The design of LTRAS and data analysis

Steve Kaffka

1. The origin and basis for the LTRAS experiment's design

Attached to this email is the LTRAS map (Fig. 1). It does not reflect the division of corn/tomato plots into half plots based on tillage because the map was made prior to that event. Plot numbers are found in the center of each plot and will be referred to at times in what follows.

Bill Williams was primarily responsible for the LTRAS design. He labeled it an "unbalanced" or "confounded" split plot design. It is a split plot design because it has main plots (irrigation treatments) and subplots (cropping systems). As a whole (considering all ten cropping systems), it is unbalanced (or confounded) because the subplot treatments differ among the main plots.

Irrigation varies from none in rain fed wheat-fallow systems which have never been irrigated, to "intermediate" systems in which irrigation is applied only to the crop phase of the wheat/ fallow systems, to fully irrigated systems where two crops are grown in sequence, and both crops and at times cover crops are irrigated. Rain fall affects all plots equally.

Subplots vary by the amounts and types of N and C supplied as inputs (N level/source treatments) and by the types of pest and disease management techniques used (Table 1). Current average input use is listed in the Table 2 attached. The comparison at the subplot level is between entire cropping systems, not individual management practices (Denison et al, 2004). Consistent management of cropping systems over time, however, allows for clear inference about the causes of changes in soil properties or crop trends.

Irrigation main plots are abstract. In practice, there are three blocks (or replications) of all ten cropping system treatments. Also, since cropping systems are each two year rotations, there are both phases of the two year cropping system present. So each block contains 20 plots. See table 3. The blocks themselves are not based completely on plot proximity- i.e., are not regular in shape. Some compromise on layout was necessary when the irrigation system was installed. As a consequence, there was some limitation on where irrigated treatments were placed. They are aligned primarily on a diagonal from northwest to southeast through the center of the plots (see Figure 1). This makes allocation of treatments to blocks somewhat artificial and irregular in shape.

While the overall design is unbalanced, subsets or restricted combinations of cropping systems are balanced. The wheat systems (leaving out the exceptional wheat-tomato system), are balanced. There are two levels of irrigation treatments: rain fed (not irrigated) and irrigated, called "intermediate". Within irrigation systems there are three fertilization systems (unfertilized, WLCC, and fertilized). In addition, each phase of the system (wheat or fallow/WLCC), is present each year. This is a very important feature of crop rotation experiments, discussed in more detail below.

The tomato-wheat system is fully irrigated. It was included to reflect a common system in the Sacramento Valley area, to provide a comparison of wheat produced in a more intensively irrigated systems with the other wheat systems mentioned earlier, and to provide a bridge to the corn/tomato fully irrigated systems from the wheat-based ones. A direct comparison with one of the corn-tomato systems, the conventional one, is possible. The wheat/tomato system is not part of a balanced set of treatments. If it were, there would also be unfertilized and WLCC/ wheat-tomato systems. These were not included for three reasons: 1. because an unfertilized system was not reasonable farming practice and therefore uninteresting, 2. due to space and cost limitations, and 3. to favor additional corn-tomato systems.

The corn-tomato systems also are a balanced set of system comparisons (subplots) within the fully irrigated main plot. They provide a comparison of fertilization intensity and type. The organic system provides an interesting comparison of between biologically-based management and conventional and intermediate management. Intermediate systems have part fertilizer, part WLCC N/C inputs. Currently, in terms of C and N, the organic system is the highest input system. Like the wheat cropping systems, each crop is present each year. In theory, the rain fed wheat/fallow systems, the irrigated wheat/fallow systems and the corn/tomato systems provide a balanced set of comparisons based on irrigation intensity. But crops and cropping systems change within that comparison, confounding the influences due simply to irrigation.

One of the prudent things to do when designing a long-term experiment is to include some additional uncommitted plots for the inclusion of new treatments at a future date. This was done with the LTRAS experiment. Ford Denison and Elizabeth Martini started an organic transition experiment in year six, and began adding organic treatments to three then unassigned, but irrigated plots (Martini et al., 2005). These plots (# 2-2, 5-7, 7-4) have been managed organically ever since. In addition, other unassigned plots remain. Some of these have been used for companion experiments, particularly for variety trials related to the cropping systems comparisons, and a few for other miscellaneous purposes.

