Intensive Soybean Management: An Integrated Systems Approach

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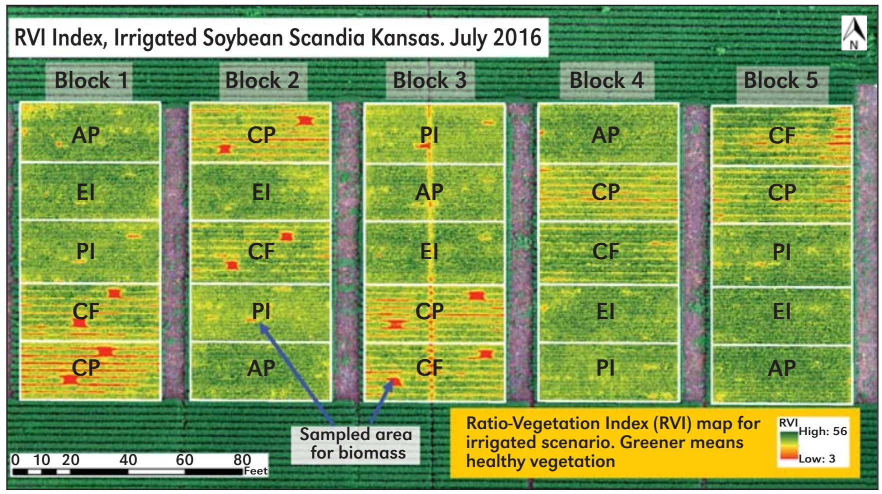
Ecological intensification impacted soybean yield, biomass and N uptake. Narrow row spacing, high seeding rate, other best production practices, and balanced nutrition increased partitioning efficiency for biomass, measured by seed harvest index (HI), grain N, and N HI (NHI).

Partial factor productivity of fertilizer (PFPf) increased when best production and fertilizer management practices were implemented in combination, with 19% and 28% increases under irrigated and dryland scenarios, respectively.

An integrated approach, simultaneously considering multiple management factors in a farming system, is needed for closing exploitable yield gaps.

The "Yield gap" can be defined as the difference between the yield that is attainable in a region (maximum yield without abiotic or biotic stresses) and the actual on-farm yield. Selecting the best crop and nutrient management practices (e.g., genotype selection, row spacing, planting date, and nutrient 4Rs—right source, rate, time, and place), and considering their interactions with each other and with the environment (soil, weather), will directly impact the size of this gap. In recent years, several soybean studies have evaluated the effect of fertilizer applications or crop management practices individually, but research investigating the impact of these factors on seed yield in an integrated system approach is scarce.

"Liebig's Law of the Minimum" establishes that growth is controlled by the most limited resource or factor. Following this rationale, when nutrients are supplied in a complete and balanced program according to plant demand, crop yield will then be limited by some other factor such as light interception or water availability. The objective of this work was to test an integrated farming system approach that simultaneously considers both crop nutrition and crop management practices, and thereby further the understanding of cropping systems based on the concept of Ecological Intensification (Cassman, 1999).



Aerial image showing differences in the Ratio-Vegetation Index [the ratio of infrared reflectance over visible red reflectance (NIR/VR)] for irrigated soybean at Scandia, Kansas. Green color is correlated with healthy growth.

Table 1. Treatment description for soybean experiment at Scandia, Kansas, average of 2014-2015 growing seasons.

Treatments	CP	CF	PI	EI	AP
Seeding rate, seeds/A	111,000	111,000	134,000	134,000	134,000
Row spacing, in.	30	30	15	15	15
Fertilization	No	(P-K-S)	No	(N*-P-K-S)	(N*P-K-S)
Micronutrients	No	No	No	1x (Fe, Zn, B)*	2x (Fe, Zn, B)**
Fungicide/Insecticide	No	No	No	1x**	2x**

CP=common practices, CF= comprehensive fertilization, PI= production intensity, EI= ecological intensification (CF+PI), AP= advanced plus. *Applied at R3. **Applied at R1 and R3. Fertilizer rates in lb N-P_2O_5-K_2O-S/A: (56-9-31-8) and (56-13-43-11) for dryland and irrigated. Treatment CF did not receive any N application.

