A Framework to Improve Nitrogen Fertilizer Use Efficiency in Intensive Vegetable Systems of Hawaii

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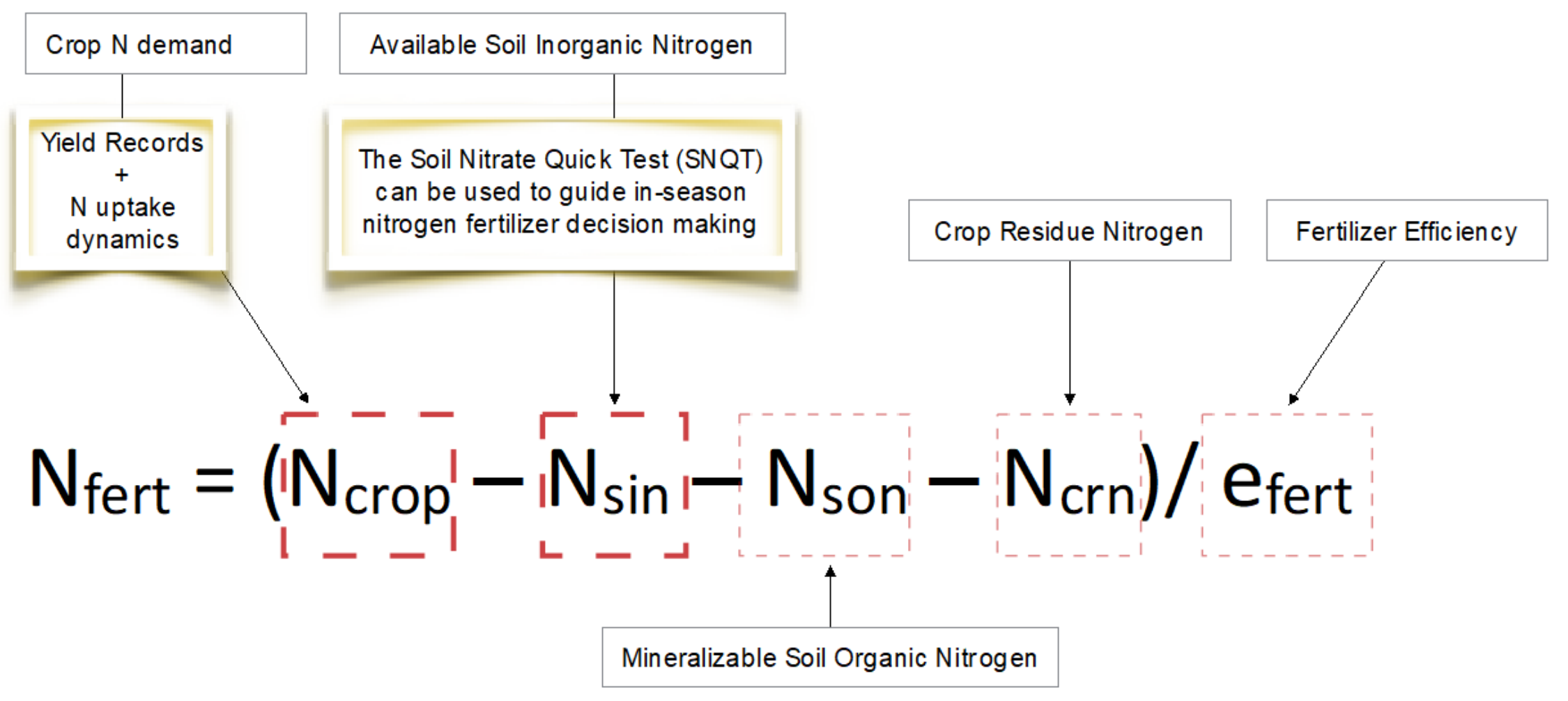
Abstract

Anthropogenic nitrogen (N) converted from atmospheric N_2 is threatening the environment at global and regional scales. The main source of anthropogenic N comes from high inputs of N fertilizers into crop production systems. Using an soil N balance framework based on site and crop specific target yields, synchronization of N fertilizer applications with plant nitrogen uptake can be optimized with knowledge of crop N demand and soil nitrogen status; hence, reducing environmental impacts and increasing farmer profits. In adapting a framework to guide N fertilizer management in Hawaii, we measured crop N demand and evaluated the SNQT method for soil inorganic N through cooperation with Hawaii growers. We developed crop N uptake models through a series of six field trials of selected brassica crops under sufficient N conditions. The use of a soil nitrate quick test (SNQT) was also assessed as a diagnostic tool to measure soil nitrogen status in tropical soils. To validate the SNQT as a viable tool, accuracy assessment of the SNQT procedure was conducted in a range of soil types differing in physical and chemical properties. Results showed that the SNQT highly correlates with the standard laboratory analysis (r^2= 0.97). Furthermore when used as a diagnostic indicator for plant yields two weeks after transplanting the SNQT has a soil NO_3-N action threshold for napa cabbage of 26 mg kg^{-1}. Finally, preliminary on-farm assessments utilizing the proposed N framework showed improved synchronization of N supplied with crop N demand.

