1.5 Spatial Variability of Turbulent Fluxes Across a Corn /Soybean Production Region in Central Iowa

J. H. Prueger[1], W. P. Kustas[2], L. E. Hipps[3], J.L. Hatfield[1],
A. Cahill[4], C. Williams[5], J. I. MacPherson[3], M. Wolde[6], J. Albertson[7], W. E. Eichinger[8], D. I. Cooper[9], N. Brunsell[7] and R. Gillies[9]

[1] U.S. Dept. of Agriculture, National Soil Tilth Laboratory, Ames, IA
[2] U.S. Dept. of Agriculture, Hydrology and Remote Sensing Laboratory, Beltsville, MD
[3] Dept. of Biological and Irrigation Engineering, Utah State University, Logan, UT
[4] Civil Engineering Department, Texas A&M University, College Station, TX
[5] Arts and Sciences, University of Virginia, Charlottesville, VA
[6] Institute for Aerospace Research, National Research Council of Canada, Ottawa, Canada
[7] Dept. of Civil Engineering, Duke University, Duke, NC
[8] Dept. of Civil and Environmental Engineering, University of Iowa, Iowa City, IA
[9] Experimental Atmospheric and Climate Physics, Los Alamos National Lab, Los Alamos, NM
[10] Dept. of Geography and Earth Resources, Utah State University, Logan, UT

1. INTRODUCTION

The Walnut Creek Watershed located near Ames, Iowa is a relatively small (47 km^2) watershed that is representative of typical corn/soybean production in the Upper Midwest Corn Belt region of the United States. This region comprises over 40 million hectares of a corn/soybean production rotation this is largely dependent on summer convective precipitation events for crop water needs. Intuitively, intensively managed cropping systems bring to mind large spatially homogeneous surfaces. Turbulent exchange fluxes of water, heat and carbon dioxide (CO_2) of corn and soybean surfaces have been assumed to be relatively uniform from field to field. Put another way, not much interesting is happening over corn or soybean fields in central Iowa. However, over the course of a growing season (planting to harvest) a number of factors can induce significant spatial and temporal differences in the exchange rates of turbulent fluxes across a corn/soybean production landscape. These can include soil type, surface topography, seed variety, time of planting, crop growth, soil water status, spatial variability of precipitation distribution and local micro-meteorological conditions. An intensive study coupling ground based soil moisture measurements with computed estimates using remotely sensed data from aircraft and satellite platforms (SMEX02, see http://hydrolab.arsusda.gov/smex02/ for details of the experiment) was conducted in central Iowa during June 20 through July 09, 2002. A joint component of SMEX02 was the Soil Moisture-Atmosphere Coupling Experiment (SMACEX), designed to compare a network of 14 tower measurements of turbulent fluxes (eddy covariance) of heat, (*H*) water vapor (*LE*) and carbon dioxide (CO_2) with estimates computed with remotely sensed data from an aircraft platform. This paper will describe the tower measurements deployed across the watershed and report on preliminary observations related to variations in available energy, turbulent flux exchange and energy balance closure.

2. SITE DESCRIPTION

The SMACEX study area was conducted in the Walnut Creek (WC) Watershed as part of the SMEX02 watershed-scale mapping mission. The study area encompassed a rectangular region of ~10 km north south x 35 km east west. The topography of the Walnut Creek watershed is characterized in general by flat to gently rolling terrain. Large depression areas (potholes) ranging in size from 10's to 100's of meters across can be found in many of the fields. Because these potholes can serve as catchments for surface runoff following heavy precipitation events, many of the fields are underlain with tile drains to prevent ponding or hasten excess soil water drainage. The presence of a tile drainage system can affect the available soil water content across a landscape surface that in turn will contribute to spatial variations in water, heat and carbon dioxide exchanges.
The watershed area had approximately equal planted areas of corn and soybeans. Tower

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Corresponding Author Address: J.H. Prueger, USDA-ARS-NSTL, Ames, Iowa, United States, 50011.
e-mail: prueger@nstl.gov

installation and instrument mounting began immediately after planting and pesticide application.

