Breaking Soybean Yield Barriers: Integrating Crop Production Practices & Comprehensive Fertilization Strategies – a Cropping System Approach (IRRIGATED & DRYLAND Research Studies)

Summary
Two soybean research trials were conducted near Scandia, KS, in both dryland and irrigated environments. The objective of this research was to study the contribution of different farming practices for developing efficient and high-yielding soybean production systems. Each experiments had five treatments: farmer practices (FP), comprehensive fertilization (CF), production intensity (PI), ecological intensification (EI = CF+PI) and advanced plus (AD). Under dryland, FP and CF treatments each yielded 34 bu/A, differing on average 27 bu/A compared with the PI, EI, and AD scenarios. Under irrigation, FP and CF presented comparable yield levels, but differed on average 35 bu/A compared with the intensified treatments (PI, EI, and AD).

Introduction
Yield gaps between potential and actual on-farm yield is primarily defined by crop management practices (e.g., row spacing, planting date, fungicide & nutrient application, among several others) and the interactions of those with the environment (weather and soil type). For example, Kansas producers have shifted soybean planting to earlier-calendar dates at a rate of about 0.5 d/yr since 1980's. Thus, after considering genetics and the environment, on-farm yield is primarily influenced by farmers' decisions. Agronomic practices are the main components of the farmer decision-making process. Crop management practices are often environment, hybrid/variety, and/or yield-level specific. Row spacing, plant population, nutrient management, and other agronomic practices can affect crop yields. By selecting appropriate management practices farmers can increase yields and close yield gaps. Increasing plant population and narrowing rows are two common intensification practices to pursue high-yielding soybean systems.

Procedures
Two soybean research trials, one dryland and the other irrigated, were conducted near Scandia, KS at the KSU North Central Kansas Experiment Field. The soybean maturity utilized in this experiment was a group 4.0, planted on May 14, 2014. The experiment was design following five production systems:

1) farmer practice (FP) – common farming practices (120,000 seeds/A + no-inoculation + no-nutrient application + 30" row spacing),
2) comprehensive fertilization (CF) – balancing nutrients (120,000 seeds/A + inoculation + nutrient application + 30" row spacing),
3) production intensity (PI) – narrowing rows and increasing plant population (180,000 seeds/A + inoculation + no-nutrient application + 15" row spacing),
4) ecological intensification (EI)– CF+PI (180,000 seeds/A + inoculation + nutrient application + 15" row spacing)
5) advanced plus (AD) further enhanced nutrient input applications (180,000 seeds/A + inoculation + nutrient application + 15" row spacing).

The treatment details are presented in **Table 1**. Each treatment was replicated five times. The soybean crop was harvested on October 15, 2014.

Table 1. Details of soybean production system treatments.

Common Practices	Treatment				
	Famer Practices (FP)	Comprehensive Fertilization (CF)	Production Intensity (PI)	Ecological Intensification (CF+ PI)	Advanced Plus (AP)
Tillage (fall/spring)	Depending on the site				
Seed Treatment	Fungicide + Insecticide				
Herbicide management	PRE + POST herbicide applications				
Agronomic management	**Famer Practices (FP)**	**Comprehensive Fertilization (CF)**	**Production Intensity (PI)**	**Ecological Intensification (CF+ PI)**	**Advanced Plus (AP)**
Soybean maturity	3.5-4.0	3.5-4.0	3.5-4.0	3.5-4.0	3.5-4.0
Row Spacing	wider	wider	narrow	narrow	narrow
Fungicide Application	NO	NO	R3	R3	R1 & R3
Plant Growth Regulator	NO	NO	YES	YES	YES
Inoculation	None	Commercial Inoculant	Commercial Inoculant	Commercial Inoculant	Commercial Inoculant
Target seeding ate (seeds/acre)	Farmer Plant Population	Farmer Plant Population	Optimum Plant Population	Optimum Plant Population	Optimum Plant Population
Nutrient management	**Standard**	**Advanced**	**Standard**	**Advanced**	**Plus**
P and K strategy	Without P & K	University Guidelines	Without P & K	University Guidelines	P-K-Non-limiting Factors
Sulfur + Zinc (Pre-Plant)	0	With S	0	With S	Sulfur as non-limiting factor
Micros (B + Zn + Mn)	0	R3 (single application)	0	R3 (single application)	R1 & R3 (single application)
N fertilizer	**No (control)**	**Yes**	**No (control)**	**Yes**	**Yes**
Total lb N/ac	0	50	0	50	
Reproductive N (late - R3)	0	N + Slow Release Product	0	N + Slow Release Product	N + Slow Release Product

Weather – 2014 Growing Season

The weather conditions in the 2014 growing season influenced the final yields in both soybean dryland and irrigated studies. For the temperature, maximum and minimum historical (4-yr average) variations presented similar trends as for the 2014 growing season (**Figure 1**).