Another important feature of the LTRAS experiment is large plots. Large plots, if possible in long-tem experiments, allow for splitting at a future date when necessary or desirable. This was the case in 2002 when scientists with the SAFS group moved their new research focus on reduced tillage comparisons to the LTRAS experiment. For their purposes, the corn-tomato plots were split in half and randomly assigned to one of two tillage treatments, either the full tillage one used up to that time on all the LTRAS plots, or a reduced tillage treatment as determined by the SAFS group applied to the other half. The conventional tillage half plots remain consistent with previous years' treatments with the original LTRAS plots now operated for 12 years. This is essential for the sake of inference from year to year. Large plots allowed for new types of work within the core experiment while preserving the ability to make comparisons over the entire 12 year period using the standard tillage half -plots, proving the wisdom of having large plots.

Another innovation set up by Ford Denison that is of significant value is the microplot system (Fig. 2 attached). There are 40-15 foot square sub- or microplots in each one-acre LTRAS plot. These are located towards the outside of each plot. In microplots, researchers can make changes to the management systems applied to the larger plot in ways that allow them to test new methods or particular hypotheses. At the same time, the center of each plot remains unchanged for the sake of long-term continuity and is used for data and archival sample collection.

An additional feature of the LTRAS experiment since its establishment has been a soil, crop and fertilizer sample archive. Prior to planting the first crops, soils were collected to 2 m deep in five composited layers (4 cores per plot). These have been archived. Core locations are known. Additional soil samples have been collected periodically, most significantly after year 10 when all plots were again sampled (six cores per plot), this time to 3 m depth in eight composite samples. Electromagnetic Induction methods (EMI) have been used on the all the wheat plots to map soil electrical conductivity (correlated with soil texture). This provides a map of each plot based on estimates of EC_e. The corn/tomato plots have not been mapped yet because of the presence of reduced tillage treatments. Each year, all above ground plant material from crops is sub-sampled, dried and archived. There have also been aerial photographs taken in most years during the growing season that are archived.

2. Experimental design and data analysis

There are three important experimental design principles that are emphasized in the literature on long-term crop rotations (Cady, 1991). These are:

1. To include every crop every year
2. To randomize, and
3. To replicate

The first two principles are more important, however, than the third. Observations made over time can substitute for replication to some degree. The more observations, the less important replication becomes.

At LTRAS, the two-year *cropping systems* contain each *phase* of the cropping system each year. This eliminates year to year variation in weather or other stochastic factors as a confounding factor in making interpretation of cause and effect comparisons. It means that trends due to treatment comparisons can be detected much sooner and with greater certainty than if crops varied with year. Stochastic variation due to weather or other influences still is present in the data set as a function of *time* (year), which is important in assessing sustainability (Hanson, 1996(. Any sustainable system must tolerate stochastic variation.

Randomization at LTRAS was constrained by the practical need to locate irrigated plots nearer the central irrigation system axis. This might be ignored in data analysis, but in practice could also have an as yet undetermined effect on the amount of variance associated with *replication*- the block term in an analysis of variance. This issue might be eliminated by using the spatial location of plots to determine any trends in variance as a function of position.

All plots are replicated three times. Financial and practical management constraints limited replications to three. This is a small number of replications, but over time this becomes less important as differences due to system management become more pronounced.

Data analysis (ANOVA) has been based on a repeated measures approach in the past (Denison et al., 2004). More recently, a mixed models approach has become possible (Singh and Jones, 2002,; Littell et al., 1996). Regression analysis is less dependent on treatment design if based on continuous variables like the amount of irrigation water applied (together with rainfall) and the amount of N and C added to plots over time. It is not clear how to separate out the effects of irrigation amounts from the types of crops produced. So the analysis of the main effects of irrigation and N/C inputs may be best done using this approach because of the confounding factor of changing cropping systems within irrigation main plots. Alternatively, some way or diverse ways of normalizing important measurements like crop yield or soil organic matter content could be devised to carry out an integrated analysis of all ten cropping systems combined. This has not yet been carried out, but is an objective of mine and some others in the next year.

The wheat/tomato fully irrigated plots, however, provide one simple way to link the irrigation treatments in a continuous analysis based on irrigation intensity. In this case, the subset of all fertilized plots including wheat can be compared for the effects of irrigation over time on the yield of wheat. These are the effects of time on wheat (how treatment means change over time), and the irrigation by time interaction (how treatment differences change over time). Another way to analyze the set of wheat data is to analyze the balanced set of wheat treatments to evaluate the effects of irrigating the wheat crop versus not irrigating the wheat crop. In this instance, the N amount/source treatments are subplots of the two irrigation treatments (rain fed and intermediate). Results from this analysis will be available at the meeting.