Soybean studies were carried out in 2014 and 2015 at Scandia, Kansas, under both dryland and irrigated conditions each year. For each of the four site-years, five farming systems ranging from very low to intensive use of inputs were tested. The following treatments were evaluated: Common Practices (CP), Comprehensive Fertilization (CF), Production Intensity (PI), Ecological Intensification (EI), and Advanced Plus (AP) (**Table 1**). The main difference between CP and CF treatments was that fertilizer (P, K, and S) was added for the CF treatment. For the PI treatment, seeding rate was increased by 23,000 seeds/A over CP, row spacing was narrowed from 30 to 15 in., and no fertilizer was added. The EI treatment is a combination of CF and PI, with a seeding rate of 134,000 seeds/A, row spacing of 15 in., balanced macro plus micronutrient fertilization, and fungicide/insecticide applications. Average precipitation for both seasons was 16.3 in. and the irrigated scenario received an average of 6.9 in. of water. Lastly, AP was similar to the EI treatment, but with a more intensive (2x) use of micronutrients and fungicide/insecticide.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; B = boron; Fe = iron; Zn = zinc. IPNI Project GBL 62.

Detailed crop phenology (V4, V6, R1, R5, R7), seasonal plant dry biomass, nutrient concentration, and canopy coverage were evaluated in all site-years.

Harvest index (HI) and N Harvest Index (NHI) were determined as follows:

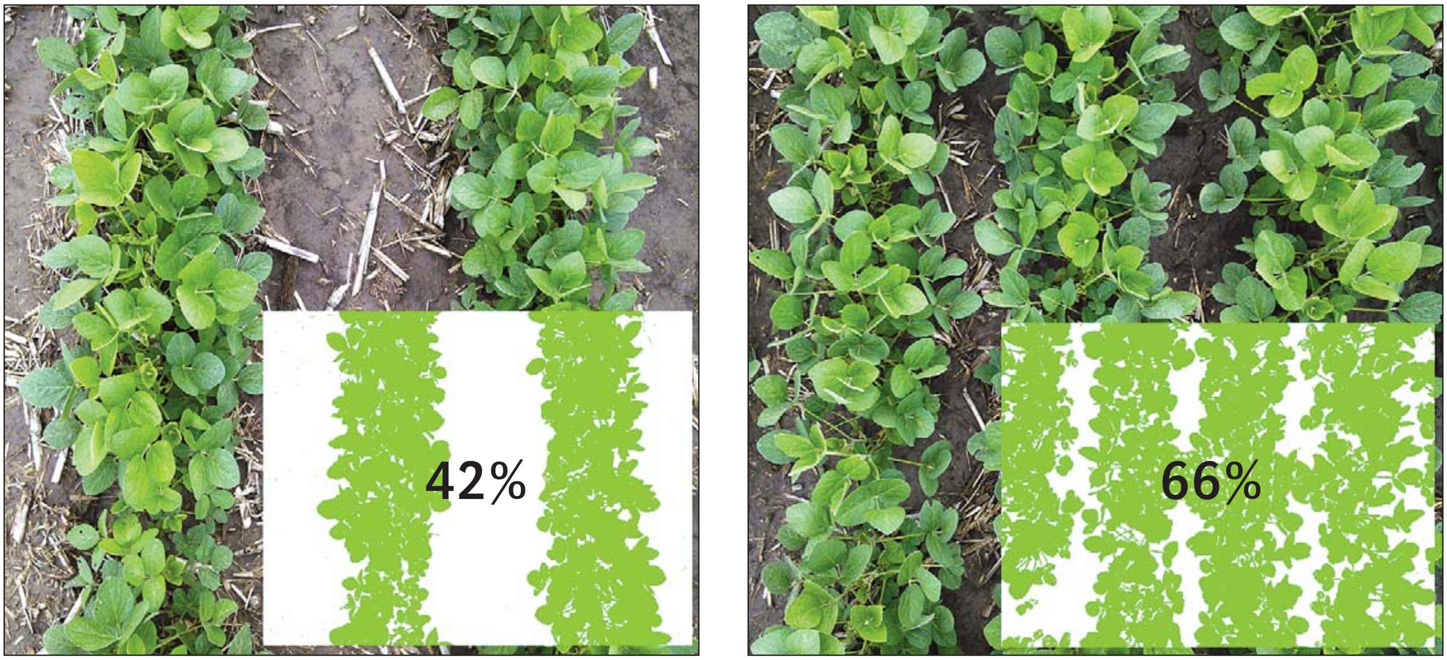


Figure 1. Soybean canopy coverage for treatment CP (left) and EI (right) at phenological stage V4 Scandia, Kansas, 2015 growing season. Image inserts and percent cover were produced using Siscob® software from EMBRAPA.

HI = Seed (lb/A) / Plant Biomass (lb/A)

NHI = Seed N Content (lb/A) / Plant N Content (lb/A)

The partial factor productivity of fertilizer (PFPf), was calculated as the ratio of yield to fertilizer applied ($N+P_2O_5+K_2O+S$) for both CP and EI.

Results

Visible differences in canopy coverage at phenological stage V4 (four-trifoliolate) in soybeans were detected by image analysis (**Figure 1**). Under irrigated conditions, canopy coverage for the CP treatment was 42%, while for the EI treatment coverage was 66%. This greater early season coverage with the EI treatment resulted in more light interception and likely increased efficiency of carbon to biomass conversion.

Seed Yield

Two-year average soybean seed yields are presented in **Figure 2**. Dryland seed yield averaged across treatments and years was 43 bu/A. The maximum average dryland yield was attained in the AP treatment (53 bu/A), but was not statistically different from the PI (48 bu/A) and EI (51 bu/A) treatments. The average of these three more intensive treatments (PI, EI, and AP) was 51 bu/A. The CP and CF treatments both yielded 31 bu/A. Thus, the exploitable yield gap calculated from this data for the dryland scenario was 20 bu/A. Although the soybean yields for the PI and EI treatments were not statistically different, the PI treatment is depleting soil nutrients and therefore risking the yield potential of future crops. In fact, in this study when corn followed soybeans, a large corn yield reduction (20 bu/A in 2015) was documented in the PI compared to the EI treatment, directly reflecting the impact of the negative nutrient balance in the soybean phase.

For the irrigated scenario, seed yield averaged across treatments and years was 69 bu/A, 26 bu/A more than the overall average under dryland conditions. Increasing production intensity by narrowing row spacing and increasing seeding rate increased yield by 24 bu/A, from 52 bu/A in the CP treatment to 76 bu/A for the PI treatment (**Figure 2**). While yields for the CP (52 bu/A) and CF (57 bu/A) treatments were numerically different, that difference was not statistically significant. The average across the lower intensity treatments (CP and CF) was 54 bu/A. The maximum irrigated yield was attained by combining the fertilizer and crop management practices in the EI treatment (82 bu/A), and although this was the highest yield, it was not significantly different from the PI (76 bu/A) and AP (80 bu/A) treatments. The average of these three more intensive treatments (PI, EI, and AP) was 79 bu/A. Therefore, the exploitable yield gap calculated from the irrigated scenario was 25 bu/A. On average, each in. of water applied produced 3.6 bu of soybean.

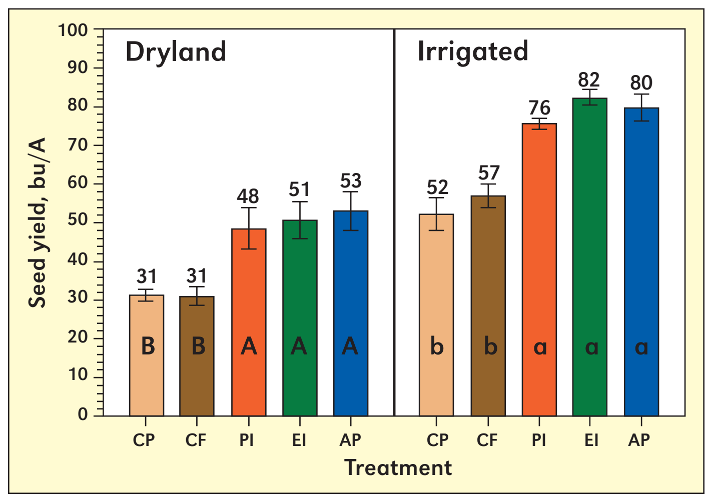


Figure 2. Soybean seed yield for dryland and irrigated conditions at Scandia, Kansas, average of 2014-2015 growing seasons. Letters within columns indicate statistical differences for seed yield ($p<0.05$).