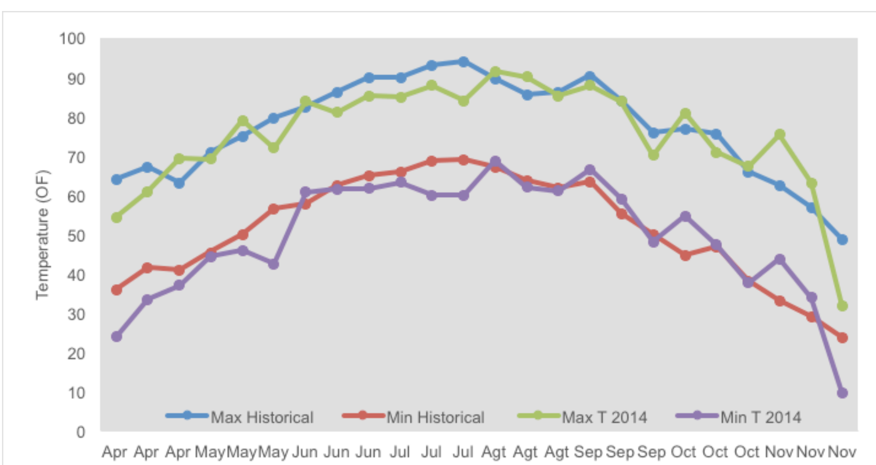

Figure 1. Historical (4-yr average) and 2014 growing season maximum and minimum temperature, Scandia, KS.

The historical growing season precipitation pattern for the study area peaks during the month of August (beginning–first two weeks of the month) (**Figure 2**). The 2014 growing season precipitation depicted a very dissimilar pattern than the historical weather trend. The 2014 precipitation was more concentrated during the last week of August and first two weeks of September, totaling nearly 16-inches during that 3-week period (**Figure 2**). This precipitation period coincides with the soybean R3-R4 growth stage.

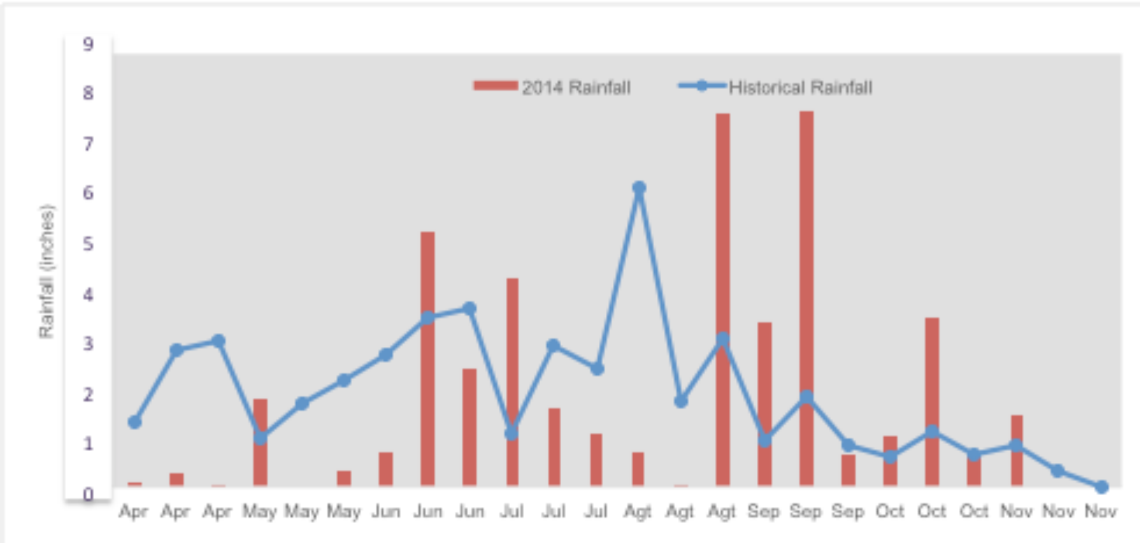

Figure 2. Historical (4-yr average) and 2014 precipitation record, Scandia, KS.

Phenological Information
Irrigated and dryland soybean trials were planted in two blocks, with and without irrigation applied, respectively. Complete information related to planting date and phenology is presented in **Table 2**. Soil characterization before planting can be reviewed in **Table 3**.

Table 2. Phenological data for the 2014 growing season for soybean.

Scandia Phenological Data	**Soybean**
Soybean Variety	MG 4.0
Planting Date	05/14/14
Emergence Date (VE)	05/24/14
Silking Date (R1)	08/04/14
Maturity	10/09/14
Harvest Time	10/15/14

Table 3. Soil characterization before planting time.