In essence, the judgment about sustainability based on these and other data from LTRAS data are based on trends in yield over time (+, -, 0), and changes in the differences among treatments, if any. This type of information may not be all that is required to inform a discussion about the sustainability of agriculture, but it is essential to such a discussion and represents an objective measure of one or more fundamental agricultural properties over time. Any correlated variable such as some measure of crop or soil quality can also be analyzed in this way.

When the corn/tomato plots were split, tillage treatments were allocated at random to each half of the plot. The allocation of degrees of freedom is given in the Table 4 for a single year's comparison. Since the reduced tillage methods used have changed each of the last three years, it may be best to analyze results on a year by year basis.

Changes in design

If the cropping systems were converted to three or four year rotations, more plots would be needed to accommodate the longer rotations. A three year rotation would require 27 irrigated plots. If a wheat/corn/tomato rotation is used, then the wheat/tomato plots can be added with a very smooth transition. The three transitional organic plots can also be added and the number of plots needed would equal 27. No new irrigated plots are needed to accomplish this change.

If instead, a four year crop rotation is used, and three replications are maintained, then all 72 plots within the LTRAS site would be needed and all of them would have to be irrigated. This would involve abandoning the wheat/fallow systems and a significant expense. In fact, given that the weather station is located in one of the LTRAS plots, and an observation well in another, there are not enough plots available for this option.

If a 4 year rotation was used but reduced to 2 reps, then 48 irrigated plots would be needed. Currently, there are 45 irrigated plots, so three more would have to be added. This would also involve abandoning all the irrigated plots in the wheat fallow systems.

If one replication of the current wheat/fallow systems was dropped, six more irrigated plots would become available, and 12 more un-irrigated plots. Some of the un-irrigated plots could be irrigated if funds were found for this purpose.

All increases in the number of irrigated plots and ant additions of cropping systems that make the experiment more complex will increase its yearly cost of operation.

References

Cady, F.B., (1991). Experimental design and data management of rotation experiments. Agron. J. 83:50-56.
Denison, R. F., Bryant, D.C., and Kearney, T.E., (2004). Crop yields over the first nine years of LTRAS, along-term comparison of field crop systems in a Mediterranean climate. Field Crops Research 86:267-277
Hanson, J.W. (1996). Is agricultural sustainability a useful concept? Agric. Sys. 50:117-143.
Kaffka, S.R., Bryant, D., and Denison, F. (2005). Comparisons of organic and conventional maize and tomato cropping systems for a long-term experiment in California. P 218-221.In: Kopke, U., Niggli, U., Neuhoff, D., Cornish, P., Lockeretz, W., and Willer, H. (Eds.). Researching Sustainable Systems. Proc. Of the First Sci. Conf. Of the International Soc. Of Organic Farming Research (ISOFAR). Research Institute of Organic Agriculture, Ackerstrasse, CH-5070 Frick, Switzerland.
Littell, R.C., Milliken, G.A., Stroup, W. W., and Wolfinger, R.D.,. (1996). SAS System for Mixed Models. SAS institute, Cary, North Carolina.
Martini, E.A., Buyer, J.S., Bryant, D.C., Hartz, T.K., Barrett, D., and Denison, R. F. (2004). Yield increases during the organic transition: improving soil quality or increasing experience? Field Crops Research. 85:255-266.
Singh, M, and Jones, M.J. (2002). Modeling yield sustainability for different rotations in long-term barley trials. J. of Agric, Biol., and Environmental Statistics, 7(4):525-535.

TABLES

Table 1. LTRAS cropping systems

System	**Abbr.**	**Odd years**	**Even years**
Rainfed wheat control	**RWC**	unfertilized wheat	fallow
Rainfed wheat/legume	**RWL**	unfertilized wheat	legume cover crop
Rainfed wheat/ fallow	**RWF**	fertilized wheat	fallow
Irrigated wheat control	**IWC**	unfertilized wheat	fallow
Irrigated wheat/legume	**IWL**	unfertilized wheat	legume cover crop
Irrigated wheat/ fallow	**IWF**	fertilized wheat	legume cover crop
Irrigated conventional wheat/tomato	**CWT**	fertilized wheat	fertilized tomato
Irrigated conventional corn/tomato	**CCT**	fertilized corn	fertilized tomato
Irrigated intermediate corn/tomato	**LCT**	winter legume followed by corn	fertilized tomato
Irrigated organic/corn/tomato	**OCT**	winter legume with compost to corn	winter legume with compost to tomato

Table 3. Data for single year combined ANOVA

Source	**df**
Blocks (b-1)	2
Treatments (cropping systems) (t-1)	19
Residual (b-1) (t-1)	38
Total (b*t-1)	59