Background / Problem Statement

- **In the intensive high yield agriculture systems of Hawaii, there is a need for development of strategies to help growers match N fertilizer applications with plant demand.**
- **The classic target yield based algorithm known as the “Stanford Equation” (Stanford, 1973) can serve as a framework for Hawaii’s N management strategies but some basic information and diagnostic tools are needed.**
- **In Hawaii there is a general lack of data sets characterizing crop specific N uptake dynamics.**
- **In Hawaii there is a need for reliable soil N testing protocols**
- **The pre-sidedress Soil Nitrate Quick Test (Hartz et al., 2000) is an onsite rapid testing procedure that has potential as a soil diagnostic tool in Hawaii.**

Nitrogen Management Framework



$$N_{fert} = (N_{crop} - N_{sin} - N_{son} - N_{crn}) / e_{fert}$$

Figure 1. Simplified N balance equation which focuses on measurable parameters. This proposed conceptual framework for N fertilizer management in Hawaii highlights the importance of soil N diagnostics to guide N fertilizer applications

Objectives

1) **Characterize crop growth and associated N uptake for key commercial vegetable crops in Hawaii as a reference for crop N demand.**
2) **Assess the SNQT procedure for accuracy in determining soil NO_3-N concentrations in Hawaiian soils.**
3) **Determine SNQT action thresholds for selected crops in Hawaii’s tropical growing conditions.**

Methods

1) **Evaluate six brassica crops for growth and N uptake in three farm sites throughout various seasons under growers N fertilizer practices.**
   - Non-linear regression conducted in SigmaPlot 10.0

Table 1. Soil classification and cooperating growers N fertilizer practice for each crop evaluated

Site	Soil series	Soil Classification	Textural Class	Minerology	Crop	Planting date	N Fertilizer Applications (kg N ha^{-1}) Pre-Plant	1st Side dress	Injection 1	Injection 2	Injection 3	Injection 4	Seasonal N rate
Helemano	Wahiawa	Haplustox	Silty Clay	Kaolinite	HC	5/21/2016	50	91	13	59	42	16.5	272
Helemano	Wahiawa	Haplustox	Silty Clay	Kaolinite	NC	6/1/2016	50	91	13	27.7	22.7	16.7	221
Helemano	Wahiawa	Haplustox	Silty Clay	Kaolinite	BR	5/17/2016	50	91	13	59	42	16.5	272
Waipio	Wahiawa	Haplustox	Silty Clay	Kaolinite	HC	8/26/2016	-	-	10	16.5	36	30	92.5
Waipio	Wahiawa	Haplustox	Silty Clay	Kaolinite	NC	8/29/2016	-	-	10	17	30	21	78
Ewa Plains	Hono'uli'uli	Haplotorrerts	Clay	Halloysite	HC	1/10/2016	50	91	10	16.5	43.7	22.7	233.9

Side dress fertilizer was applied one week after planting; all other in-season fertilizers were applied through fertigation
Brassica crops: head cabbage (HC), napa cabbage (NC), and broccoli (BR)

2) **Compare SNQT procedure to the standard procedure for soil NO_3-N determination in a range of Hawaiian soils and NO_3-N concentrations.**
   - Linear regression conducted in SigmaPlot 10.0

Table 2. List of soils used for accuracy assessment of the SNQT method

Island	Farm (Site)	N mgt. Practice	Soil Series	Soil Classification	Textural Class
Oahu	Helemano	Conventional	Wahiawa	Very-fine, kaolinitic, isohyperthermic Rhodic Haplustox	Silty clay
Oahu	Wahiawa	Organic	Wahiawa	Very-fine, kaolinitic, isohyperthermic Rhodic Haplustox	Silty clay
Oahu	Wahiawa	Hybrid	Wahiawa	Very-fine, kaolinitic, isohyperthermic Rhodic Haplustox	Silty clay
Oahu	Waimanalo	Conventional	Waialua	Very-fine, mixed, superactive, isohyperthermic Pachic Haplustolls	Silty clay
Oahu	Waimanalo	Organic	Waialua	Very-fine, mixed, superactive, isohyperthermic Pachic Haplustolls	Silty clay
Oahu	Waimanalo	Native	Waialua	Very-fine, mixed, superactive, isohyperthermic Pachic Haplustolls	Silty clay
Maui	Makawao	Hybrid	Keahua	Fine, kaolinitic, isohyperthermic Ustic Haplocambids	Silty clay
Maui	Makawao	Native	Keahua	Fine, kaolinitic, isohyperthermic Ustic Haplocambids	Silty clay
Maui	Kula	Conventional	Keahua	Fine, kaolinitic, isohyperthermic Ustic Haplocambids	Silty clay
Maui	Kula	Organic	Kamaole	Clayey fragmental, mixed, semiactive, isothermic Aridic Haplustolls	Stony silty loam
Hawaii	Kamuela	Conventional	Waimea	Medial, amorphic, isothermic Humic Haplustands	Very fine sandy loam
Hawaii	Lalamilo	Organic	Waimea	Medial, amorphic, isothermic Humic Haplustands	Very fine sandy loam
Hawaii	Kamuela	Native	Waimea	Medial, amorphic, isothermic Humic Haplustands	Very fine sandy loam
Hawaii	Kamuela	Conventional	Maile	Hydrous, ferrihydritic, isothermic Acrudoxic Hydrudands	Silt loam
Hawaii	Kamuela	Native	Maile	Hydrous, ferrihydritic, isothermic Acrudoxic Hydrudands	Silt loam
Hawaii	Kamuela	Organic	Paauhau	Medial hydrous, amorphic, isohyperthermic Dystric Haplustands	Silty clay loam
Oahu	Wainae	Conventional	Lualualei	Fine, smectitic, isohyperthermic Typic Gypsitorrerts	Clay
Oahu	Wainae	Organic	Lualualei	Fine, smectitic, isohyperthermic Typic Gypsitorrerts	Clay
Oahu	Wainae	Native	Lualualei	Fine, smectitic, isohyperthermic Typic Gypsitorrerts	Clay