Instrumentation-eddy covariance

Fourteen eddy covariance (EC) stations were in operation during the intensive measurement period of the field campaign. A figure showing the deployment of the stations within the watershed can be found in Kustas *et al.*, 2003 (this issue). Instrumentation at each of the EC towers included Campbell Scientific Inc. (CSI) CSAT3 3-D sonic anemometers. Ten of the towers were equipped with a LiCor-7500 H_2O/CO_2 sensor and the remaining 4 with a CSI Krypton Hygrometer (KH20) **[Trade and company names do not imply endorsement by USDA]**. Of the 14 towers, 12 were operated in "time series" mode (i.e., acquisition of all the raw 20 Hz data), with the remaining 2 sites operating in "flux mode" where initial processing of the raw 20 Hz was performed in the data logger and 30-min average fluxes and associated statistics were stored. A total of 20 days of continuous 20 Hz (24 hours day^{-1}) time series data from 12 towers were acquired beginning on June 23, 2002 until the end of the study July 09, 2002. At three of the sites, issues related to power supply necessitated operating the towers in flux rather than time series mode for several days. At all times during the intensive measurement period of the study, all towers were either recording high frequency (20 Hz) data or 30-min flux averages.

Instrumentation-ancillary

Each tower in the study was configured as a complete energy balance system. Ancillary data included continuous below ground measurements of soil heat flux (G) (REBS), temperature (Cu-Co, Type-T thermocouples), and water content (Vitel) for the 0-0.06 m layer below the surface to compute the most reliable estimates of soil heat flux (G) and storage. At each location 4-soil heat flux plates were spatially distributed to represent the contribution to *G* as a function of row space / orientation and vegetation cover. The *G* plates were buried 0.06 m below the soil surface. Two-soil thermocouples were located at 0.02 and 0.04 m above each soil heat flux plate. A soil water content sensor (Vitel) was placed at a depth of 0.05 m at each tower to provide a measure of the near-surface soil moisture condition.
Above ground measurements included net radiation, air temperature, relative humidity, and radiometric surface temperature. Net radiation (R_n) measurements were made with two types of sensors, a four component system from Kip & Zonen (CNR-1) which measured independent components of incoming and outgoing short and long-wave radiation and a thermopile version from REBS, the Q^*7.1 Seven towers were equipped with the Kip & Zonen sensor and seven with the REBS sensor. All net radiation measurements were made approximately 4 m above the surface for corn and 2.5 m for soybeans. Air temperature and humidity were measured with Vaisala HMP-35 sensors at each tower 2 m above the soil and as the season progressed above the vegetated surfaces. Radiometric temperatures were made using 2 Apogee high precision infrared (IRT) sensors at each tower. One IRT was positioned at 0.15 m above the soil surface (at a 45° view angle) and the second IRT was mounted at the same height as the net radiometer and positioned so that it obtained a nadir view of the soil/vegetated surface. All ancillary measurements were recorded on a separate (from the EC) data logger as 10-minute averages.

Instrument intercomparison

To aid in our ability to discern real differences from random noise or instrument bias, two intercomparisons were performed for the eddy covariance instruments. The first was conducted over a 0.15 m tall alfalfa field in early June prior to deployment in the watershed. The second was conducted in late August after all measurements were completed. The second intercomparison was made over a grass surface and included an intercomparison of the net radiation sensors as well. Soil heat flux plates were evaluated and calibrated in early May in the laboratory as well as the Vaisala temperature and humidity sensors that were calibrated with a dew-point hygrometer. Thus every attempt was made to characterize the variance of the instruments used to measure the four basic components of the surface energy balance, net radiation, soil and sensible heat and latent heat flux. All LI7500 sensors except one were recently evaluated and serviced by the manufacturer prior to deployment in Iowa.