Scandia Soybean Studies	**OM%**	**$N0_3$-N (ppm)**	**pH**	**Buffer pH**	**P (ppm)**
Irrigated	2.7	12.9	4.9	5.9	68.5
Dryland	3.1	22.5	6.3	6.6	18.2

Results

Yields- Dryland study

Under dryland, FP and CF scenarios presented equal soybean yields (34 bu/A), differing on average 27 bu/A compared with the higher intensity treatments (PI, EI, and AD). The yields among PI, EI, and AD did not significantly differ, averaging 61 bu/A (**Figure 3**).

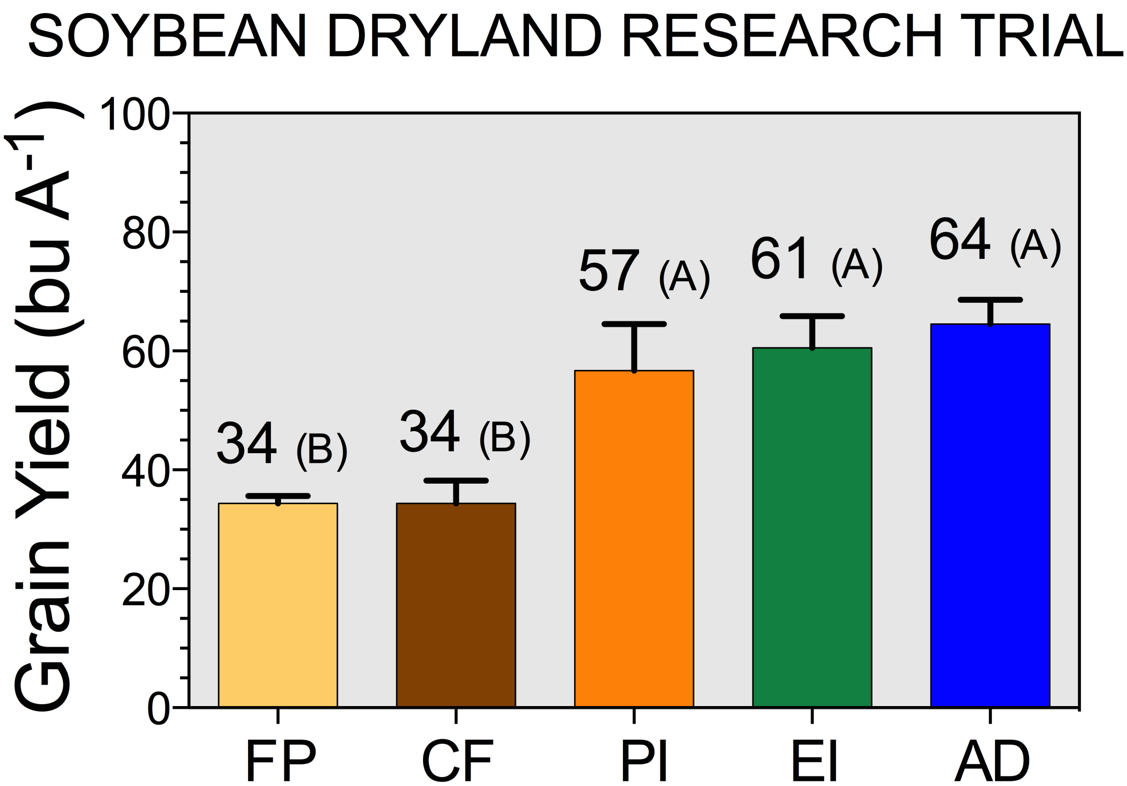

Figure 3. Soybean grain yield (13% moisture), expressed in bu/A, for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

Yields- Irrigated study

The FP and CF treatments presented comparable yields (48 bu/A average), differing on average 35 bu/A with the intensified crop production treatments (PI, EI, and AD). There was no significant difference in yields among the intensified treatments, where yields averaged 83 bu/A (**Figure 4**).