Table 4. Corn/tomato two year rotations: n=management systems (3), b=reps or blocks, (3), c= crops (2), ts= tillage systems (2)

Source of variance	**df**
total (n* b* c* t -1)	35
main plots (n*b-1)	8
b (b-1)	2
n (n-1)	2
main plot error (b-1) (n-1)	4
crops (c-1)	1
c*n	2
sub-plot error (b-1)(c-1) = (b-1)(n-1)(c-1)	6
tillage systems (ts-1)	1
n*ts (n-1)(ts-1)	2
c*ts (c-1)(ts-1)	1
n*c*ts (n-1)(c-1)(ts-1)	2
residual or subplot error (b-1)*(t s-1)+(b-1) ((c-1)*(ts-1))+(b-1)((n-1)(c-1)(ts-1)	12

Table 2, next page

TOMATO 2004

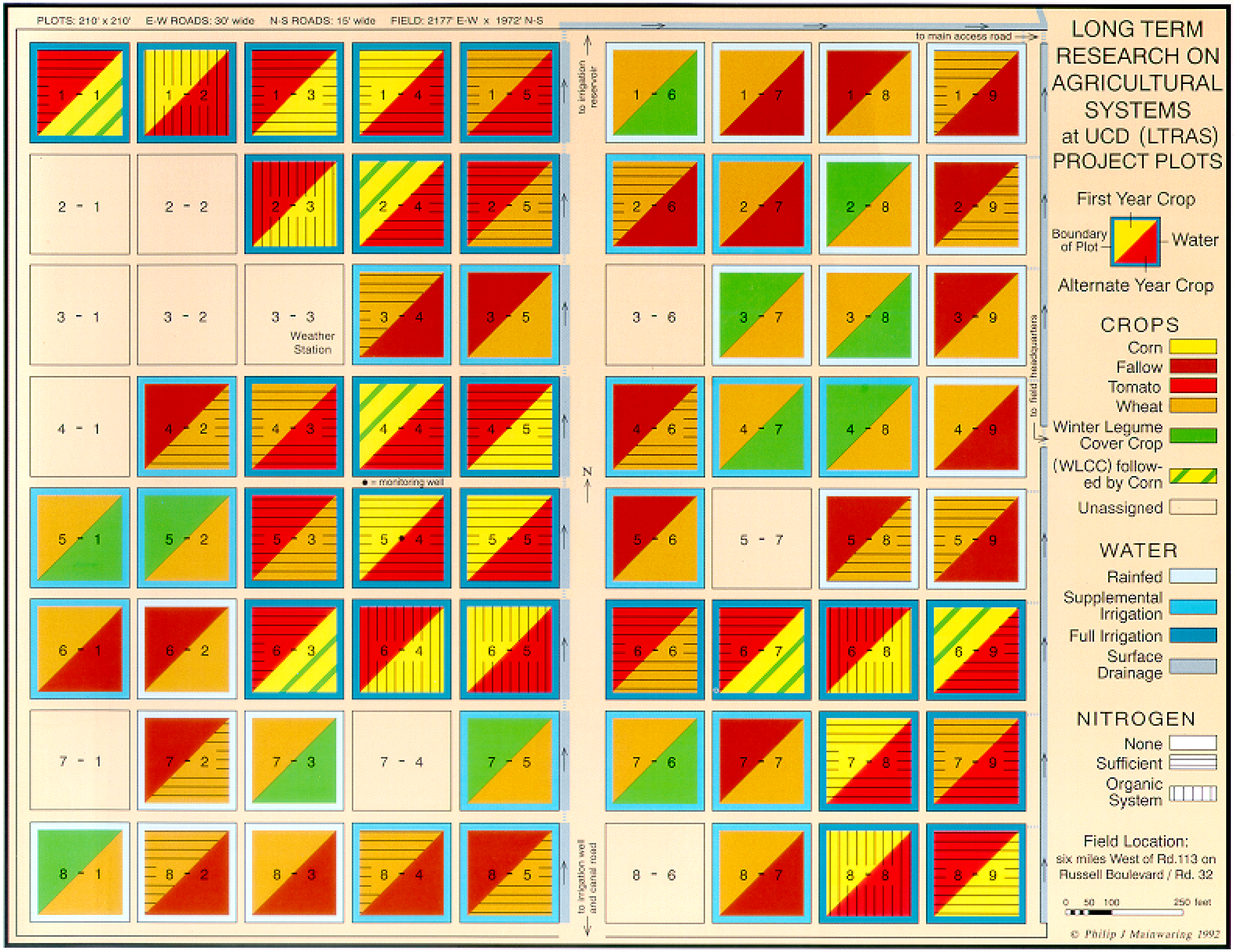
	WINTER LEGUME COVER CROPS	CONVENTIONAL	WHEAT	ORGANIC
Variety	Halley 3155 transplanted @ 10,500 plants/A			
Herbicide	1) Treflan bed center band 2) Treflan + Dual			Lana vetch/Magnus pea Composted poultry litter 4 ton (wet wt) Herbicide: NONE
Nutrient Inputs	Lana vetch/Magnus pea	1) 45 lb N,P,K/A preplant 2) 100 lbN/A ammon. Sulfate	1) 45 lb N,P,K/A preplant 2) 100 lb N/A (ammonsulfate)	
Irrigation	Furrow run, sufficient as required			