3. DATA PROCESSING

The time series data were collected in binary form on Toshiba Libretto mini-computers. The data were stored onto 120 Mb PCMCIA storage cards. The PCMCIA cards were exchanged every 24 hours at dawn during which sensor input location values were evaluated to assess instrument performance. Sensor lenses (LI7500 and KH20) were cleaned every 72 hours with distilled water. Sonic orientation was examined and transducer pads were wiped clean of dust or spider webs. Binary data were post-processed to ASCII. The raw data were further processed into 1-hour blocks for each site. This process included the appropriate scan-offset correction. Due to differential pipeline delays in the data transfer among the sonic anemometer, LI7500 and KH20 instruments, this correction ensured the appropriate alignment of all measured variables of pressure, water vapor and carbon dioxide parameters with those of the sonic wind speed components (*u, v* and *w*) and sonic temperature T_s. The 1-hour blocks of were then evaluated for non-stationarity (trend) conditions and obvious instrument interference (from insects/water droplets) malfunction. Turbulent fluxes of *H, LE* and CO_2 as well as a number of turbulent statistics were computed for various time intervals. Initial computations of the fluxes included standard adjustments for heat and water vapor density effects (Webb, Pearman and Leuning, 1980) as well as the coordinate rotations outlined by Tanner and Thurtell, 1969 and Baldocchi, 1982).

4. PRELIMINARY RESULTS

The start of SMACEX began on June 20, (DOY 171) and ended on July 09 (DOY 191). After July 09, all of the towers operating in "time series" mode were converted to 30-min average flux mode and continued to collect data until the end of August.
During the SMACEX study period the corn and soybeans crops grew rapidly. Observations near EC towers indicated canopy heights starting at nominally 0.15 and 0.50 m, for soybean and corn respectively and reaching heights ~0.50 and 2.5 m by DOY 193. Due to the volume of data acquired from 12-eddy covariance towers at a scan rate of 20 Hz for 20 days we have initially selected four sites to illustrate some preliminary results. Figure 1 shows the spatial variability of the available energy (R_n–G) from 4 sites, two in corn and two in soybeans. Two 1-hour periods (1100 and 1200 hrs) for each of the four sites were selected from four days that represent approximately the beginning, middle and end of the 20–day intensive measurement period. Larger available energy values were generally observed on DOY 174 and 176 at the two corn sites compared to the soybeans. This was to be expected, as there was considerably more vegetation covering the soil surface at the corn sites relative to the soybeans. This becomes more evident in Fig. 2 which show the sensible heat flux values for the same times and locations as the available energy. On DOY 174 and 176 *H* values were clearly larger at the soybean sites than at the corn.

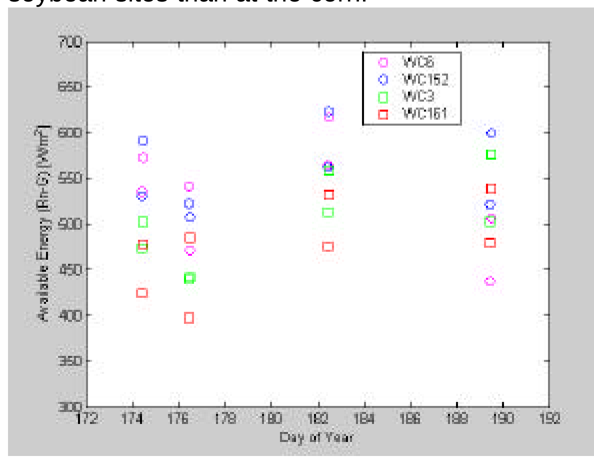

Figure 1. Spatial variability of two (1100 and 1200) hourly average available energy (R_n– G) measurements over corn (WC06 and WC152) and soybean (WC03 and WC161) fields.