Soils collected for a separate long-term aerobic incubation study on mineralization potential, was used to assess the accuracy of the SNQT procedure in a range of soil types found throughout the Hawaiian islands

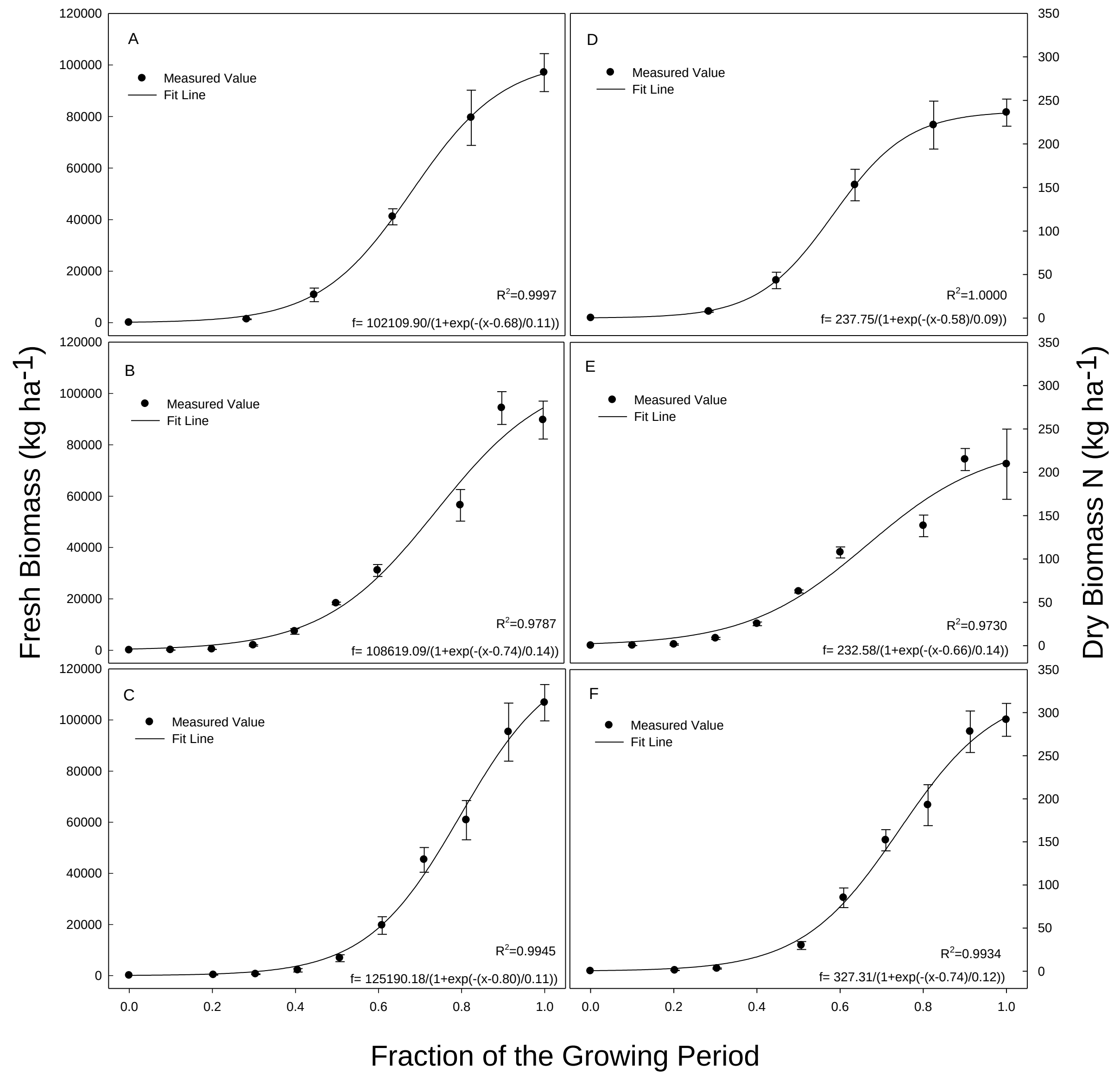
3) **Conduct a N rate experiment to determine SNQT threshold for napa cabbage.**
   - Measure soil NO_3-N weekly throughout the growing period.
   - Measure biomass at harvest.
   - Determine SNQT action threshold at week 2 using Cate-Nelson analysis (Cate and Nelson, 1971).

