

Article



Case Study on the Use of the Leaf-Count Method for Drip Fertigation in Outdoor Cucumber Cultivation in Reconstructed Fields Devastated by a Tsunami

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Abstract: Drip fertigation was tested in fields using a nitrogen fertilization method based on leaf increments, with the aim of increasing the cucumber yield in outdoor fields restored after the tsunami disaster in Rikuzentakata City, Iwate Prefecture, in 2011. The 2016 test site (Takata field) was restored as a paddy field, and there were problems with water retention and gravel contamination. The condition of the 2017 test site (Yonesaki field) was better than that of the 2016 site. The drip fertigation method increased cucumber yield by 93% and 27% in the Takata and Yonesaki fields, respectively, when compared to the yield from fields cultivated conventionally. Drip fertigation enables the constant supply of liquid fertilizer to the rhizosphere, and the easy application prevents the scarcity of fertilizer, especially at later stages of growth. In contrast, a real-time soil diagnosis, using the Dutch 1:2 soil–water extract method, was unsuccessful due to flooding, especially in the Takata field. As the purpose of this method is not to reduce the amount of nitrogen provided, but to increase the yield, and because it is difficult to precisely control the application of fertilizer due to precipitation, we suggest that the real-time soil diagnosis and feedback should be omitted to further simplify fertilizer application.

Keywords: leaf-count method; liquid fertilizer; nitrogen; reconstructed field; simple diagnostics

1. Introduction

The Great East Japan Earthquake (11 March 2011) and the subsequent tsunami devastated a large area of farmland in the Tohoku district. In coastal areas, all protected cultivation facilities were demolished, and the topsoil of farmland was washed off; salt pollution continued to pose challenges for several years [1]. One of the cities damaged by the tsunami was Rikuzentakata in Iwate Prefecture. Damaged fields have now been reconstructed using virgin soil from neighboring forests; however, complete recovery of field productivity will require more time. There are various issues in the fields damaged by the tsunami, such as field drainage and the mixing of seawater with groundwater [2,3], resulting in changes to the biological [4] and chemical condition of topsoil [5]. Furthermore, in the case of Rikuzentakata city, due to subsidence and erosion caused by the earthquake and tsunami, soil dressing was needed. However, the soil quality and construction method both proved inadequate. There are few records of cultivation tests to restore crop productivity in soils devastated by the tsunami disaster.

The production of outdoor cucumbers has been initiated in this area, as they do not require any special facilities for growth and are economically profitable as a cash crop. However, the poor soil environment has decreased productivity. The topsoil used to restore the land was immature, and the application of livestock compost to amend the soil has been a challenge due to a lack of livestock production.



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). To maintain the growth of cucumber for several months, expert producers often use drip fertigation to apply liquid fertilizer. Liquid fertilizer is applied every day or every week, along with 100 to 200 L of water per 100 m² per day. However, the application of high levels of nitrogen has caused various problems, such as growth inhibition [6], salt accumulation [7,8], nitrate run-off, production of bitter fruits [9], and increased labor and production costs [8]. Despite these problems, substantial quantities of fertilizer, on average 7.0 kg nitrogen 100 m⁻² per year, have been applied, because the negative effects of excess fertilization were not noticeable to the producers [10]. Furthermore, Yuasa et al. [11] reported that only 1.58–1.92 kg nitrogen 100 m⁻² was absorbed by the autumn greenhouse cucumber.

Various methods have been used to inform nitrogen management in cucumber, for example, chlorophyll concentration [12], the relative addition rate technique [13], and nearinfrared hyperspectral imaging [14], which provide bio-information that reflects nitrogen content in plant biomass. Marcelis and Gijzen [15] suggested estimating the amount of nitrogen application from fruit yield. The simulation models, such as the EU-Rotate_N model [16,17], involve plant and environmental factors. Generally, combining real-time monitoring of nitrogen sufficiency and adjustment of the application rate enables more precise and effective nitrogen management compared with predefined fertilization inputs. However, almost all these techniques (except fruit yield) require the use of instruments that the producers never possess. A nitrogen application method based on leaf increments (hereafter referred to as the leaf-count method) has been developed to prevent the occurrence of excess fertilization by drip fertigation in autumn greenhouse [18] and spring cucumbers [19]. This technique was developed according to a theory formulated by Marcelis [20,21] and was based on the results of a growth analysis [22,23]. The leaf-count method is a simple strategy to estimate nitrogen demand that does not require the use of any instruments, and the process of using the technique can be easily understood by producers, although the accuracy is less than that of modern methods.

Yield-based nitrogen fertilization [15] is a preferred and practical method in actual fields. However, the rapid fluctuations of yield render this method harder to apply in Japan, probably because cucumber is harvested when the fruit reaches approximately 100 g in weight, which occurs less than one week after flowering in the summer season. Thus, we concluded that a more accurate approach to analyze growth conditions, such as nitrogen absorption, was to use the leaf-count method [22,23]. The leaf-count method has been used to minimize the amount of nitrogen provided without causing any loss of yield. Additionally, the development of a real-time soil diagnosis method has enabled the calibration of the amount of nitrogen fertilizer intended to be provided effectively [24]. However, this method has not been tested outdoors thus far.