This was the result of greater soil exposure (less vegetation) resulting in more incoming radiation to be reflected and as well a greater fraction of the incoming radiation to be used to heat the soil surface. The contrast between corn and soybeans for DOY 174 and 176 becomes progressively more evident when viewing *LE* and CO_2 fluxes shown in Figs. 3 and 4. There is more evaporation by nearly a factor of two occurring at the corn sites than at the soybeans. Carbon dioxide uptake can be seen to be nearly 4 times greater for corn than for soybeans. From DOY 171 to 184 no precipitation was recorded in the watershed. Plant stress was visibly apparent for corn and some soybean fields. Nevertheless plant biomass continued to increase for both corn and soybeans with more significant increases observed in the soybeans. On July 4, 5, and 6 (DOY 185,186 and 187) scattered thundershowers moved through the watershed. Rainfall accumulations were highly variable with the western half of the watershed receiving nearly on average double the precipitation relative to the central and eastern portions (13 mm vs. 26 mm). These types of precipitation patterns are not unusual for the Midwest region. Returning to Figure 1 and observing the available energy for DOY 189 the spatial variation is considerable. For DOY 189 two of the soybean sites showed greater available energy than three of the corn sites. Latent heat fluxes (Fig. 3) for two of the soybean sites were comparable to the corn with site 6 (western most field that received the most precipitation 30 mm) having the highest *LE* fluxes. Figure 2 supports the *LE* results, which show very low sensible heat flux values (<50 W m^{-2}) for all four sites indicating that a greater fraction of available energy was going into evaporation.

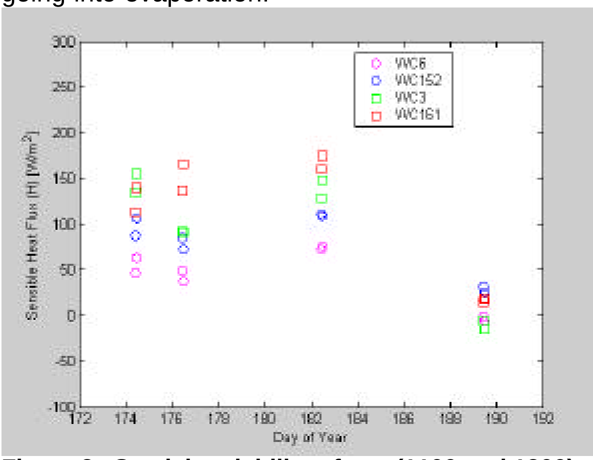

Figure 2. Spatial variability of two (1100 and 1200) hourly average sensible heat (H) measurements over corn (WC06 and WC152) and soybean (WC03 and WC161) fields.

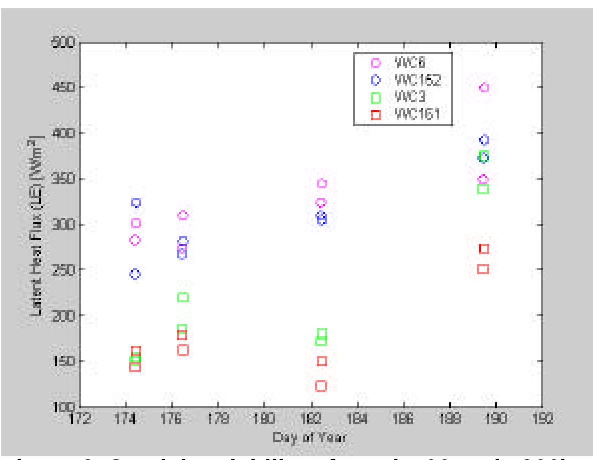

Figure 3. Spatial variability of two (1100 and 1200) hourly average latent heat (LE) measurements over corn (WC06 and WC152) and soybean (WC03 and WC161) fields.

Carbon dioxide fluxes for the corn exceeded 2 mg m^{-2} s^{-1} while for the soybean CO_2 flux rates nearly doubled compared to the previous week. Differences can be attributed to variation in soil moisture content and cloud cover across the watershed. Dramatic increases in vegetation height biomass and leaf area index in the soybean field may have also played a role. Detailed vegetation sampling data were collected on a weekly basis for EC tower and soil moisture sampling sites and are currently being analyzed and processed.