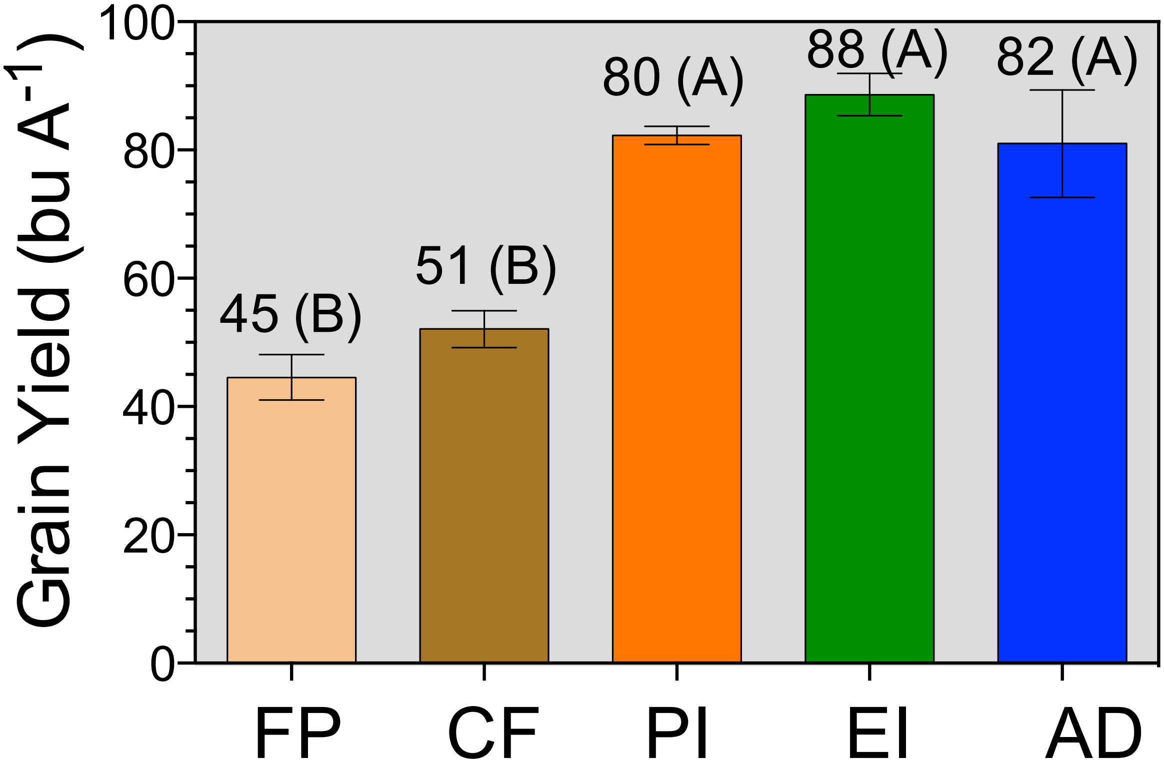

Figure 4. Soybean grain yield (13% moisture), expressed in bu/A, for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

Economic Evaluation, Dryland & Irrigated Studies

The yield gap documented between the FP and the intensive use of inputs (PI, EI, AD) for dryland and irrigated sites ranged from 27 to 35 bu/A. Assuming a soybean price per bushel ranging between \$8-9, then the gross profit per acre increased by \$200-250/A. The use of more inputs can produce an extra cost (seed, fungicide, fertilizer, and plant growth regulators) of \$25-75/A. Thus, promoting greater plant population, narrowing rows, and increasing the use of inputs can increase net profits and final nutrient utilization.

Biomass, Grain Harvest Index and Nitrogen Uptake: Dryland vs. Irrigated Scenarios

For the dryland environment, whole-plant biomass (aboveground biomass, dry basis) was maximized in the PI treatment, presenting similar plant biomass values for the rest of the treatments with exception of the FP (6,762 lb/A). Under full irrigation, plant biomass was maximized in the EI treatment (12,333 lb/A), presenting the following ranking from high to low plant biomass: EI>PI>CF>AD>FP (**Figure 5**). The main distinctions between dryland and irrigated environments for plant biomass were:

1- maximum plant biomass (dry basis) was 12,333 lb/A for irrigated (EI) vs. 8,255 lb/A for dryland (PI).

2- biomass gap between FP vs. rest of the treatments was of 1,015 lb/A for dryland vs. 4,332 lb/A for irrigated (larger difference –four-fold under irrigation).
3- minimum plant biomass was observed with the FP treatment, 6,762 lb/A in dryland vs. 7,474 lb/A under full irrigation.