Results.1

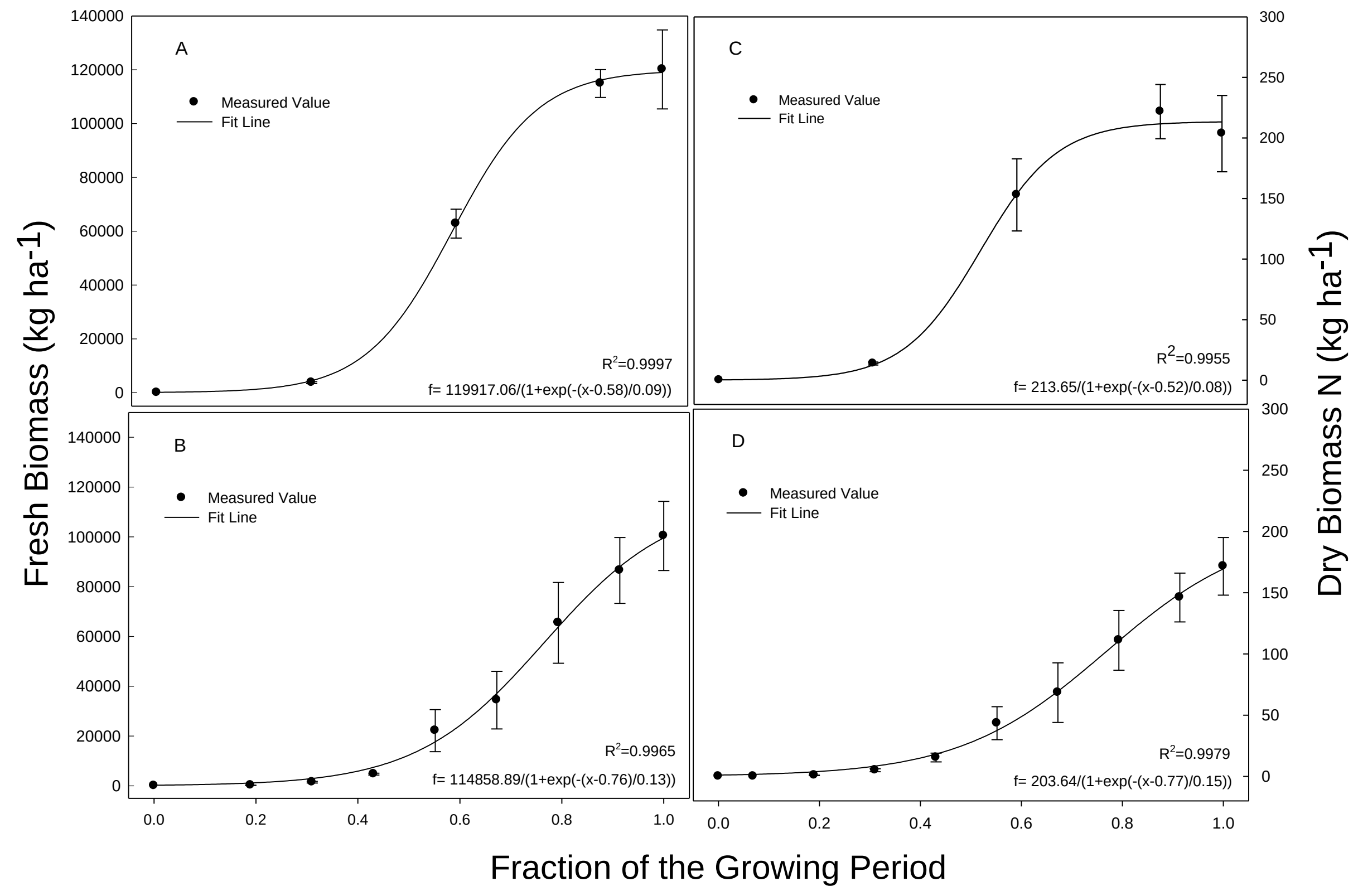
Table 3. Effect of Seasonal N on crop fresh biomass, and biomass N, in six crop cycles

Site	Crop	Planting date	Seasonal N (kg ha^{-1})	Soil NO_3-N (mg N kg^{-1})[z]	Fresh Biomass (kg ha^{-1})	Dry biomass N (kg N ha^{-1})	Tissue N (%)[S]	Tissue N (%)[L]	Tissue N (%)[H]	Marketable Biomass (kg ha^{-1})	Harvest Index	Residue N (kg N ha^{-1})
Helemano	HC	5/21/2016	272	79	97036	236	-	3.98	3.16	61,722	0.63	119
Waipio	HC	8/26/2016	93	16	89629	209	-	4.00	3.14	56,734	0.63	115
Ewa Plains	HC	1/10/2016	234	24	106746	292	-	3.86	3.86	55,237	0.52	165
Helemano	NC	6/1/2016	221	86	120136	204	-	4.47	4.68	64,657	0.54	93
Waipio	NC	8/29/2016	78	10	100391	172	-	3.68	3.74	51,952	0.54	90
Helemano	BR	5/17/2016	272	128	54276	234	2.94	5.42	5.44	12,330	0.22	178