CORN 2004

	WINTER LEGUME COVER CROPS		CONVENTIONAL		ORGANIC	
Variety	ST 7570RR		ST 7570RR		ST 7570	
Seed/rate Pla	24,500		32,500		32,500	
	CT	ST	CT	ST	CT	ST
Herbicide	Roundup	Bladex Dual	Roundup	Bladex Dual pre-plant	NONE	NONE
Nutgrient Inputs seed rate	Cover crop: Lana vetch Mangus winter pea vetch 40lb/p80lb./A		1) 45lb N, P, K/acre Triple 15 granules 2) 165 lb N/acre urea		Cover Crop: Lana vetch/Magnus pea Composted Poultry Litter 4 ton (wet wt) (Foster Farms)	
Irrigation	Furrow run, sufficient as required					

WHEAT 2004

	IRRIGATED				RAINFED		
	WHEAT-TOM	WHEAT-FALLOW	WHEAT-WLCC	WHEAT-FALLOW (CONTROL)	WHEAT-FALLOW	WHEAT-WLCC	WHEAT-FALLOW (CONTROL)
Variety	Summit				Summit		
Plant rate	120lb seed/A				120 lbs/A		
Herbicide	Puma/Buctril				Puma/Buctril		
Irrigation	Spring Suppliment				None		
Nutrient Inputs	1) 100 lb N/A pre-plant ammon. nitrate 2) Top dress 50 lb N/A urea solution as foliar		Alt year Lana vetch/Magnum pea (40 lb + 80 lb/A)	NONE	1) 75lb N/A pre-plant ammon. nitrate 2) 25lbN/A Urea foliar solution	Alt. Year Lana vetch/ Magnum pea 40lb + 80lb /A	NONE


PLOTS: 210' x 210'   E-W ROADS: 30' wide   N-S ROADS: 15' wide   FIELD: 2177' E-W x 1972' N-S
LONG TERM RESEARCH ON AGRICULTURAL SYSTEMS at UCD (LTRAS) PROJECT PLOTS
First Year Crop
Boundary of Plot
Water
Alternate Year Crop
CROPS
Corn
Fallow
Tomato
Wheat
Winter Legume Cover Crop
(WLCC) followed by Corn
Unassigned
WATER
Rainfed
Supplemental Irrigation
Full Irrigation
Surface Drainage
NITROGEN
None
Sufficient
Organic System
Field Location:
six miles West of Rd.113 on Russell Boulevard / Rd. 32
0 50 100 250 feet
© Philip J Mainwaring 1992
to main access road
to irrigation reservoir
to field headquarters
to irrigation well and canal road
N
• = monitoring well
Weather Station
1 - 1
1 - 2
1 - 3
1 - 4
1 - 5
1 - 6
1 - 7
1 - 8
1 - 9
2 - 1
2 - 2
2 - 3
2 - 4
2 - 5
2 - 6
2 - 7
2 - 8
2 - 9
3 - 1
3 - 2
3 - 3
3 - 4
3 - 5
3 - 6
3 - 7
3 - 8
3 - 9
4 - 1
4 - 2
4 - 3
4 - 4
4 - 5
4 - 6
4 - 7
4 - 8
4 - 9
5 - 1
5 - 2
5 - 3
5 - 4
5 - 5
5 - 6
5 - 7
5 - 8
5 - 9
6 - 1
6 - 2
6 - 3
6 - 4
6 - 5
6 - 6
6 - 7
6 - 8
6 - 9
7 - 1
7 - 2
7 - 3
7 - 4
7 - 5
7 - 6
7 - 7
7 - 8
7 - 9
8 - 1
8 - 2
8 - 3
8 - 4
8 - 5
8 - 6
8 - 7
8 - 8
8 - 9

Bed numbers for systems w/ 5 ft beds (tomato, wheat)