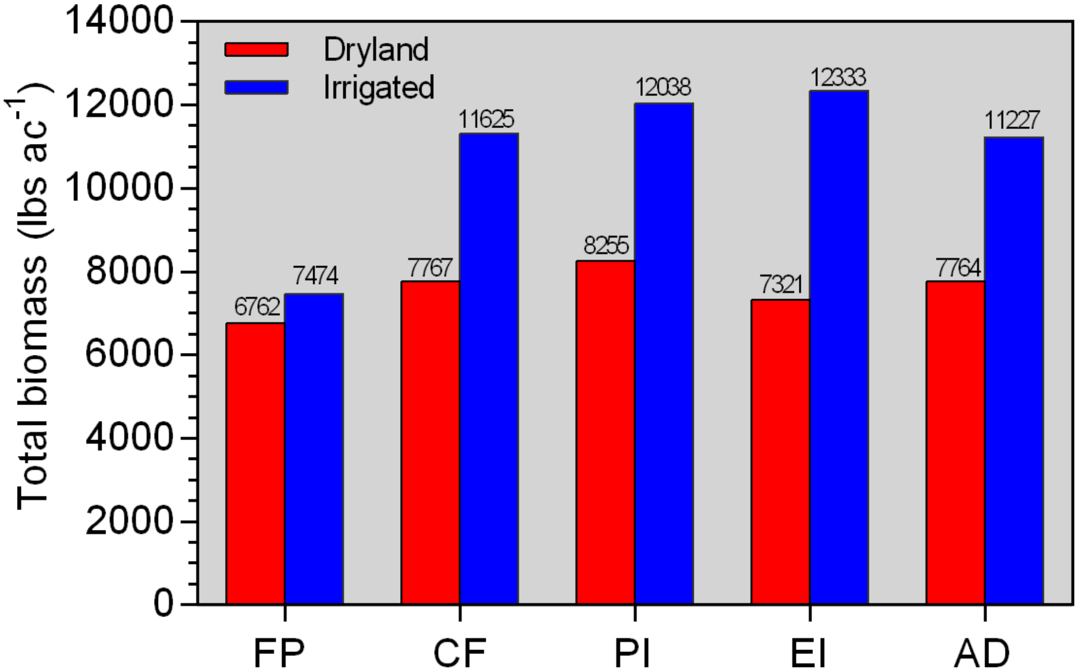

Figure 5. Soybean whole-plant biomass (dry basis), expressed in lb/A, under both dryland and irrigated sites for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

Grain harvest index (HI) was calculated as the ratio of the grain biomass to the whole-plant biomass –grain + stover- (dry basis). Under dryland, grain HI was maximized for the EI and AD treatments (0.5 units). Minimum grain HI was observed in the FP and CF treatments, 0.31 and 0.27 units, respectively (**Figure 6**). Overall, the irrigated site presented a lower grain HI (0.43 units) as compared to the dryland site (0.50 units). The grain HI ranking recorded under irrigation was similar to that obtained in the dryland site, from high to low grain HI: EI=AD>PI>FP>CF. The lower grain HI obtained under full irrigation (compared to dryland) for the high-yielding treatments (PI, EI, & AD) may help identify plant trait factors that can be improved for closing soybean yield gaps. If the grain HI obtained under full irrigation can be increased to that documented in dryland (from 0.43 to 0.50 units), grain yields can increase by 15 bu/A (exceeding the 100 bu/A yield barrier). The lowest grain HI registered in the CF treatment (0.27 units), for both water scenarios, might be related to an imbalance between the source (leaf production) and sink (pods and grain number) forces, i.e., greater plant biomass production with low efficiency in grain conversion.

Leaf Area Index (Irrigated site)
Leaf area index (LAI, expressed in leaf area produced per soil area) evolution throughout the entire growing season followed a bell-shaped function in the irrigated site, with smaller differences among treatments at the peak of the LAI (maximum of 5 units) around flowering time. Larger absolute differences were documented during the reproductive stages, with the EI and CF treatments depicting a "stay-green" trait (longer functional –photosynthetic- duration of the grain-fill period). The AD treatment presented the highest LAI value around flowering, but declined rapidly thereafter (**Figure 7**). The above-mentioned trend could be explained by potential foliar damage experienced with the successive foliar applications during the reproductive stages (extra application of fungicide/insecticide as compared with the EI treatment). Therefore, superior stay-green and yield potential could be expected if leaf tissue remained functional (similar to the EI).