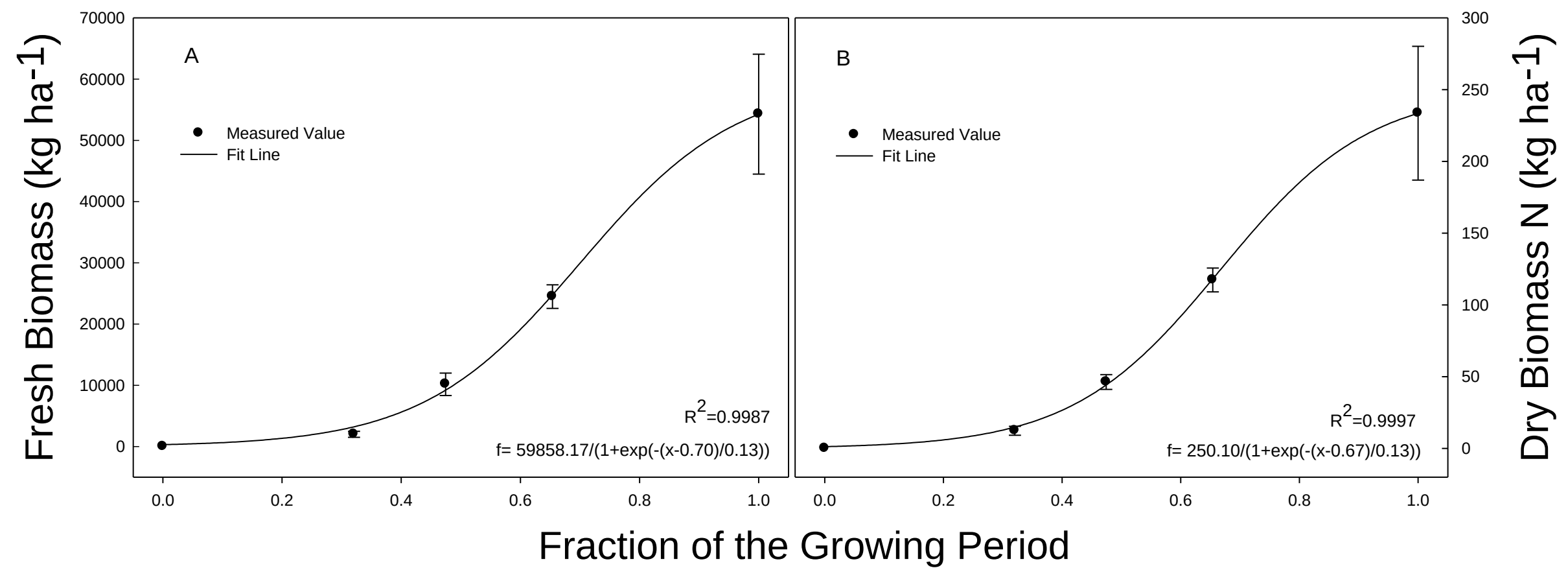
[z]Prior to exponetial growth phase, [S]stalk residue, [L]leaf residue, [H]harvest
Brassica crops: head cabbage (HC), napa cabbage (NC), and broccoli (BR)



- Fig. 2. Head cabbage above ground biomass and dry biomass nitrogen as a function of the fraction of the total growing period in three crop cycles; crops grown at the Helemano site in the summer of 2016 (A and D), crops grown at the Waipio site in the fall of 2016 (B and E), crops grown at the Ewa plains site in the spring of 2017 (C and F).



- Fig.3. Napa cabbage above ground biomass and dry biomass nitrogen as a function of the fraction of the total growing period in two crop cycles; crops grown at the Helemano site in the summer of 2016 (A and C) and crops grown at the Waipio site in the fall of 2016 (B and D).



- Fig.4. Broccoli above ground biomass and dry biomass nitrogen as a function of the fraction of the total growing period grown at the Helemano site in the summer of 2016.

Results.2

Figure 5.

