), or near average (1974 - 1989); thereafter, PPT was fairly consistently above average, as was the yield trend.

However, the continued steady decline in the yield trend from mid 1970s to 1990 (Fig 3a) was mainly a reflection of the above-average PET in this period (Fig 4b). The below-average PET after 1990 coupled with above-average PPT explains the above-average trends in yields during this period (Fig 3a).

*When we combined the trends in growing season precipitation (Fig 4a) with trends in PET (Fig 4b) to give the trends in precipitation deficit (i.e., PET minus PPT) we found that the latter parameter (Fig 4c) was very closely correlated with the trends in yield (Fig 3a) ($R^2 = 0.811$***).

* There was no consistent trend in water conserved between harvest and seeding of Cont W (N+P), with values generally straddling the 40-yr mean (Fig 4d), indicating that this parameter had little influence on the yield trends; it was mainly the growing season weather that influenced yield trends.

*Trends in the yield of wheat grown on summer fallow (Fig 3b) were similar to those of Cont W (N+P) (Fig 3a) and therefore the explanation of these trends relative to trends in PPT, PET, and PPTDEF would be the same as for Cont W (N+P).

*However, unlike the neutral trends in water conserved for Cont W (N+P) (Fig 4d), trends for water conserved for F-W (N+P) showed values that were generally above average prior to 1989 and below average thereafter (Fig 4c).

One might hypothesize that stored soil water would contribute to greater summer fallow yields prior to 1990 and would be less likely to enhance yields in the post-1990 period. However, since yield trends for F-W (N+P) were mainly a function of PPTDEF ($R^2 = 0.908$***), we must again assume that the growing season conditions were the main factor influencing the yield trends.

*When grain yields were related to PPTDEF and water conserved in the non-cropping period (SWC) using multiple regression, we were able to account for about 69 % of the variability in yield in the Cont W (N+P) and 63 % in the F-W (N+P) treatment. However, to provide a more detailed analysis we separated PPTDEF into PPT and PET and re-analyzed the data.

*We were able to account for 66% of the yield variability of Cont W (N+P) and 59% of the variability for F-W (N+P). As expected, yield was inversely related to PET and directly related to PPT and SWC. The squared semipartial correlation coefficients indicated that for Cont W (N+P), PPT was twice as important as PET and four times as important as SWC, while for F-W (N+P) PPT was three times as important as PET and six times as important as SWC.

*The regression equation overestimated the lower yields and underestimated the higher yields for both Cont W (N+P) and F-W (N+P) (Figs 5a and 5b), with the intercepts being significantly different from zero and the slopes being significantly different from one.

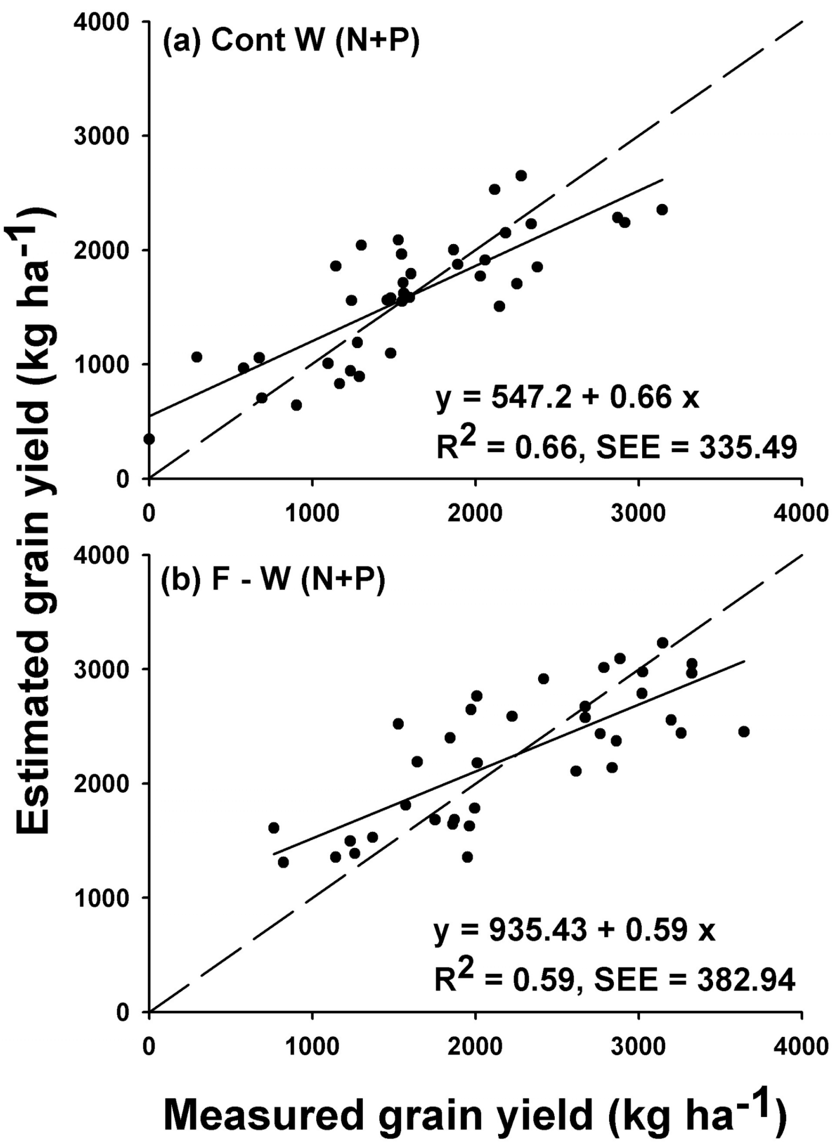

Fig 5. Relationship between measured grain yield and the estimated one from growing season precipitation, potential evapotranspiration and soil water conserved during the non-cropping period for (a) Cont W. (N+P) and (b). F-W(N+P).

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