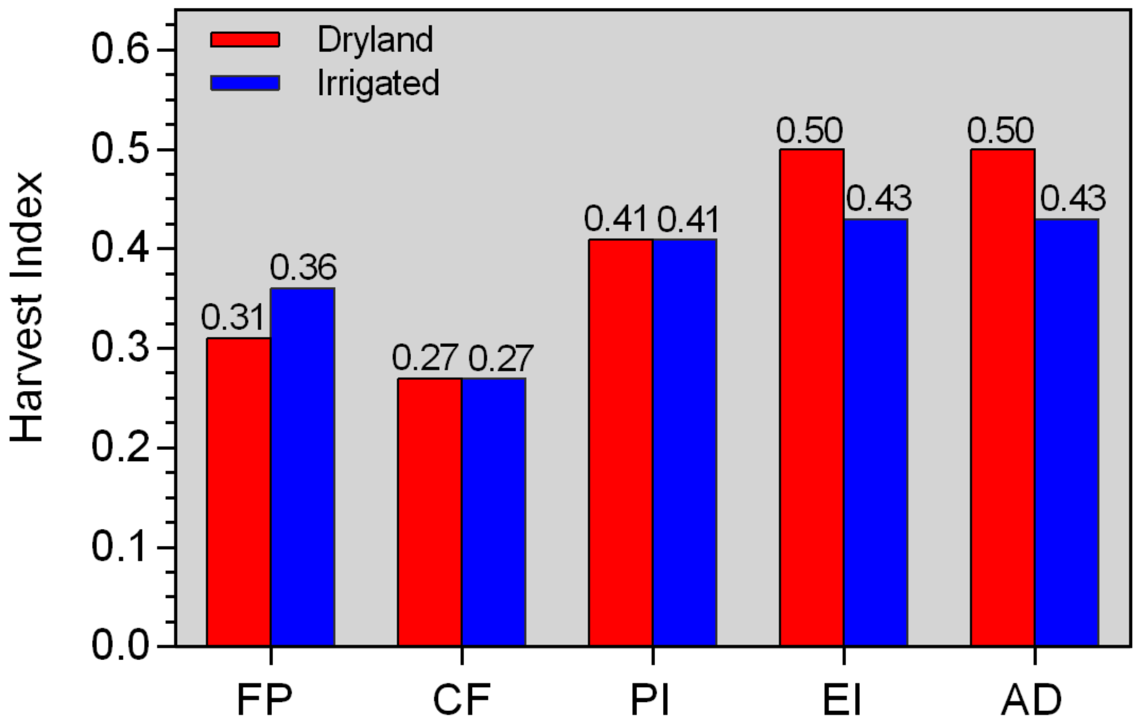

Figure 6. Grain harvest index (dry basis), calculated as the ratio between grain and whole-plant biomass fractions (dimensionless), under both dryland (blue bars) and irrigated sites (red bars) for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

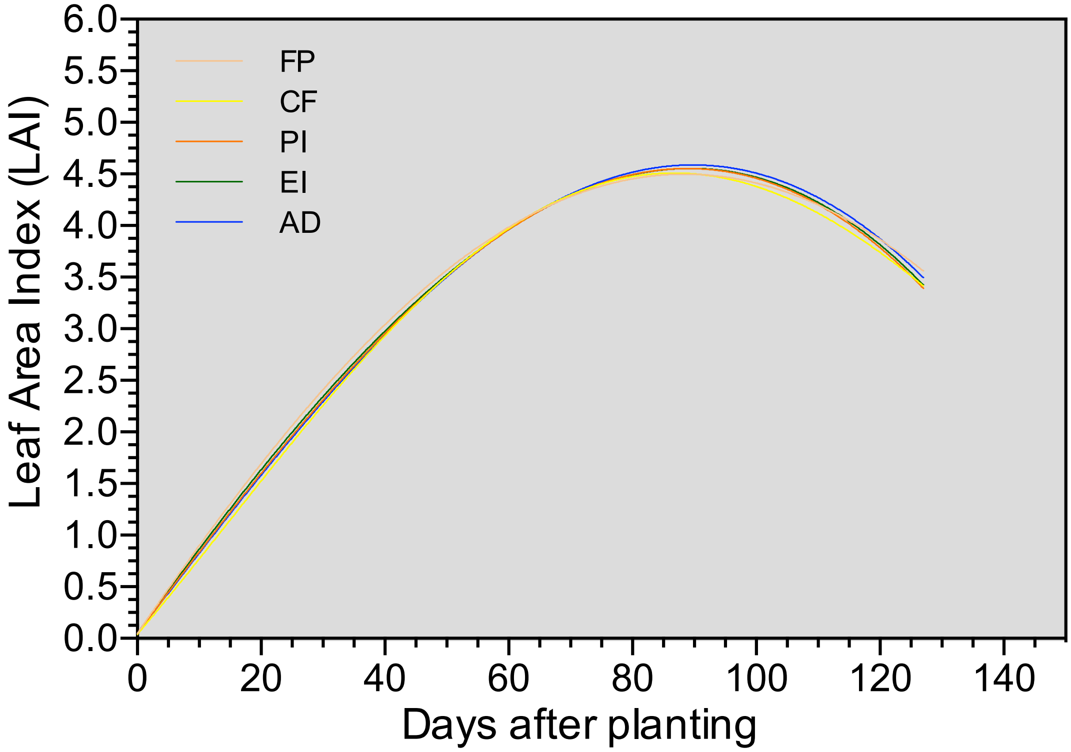

Figure 7. Leaf Area Index (m^2 m^{-2}) under full irrigation for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

Plant Nitrogen Uptake and Efficiencies (N harvest index)

Plant nitrogen (N) uptake was determined for both grain and stover (leaf, stem, and rest of reproductive structures) plant fractions. For dryland, maximum total plant N uptake –including both grain + stover- was recorded for the AD treatment (365 lb N/A), with similar values for the PI and EI treatments (**Figure 8**). Minimum plant N uptake was recorded for the FP treatment (219 lb N/A). The plant N uptake pattern generally follows that of grain yield depicted in **Figure 3**. The stover N content was similar across cropping systems approaches, ranging from 87 (FP) to 137 (PI) lb N/A. The primary difference was the efficiency of partitioning N to the grain, or so called N harvest index (NHI). Average NHI across treatments was 0.61 units. The NHI ranking from high to low for the dryland site was: 0.68(AD)=(EI)>0.61 (FP)>0.60 (PI)>0.50 (CF) (**Figure 8**).