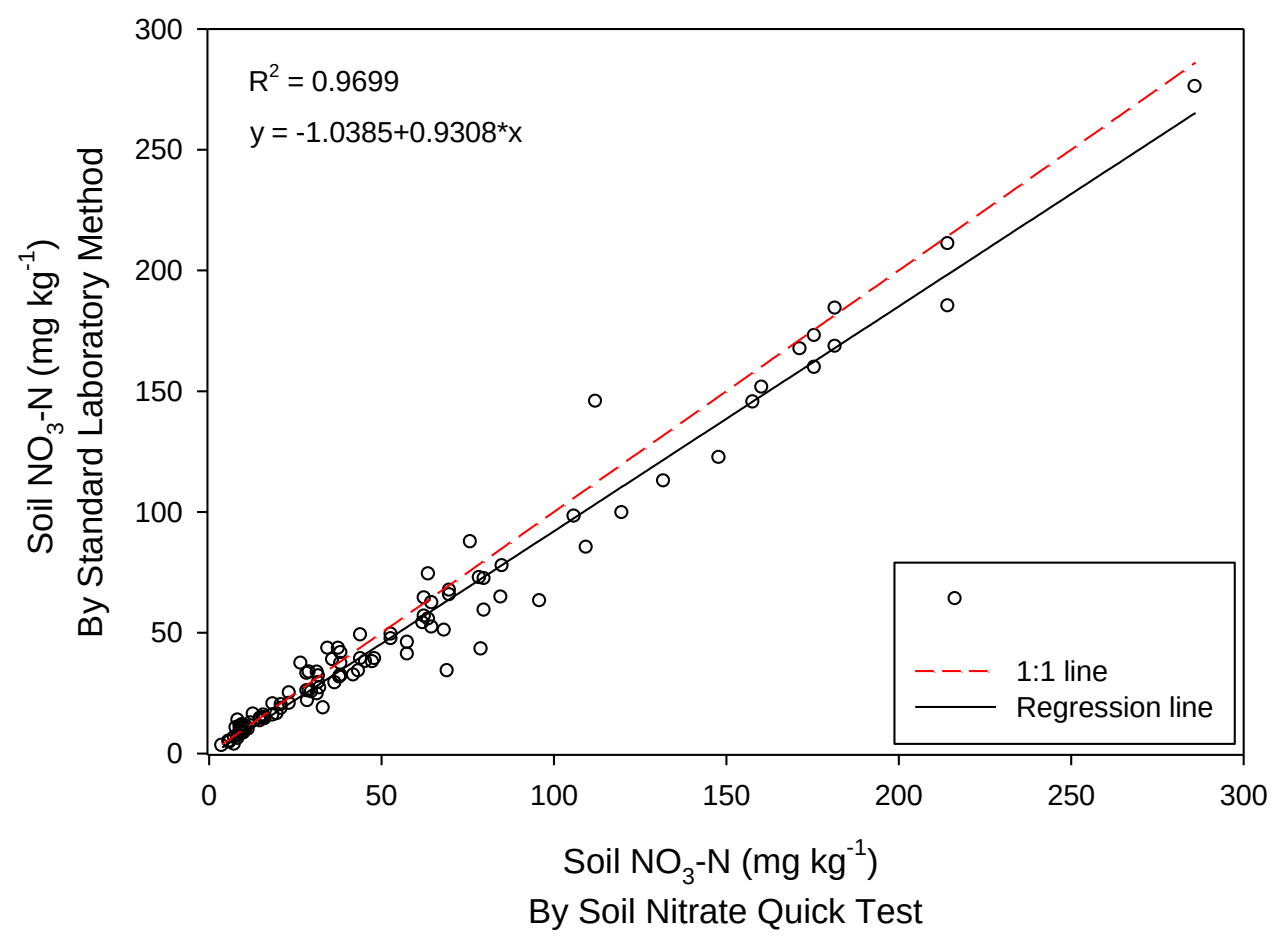
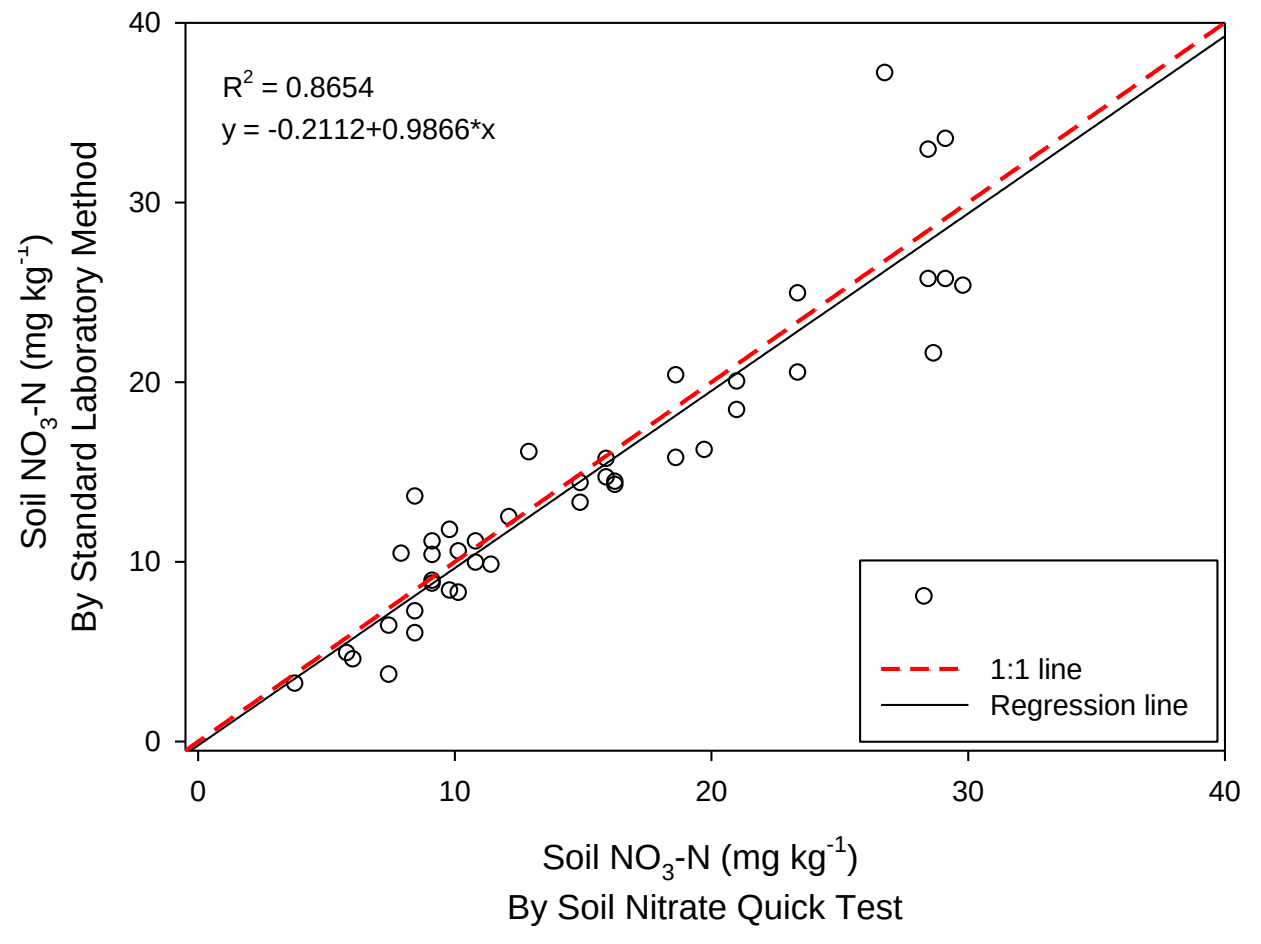