Under irrigated conditions the PFPf, or seed yield divided by the total quantity of fertilizer applied, was 14 (lb yield/lb

Table 2. Total biomass production, stover, and seed harvest index (HI) under dryland and irrigated conditions (Scandia, KS), average of 2014-15 growing seasons.

	Dry biomass, lb/A		Stover, lb/A		HI	
Treatments	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated
CP	7,516 b	9,024 c	5,667 a	5,915 c	0.25 c	0.34 a
CF	7,399 b	11,653 b	5,570 a	8,254 b	0.25 c	0.29 b
PI	9,632 a	13,759 a	6,804 a	9,247 a	0.29 b	0.33 a
EI	8,693 a	14,853 a	5,748 a	9,935 a	0.34 a	0.33 a
AP	9,356 a	14,449 a	6,281 a	9,687 a	0.33 a	0.33 a

CP=common practices, CF= comprehensive fertilization, PI= production intensity, EI= ecological intensification (CF+PI), AP= advanced plus. HI=Harvest Index. Letters indicate statistical differences (p<0.05).

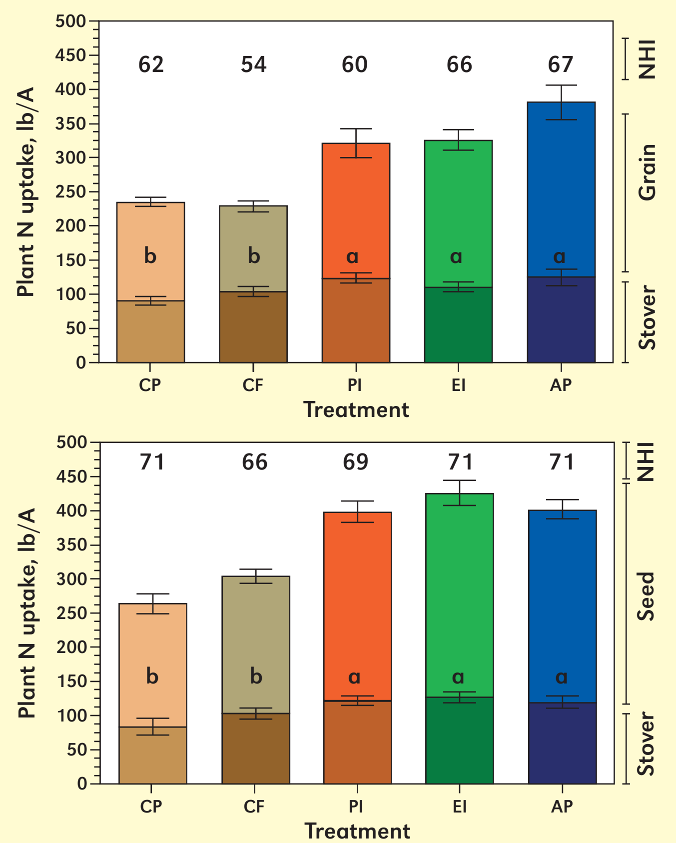


Figure 3. Plant N uptake and Nitrogen Harvest Index (NHI) for soybean treatments under dryland (top) and irrigated (bottom) environments at Scandia Kansas, average of 2014-2015 growing seasons. Letters within columns indicate statistical differences for plant N uptake (p<0.05).

fertilizer) for the CP treatment and 17 for the EI treatment. For the dryland environment, PFPf for CP was 11, and for EI it was 14. The PFPf for EI treatment was 19% greater under irrigation, and 28% greater under dryland conditions than the CP treatment. By intensifying production practices (narrow row spacing and increasing seeding rate), each unit of fertilizer added to the system was more efficient in producing seed yield.