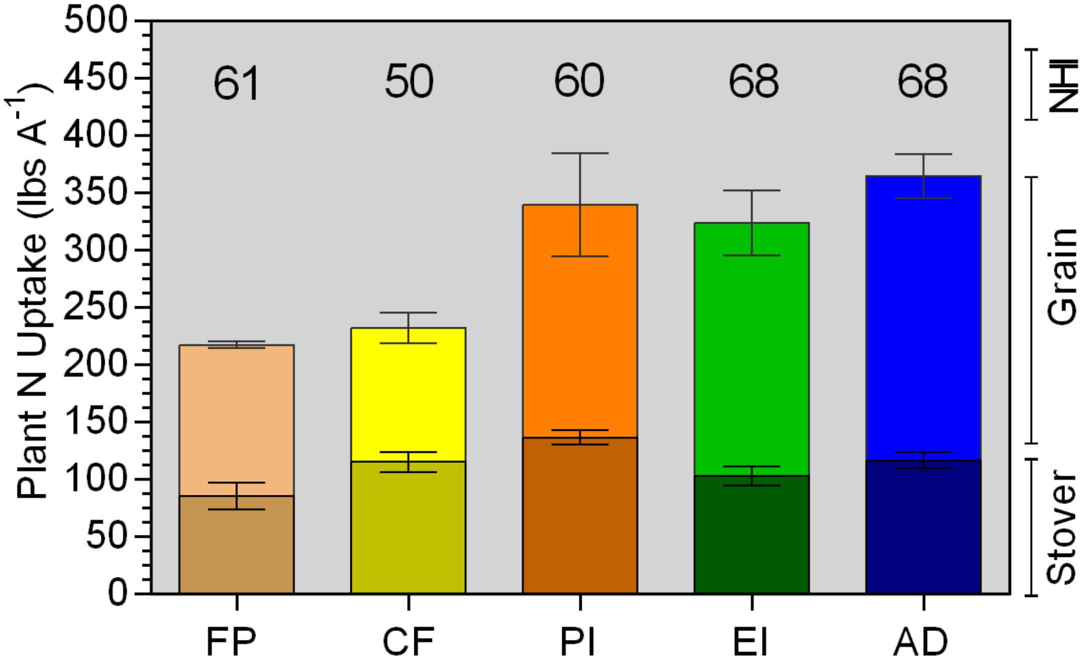

Figure 8. Stover and grain (whole-plant) nitrogen (N) uptake (dry basis), expressed in lb/A, under dryland site for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

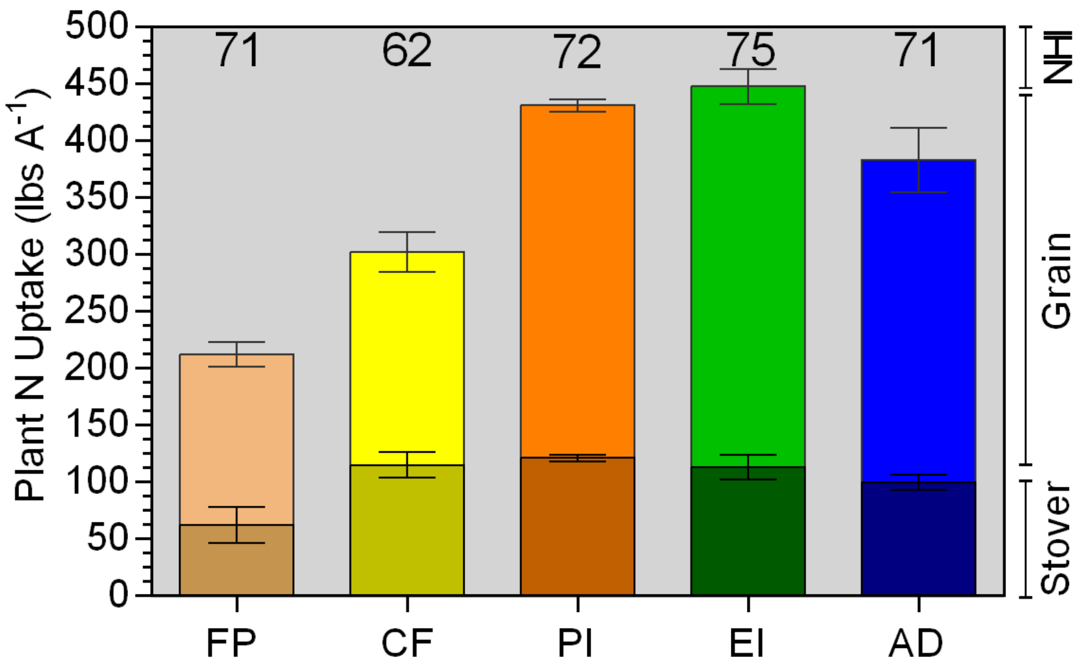

Figure 9. Stover and grain (whole-plant) nitrogen (N) uptake (dry basis), expressed in lb/A, under full irrigation for diverse farming scenarios: FP = farmer practice; CF = comprehensive fertilization; PI = production intensity; EI = ecological intensification; and AD = advanced treatment.