Figure 6.



- The SNQT is well-correlated to the standard laboratory method across a wide range of soil types and soil NO_3-N concentrations (Fig. 5).
- Focusing on the diagnostic range of the SNQT most critical to decision making (0-30 mg N kg^{-1}) , the SNQT regression line shows an better alignment to the 1:1 line but results in a lower regression coefficient (Fig. 6).

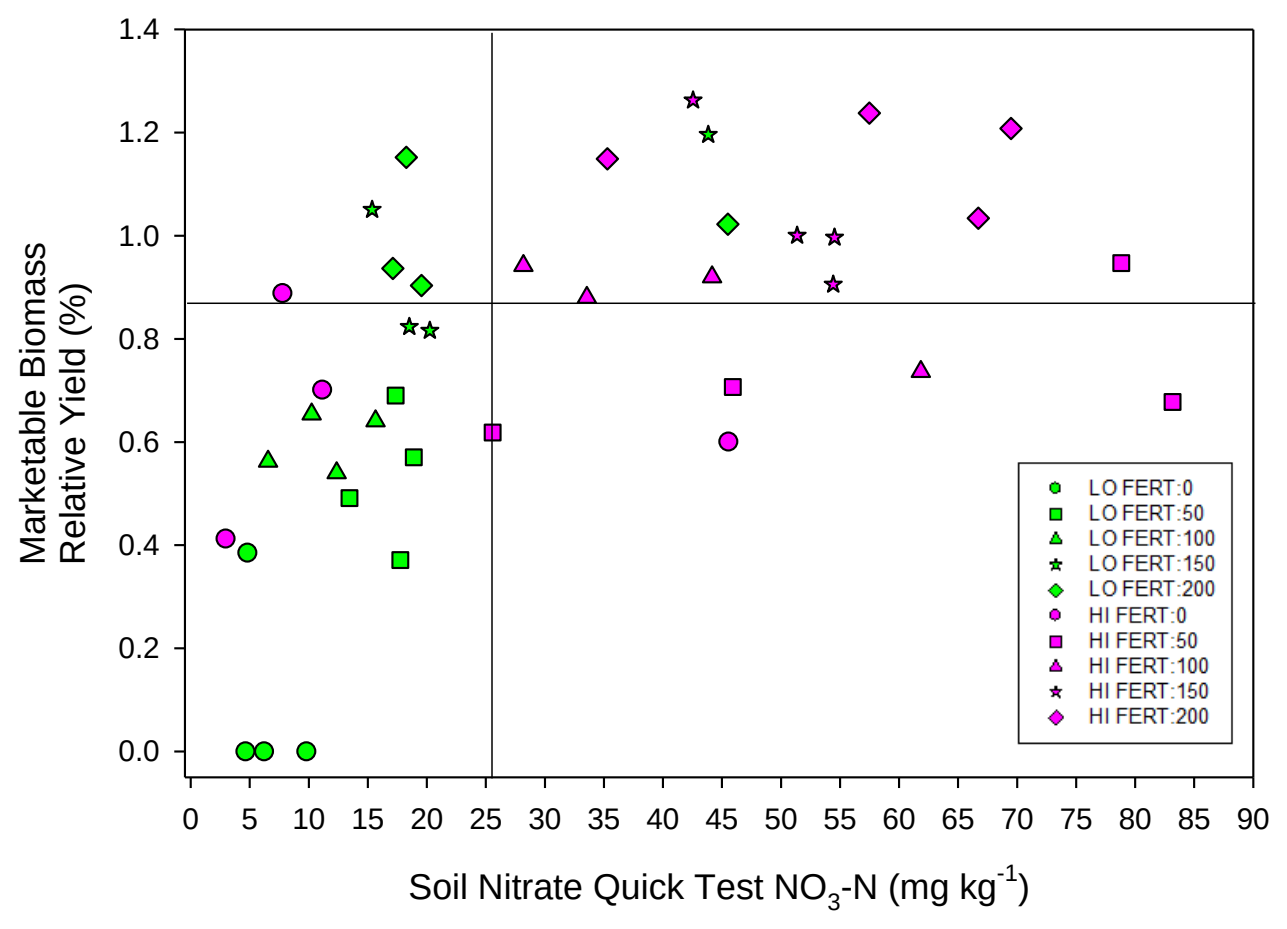
Results.3

- Napa cabbage N rate experiment conducted at the UH Poamoho research station in the summer of 2017.