Total Plant Biomass and Seed Harvest Index

Under irrigated conditions total biomass production averaged 12,748 lb/A, which was 50% greater than the dryland scenario (**Table 2**). The CP treatment consistently produced less total plant biomass and stover than the rest of the treatments under irrigation. Under dryland conditions, total plant biomass followed the same trend as seed yield (**Figure 2**), and treatments with more intensification (PI, EI, and AP) produced 24% (or 1,770 lb/A) more biomass than the CP-CF treatments. Under irrigation, the more intensive treatments increased biomass by 39% (or 4,015 lb/A) over the CP-CF treatment average (**Table 2**). Balanced nutrition alone (CF) under irrigation increased total biomass production by 29% (or 2,629 lb/A) relative to the CP treatment; and a 65% (or 5,829 lb/A) increase in biomass was documented when balanced nutrition was combined with the more intensive EI management.

In summary, this study demonstrated a large impact of fertilizer and crop management practices on total plant biomass production under both dryland and irrigated scenarios. As for the seed HI component, under dryland conditions, intensifying production increased yields via improvement of seed HI; while under irrigated conditions the intensification process was primarily governed via changes in total plant biomass (**Table 2**).

Total N Uptake

The increase in total plant biomass corresponded with an increase in total plant N uptake. Total plant N uptake averaged across the two seasons ranged from 230 to 380 lb/A under dryland and 270 to 425 lb/A for the irrigated conditions (**Figure 3**). For both water availability scenarios, the more intensified treatments (PI, EI, and AP) resulted in greater plant N uptake relative to CP-CF treatments. A stable trend in NHI was observed across the treatments under irrigation, with an average of 70% of total aboveground N in the seed. The NHI for treatments under dryland conditions was less predictable, but tended to be higher with the EI and AP treatments. Under dryland conditions the average aboveground N in the seed was 62%, which was 8% less than for the irrigated treatments.

Seasonal Plant Biomass, Nitrogen, and Partitioning

The seasonal plant biomass and N dynamics presented here will focus on the CP and EI treatments of the irrigated environment. Large differences in seasonal biomass accumulation were observed from low (CP, **Figure 4a**) to the high (EI, **Figure 4b**) intensification treatments. At flowering (R1 stage), cumulative plant biomass relative to the final end-season value was lower (16%) for the EI treatment than the CP treatment (27%). A lower value means that a higher proportion of total plant biomass (more than 80%) for the EI treatment was accumulated during the most critical stages of the reproductive period. The EI treatment accumulated 60% more biomass by the end of the season than the CP treatment. This additional EI treatment biomass was primarily produced after the beginning of flowering (R1), with a stable rate of accumulation up until the end of the grain-filling period (**Figures 4a** and **4b**). This difference in total plant biomass and seasonal accumulation was the main factor governing yield differences between these two "input" scenarios, since the difference in HI between EI