Figure 5 show the closure ratio of the energy balance measurements for the four towers. Here closure ratio is expressed as the ratio of *LE+H* to the available energy i.e. $(LE+H) / (R_n - G)$. In general a ratio of near unity (0.95 or better) is desired but not easily achieved. Figure 5 shows early in the study (DOY 174) rather poor closure results (~0.60) for both corn and soybean sites with only site 152 showing a slightly better result (~0.70). As the season progresses, corn closure ratios appear to improve while the soybean actually decreased. One point does stand out, on DOY 189 the range of closure values is at its largest relative to other previous days (0.53-0.83). This is puzzling however we are just in the initial analysis phase and will be incorporating further analysis techniques (e.g. Foken and Wichura, 1996, Lee, 1998, Finnigan, 1999, and Paw U, et al., 2000) to better evaluate our closure values.

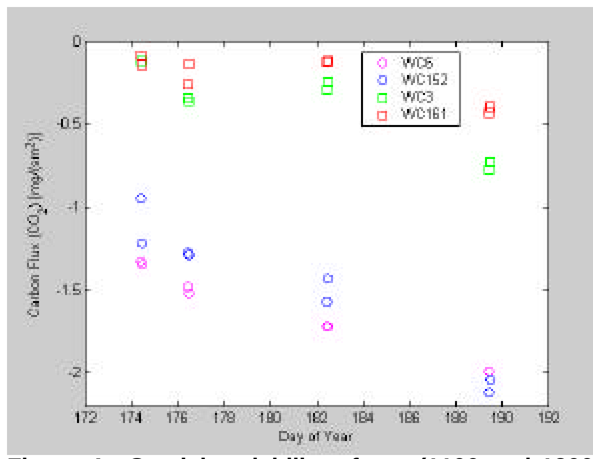

Figure 4. Spatial variability of two (1100 and 1200) hourly average carbon dioxide flux (CO_2) over corn (WC06 and WC152) and soybean (WC03 and WC161) fields.

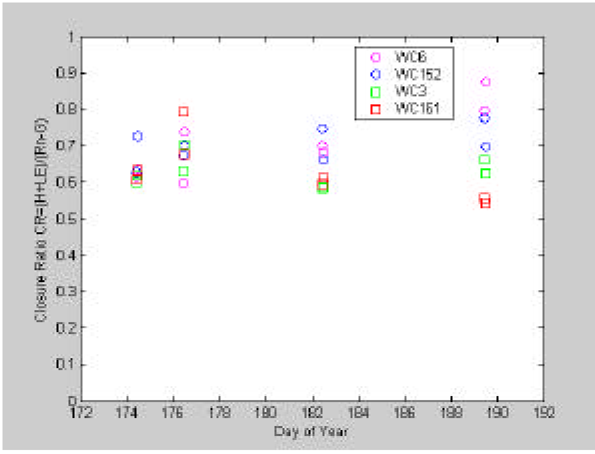

Figure 5. Spatial variability of two (1100 and 1200) hourly average energy closure ratios (H+LE / R_n – G) over corn (WC06 and WC152) and soybean (WC03 and WC161) fields.

5. SUMMARY COMMENTS

The first phase of the SMACEX project, was successful in the collection of water-energy-carbon fluxes, remotely sensed data from aircraft and satellite-based sensors, and atmospheric properties over a wide range of vegetation biomass/cover conditions and under both wet and dry surface soil moisture conditions. Preliminary results suggest a number of factors can contribute to the spatial variation in turbulence energy exchange. The period from emergence to full canopy is a period of rapid transitions in terms of vegetative cover and soil moisture contents both, which can significantly affect each of the energy balance components. At the time of this writing more analysis are being performed with the time series and flux average data after the intensive measurement period. Results will be presented at the conference.

6. ACKNOWLEGEMENTS

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