Table 4. Average soil mineral N and relative yield for the napa cabbage rate experiment.

N fertilizer treatments Pre plant N	Fertilizer N rate (kg N ha^{-1})	n	Average soil NO_3-N (mg N kg^{-1}) Wk. 1	Wk. 2	Wk. 3	Wk. 4	Wk. 5	Wk. 6	Yield parameters Fresh Biomass (kg ha^{-1})	N uptake (kg N ha^{-1})	Harvest index	Marketable biomass
-	0	4	9	6	9	0	0	0	55,372	63	0.08	6,244
+	0	4	52	17	26	4	1	2	90,144	115	0.46	42,221
-	50	4	16	17	5	0	0	0	90,339	102	0.38	34,429
+	50	4	92	58	65	37	3	2	101,404	139	0.47	47,844
-	100	4	8	11	10	1	1	0	85,038	101	0.46	38,885
+	100	4	42	42	34	70	2	1	108,513	143	0.52	56,425
-	150	4	21	24	18	4	1	0	116,890	160	0.54	63,023
+	150	4	63	51	77	37	8	7	122,904	180	0.55	67,550
-	200	4	10	25	15	3	1	2	119,296	183	0.55	65,107
+	200	4	70	57	111	29	9	2	135,874	199	0.55	75,070

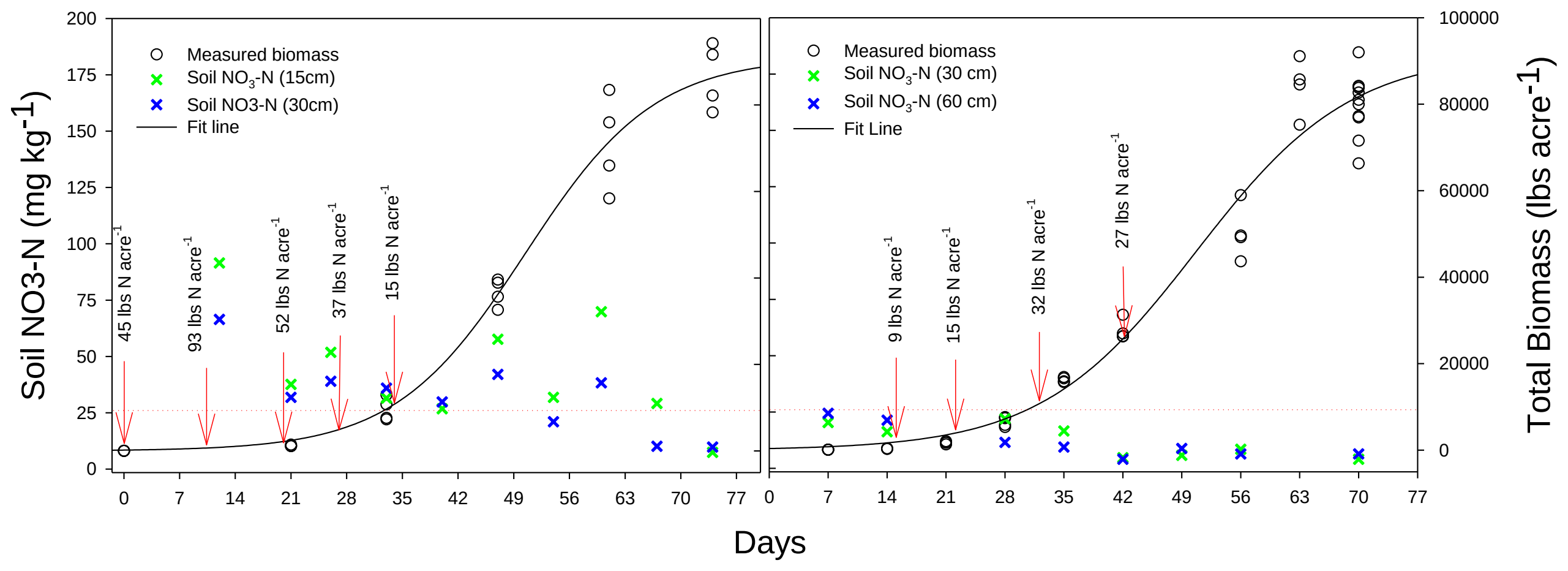
The experimental design was a split block design where half of the plots got pre-plant fertilizer at 50 kg N ha^{-1} to increase the residual soil NO_3 concentration in the soil prior to starting the experiment.



- Fig.7. Results from the experiment suggest that the action threshold for fertilizer decision making for a napa cabbage crop is 26 mg N kg^{-1} of soil when used two weeks after transplanting into the field.

Discussion and Conclusions

- When data parameters were put into the N management framework and simplified for growers convenience, proper fertilizer applications were achieved with both timing and rate of N was better synchronized to crop demand.
- Collaborating grower were able to use data to reduce N fertilizer inputs by 160 lbs $acre^{-1}$ with no significant reduction in yields.



- Fig.8. Two rounds of head cabbage production showing significant reductions in N fertilizer as well as soil NO_3-N in the root zone while maintaining adequate yields. SI units were converted to non-SI units for growers convenience.
- Future research directions include collection of detailed data sets for different crops important to Hawaii agriculture as well as studies that characterize the mineralization potential of Hawaiian soils.

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