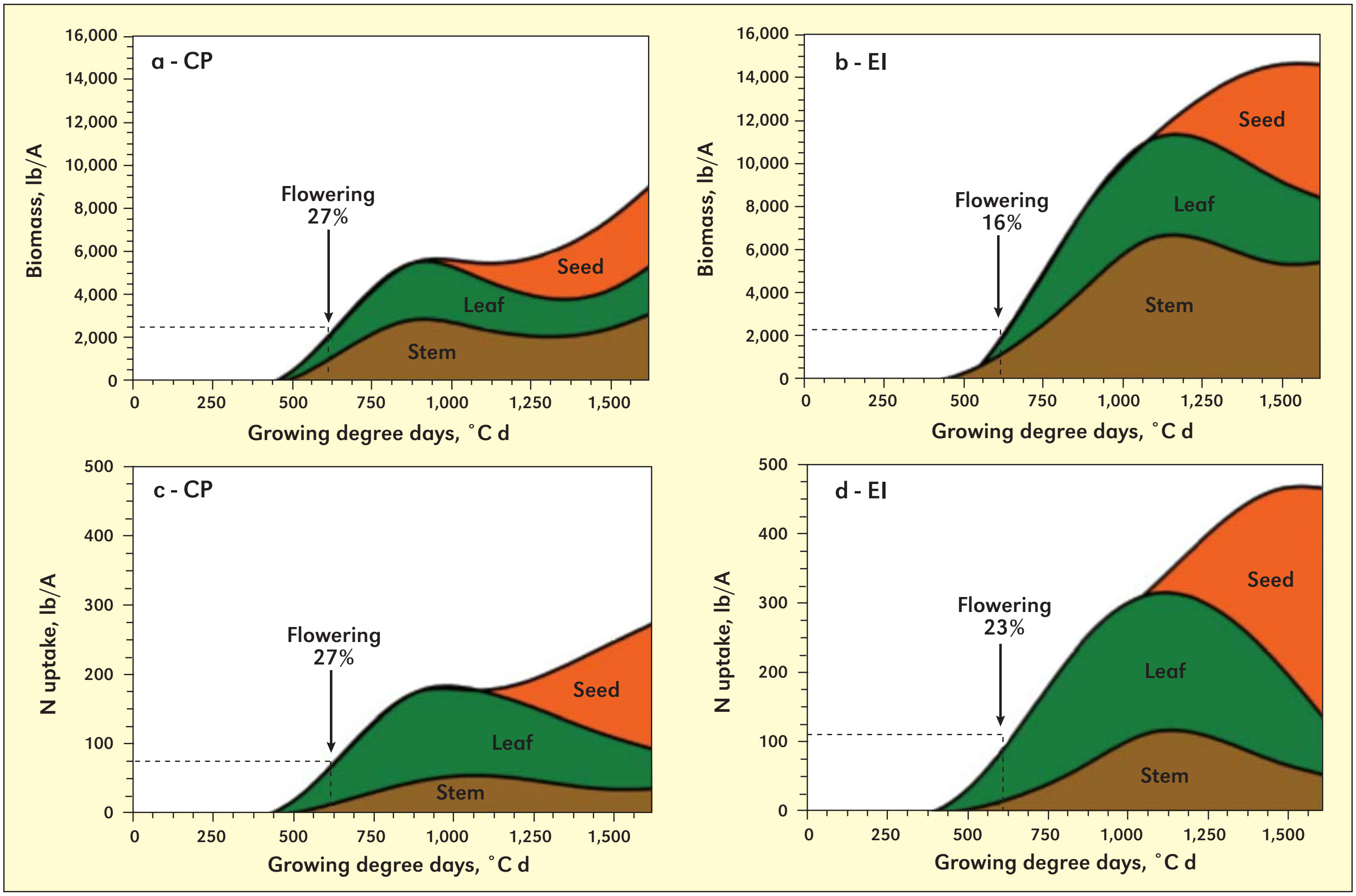


Figure 4. Soybean seasonal plant biomass and N uptake for common practice (CP) and ecological intensification (EI) by plant fractions in the irrigated scenario at Scandia, Kansas, average of 2014-2015 growing seasons.

and CP treatments was negligible.

Seasonal N uptake for the CP and EI treatments followed the same patterns as plant biomass accumulation (**Figures 4c** and **4d**). Greater plant N uptake—close to two-fold—was observed with the high-yielding EI treatment compared to CP. The lower N uptake with CP corresponded with lower yield compared to the EI treatment. Furthermore, the greater N uptake for EI was accompanied by a 5% improvement in seed N partitioning (NHI of 71% for EI vs. 66% for CP).

Summary

Intensifying productivity via utilization of improved fertilizer and crop management practices (i.e., narrower row spacing, higher seeding rate, and balanced nutrition) impacted plant biomass, N uptake, and the partitioning efficiency measured by seed HI and NHI components.

Nitrogen partitioning, or NHI, increased with the intensification of the farming system; meanwhile, seed HI remained unchanged under the high-yielding, irrigated environment. In this environment, balanced nutrition was a key factor in sustaining greater biomass and N uptake.

Early light interception, which was greater for EI than CP, was not translated into early biomass changes; however, a greater rate and duration of plant growth was documented during the late-reproductive period with better early canopy coverage and light interception, as was indicated by the ultimate 60% greater biomass with EI compared to CP.

Sustainable intensification of soybean production systems requires an integrated approach, which combines optimal nutrient and crop production practices that result in improved efficiency of the overall farming system.

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