Under full irrigation, maximum plant N uptake was observed in the EI treatment (448 lb N/A), followed by the PI (431 lb N/A) and the AD treatments (383 lbs N/A) (**Figure 9**). Minimum plant N uptake was recorded for the FP treatment (212 lb N/A). The stover N content ranged from 62 (FP) to 113-121 (EI-PI) lb N/A (**Figure 9**). The N conversion to the grain, or NHI (grain N: whole-plant N ratio) for the irrigated site averaged 0.70 units, which was greater than that for the dryland site (0.61). Maximum NHI was recorded in treatment EI (0.75 units). The NHI ranking from high to low was: 0.75 (EI) > 0.72 (PI) > 0.71 (AD) = (FP) > 0.62 (CP) (**Figure 9**).

Relationship between Grain Yield and Plant Nitrogen Uptake

A relationship between grain yield and whole-plant N uptake was performed for all treatments (mean values) under both dryland and irrigated conditions (yellow circles; **Figure 10**). Information collected from previous published and unpublished scientific manuscripts was also included (green squares) (Ciampitti, Balboa et al., unpublished). The 2014 season findings from this study follow a similar pattern as the historical dataset (**Figure 10**), and are in agreement with the soybean N review project previously published by Salvagiotti et al. (2008).

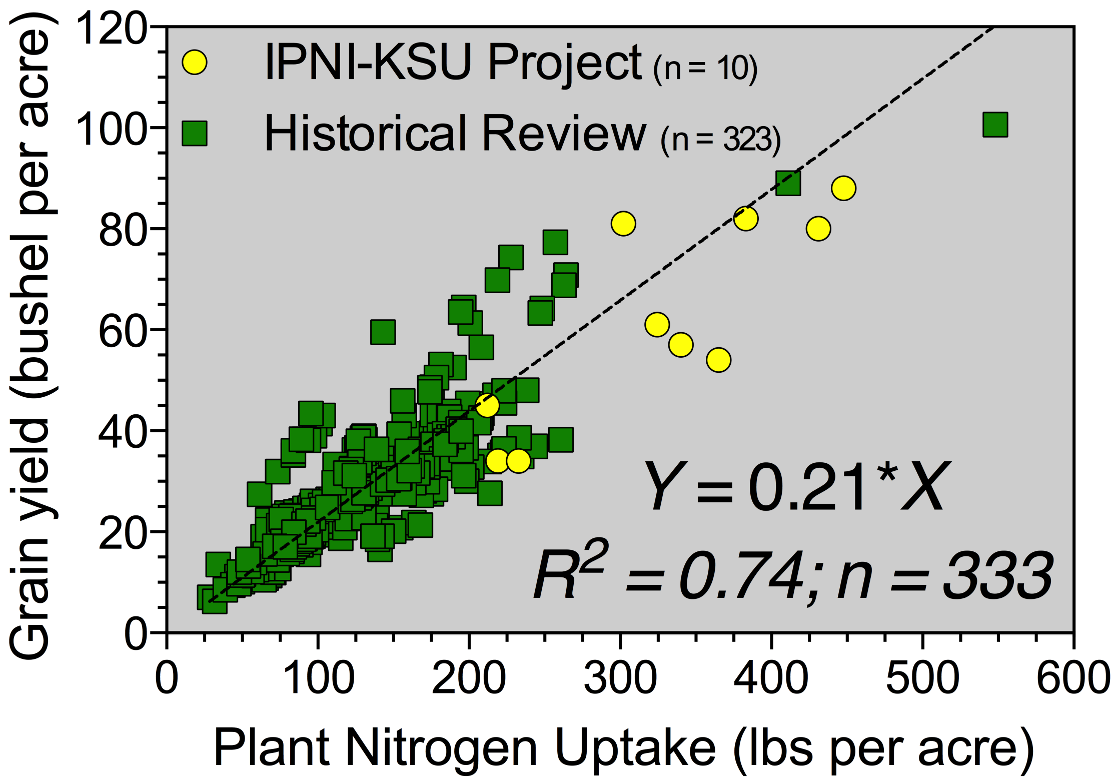

Figure 10. Grain yield versus plant N uptake relationship for historical literature review (green squares; Ciampitti, Balboa et al., unpublished) and for the information obtained during the 2014 (yellow circles) growing season (5 treatments –cropping systems- x 2 water scenarios, dryland vs. irrigated).

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Irrigated

Dryland