In this study, we tested whether the leaf-count method could improve outdoor cucumber production in immature farming soil devastated by the tsunami via a practical demonstration. The goal of this study was to maximize cucumber yield under immature, restored soil conditions. We discuss the practicability of the leaf-count method for nitrogen application in restored, immature soil in outdoor cucumber production, as well as the availability of this simple soil diagnosis approach.

2. Materials and Methods

2.1. Experimental Design

To determine the effectiveness of drip fertigation, we considered the influence of rainfall, the real-time soil diagnosis, and the precision of the nitrogen application. As this study was conducted in an arduously accessible area, we evaluated daily yield and other management works based on producers' shipping tickets and farm work diaries, respectively. The experimental design was also simplified to avoid disturbing the producer's routine and the possibility of errors. The studied disaster-affected field was under the process of reconstruction, and the producers faced several problems, such as a lack of experience, instruments, and labor. This made cooperation on this research project challenging for the producers. For this reason, we decided against the inclusion of repetitive plots in the test fields. Instead, we repeated the same experiments for four consecutive years from 2014 to 2017 in Rikuzentakata city to confirm the reproducibility. We obtained similar results in all years, although acquired data were incomplete in 2014 and 2015. In this study, we report the results based on the analysis of two trials conducted in 2016 and 2017 with complete data.

2.2. Test Sites

In 2016, a test field (Takata field, 370 m^2) was constructed in Takata, Rikuzentakata city, Iwate Prefecture. After the tsunami disaster in 2011, this field was restored as a paddy field by adding virgin stony soil from neighboring forests and subjecting it to firming using mechanization. The producer had been cultivating cucumber since 2013. Undecomposed mushroom bed waste was applied at a concentration of 3000 kg 100 m⁻² before cultivation, instead of livestock compost. In 2017, another producer's field (Yonesaki field, 1000 m²) was selected at Yonesaki, Rikuzentakata city. This upland field was restored by adding virgin soil, although only slight stone contamination was observed. No organic material was applied prior to cultivation. The producer had been cultivating cucumber since 2014. Irrigation water was collected from an open channel along each field and provided using an engine pump. The soil texture of the dressed topsoil was classified as loam in all fields. The soil penetration hardness was measured using a cone penetrometer (DIK-5590; Daiki Rika Kogyo Co., Ltd., Saitama, Japan), and the test site soil properties are described in Table 1. If the electrical conductivity (EC) is 0.5 dS m^{-1} or less, by convention, it can be considered that there is no residual nitrogen in the soil in this district.

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Year		рН (H ₂ O)	EC (dS m ⁻¹)	CEC (cmol _c kg ⁻¹) –	Exchangeable Base (mg kg ⁻¹)			Available Phosphate	Phosphate Absorption
					CaO	MgO	K ₂ O	(mg ${ m kg}^{-1}$)	Coefficient
2016	Mean	6.84	0.36	14.7	33.4	6.80	6.03	10.6	414
	SE	0.12	0.07	0.3	1.1	0.41	1.49	0.9	19
2017	Mean	6.09	0.11	23.0	40.4	5.35	2.73	5.6	1275
	SE	0.04	0.02	0.6	2.5	0.46	0.99	1.0	93

Table 1. Soil properties of test fields

2016: n = 7, 2017: n = 4.

2.3. Plant Materials and Growth Conditions

Seedlings of *Cucumis sativus* L. 'Taibo I' grafted on rootstock 'Tokiwa power Z2' seedlings were purchased from a nursery. The fields for both years were prepared by May 24. The transplantation date for 2016 was scheduled in early June; however, due to the poor growth of the seedlings at low temperatures, the transplantation was delayed by 10 days to 14 June. The transplantation for 2017 was scheduled for 4 June and proceeded as planned. Planting density was 0.50 plants m⁻² in 2016, with an average row width and plant distance of 2.00 m and 1.00 m, respectively, and 0.77 plants m⁻² in 2017, with a row width of 1.29 m and a plant distance of 1.00 m, respectively. The bed was covered with black mulch film, and seedlings were arranged in two rows in a zigzag pattern. A drip tube (Streamline 80; Netafim, Tokyo, Japan) was placed along each row. The weather data were obtained using the Automated Meteorological Data Acquisition System [25].

2.4. Practicability of the Leaf-Count Method for Nitrogen Application

Half the area of each field was fertilized using drip fertigation (DF), and the other half was subjected to conventional cultivation (CV), to compare the efficiency of the two methods. For DF, a commercial liquid fertilizer (Kumiaiekihi 2, N-P₂O₅-K₂O: 10-4-8; Katakura & Co-op Agri Corp., Tokyo, Japan) was applied with water through a drip tube. The total amount of periodic fertilizer was determined every fourteen days. Fourteen days

after transplanting, a total of 210 g of nitrogen, divided into four to five doses and diluted with water, was applied per 100 m² every three or four days using a liquid fertilizer mixer. Thereafter, every fourteen days the number of leaves on five plants displaying median growth, selected by visual inspection, were counted and compared to the number of leaves counted two weeks prior. The difference between these numbers was termed the leaf increment. Then, the following formula [23] was used to determine the amount of nitrogen absorbed in the preceding 2 w period:

Absorbed nitrogen $(g/100 \text{ m}^2/14 \text{ days}) = (\text{Leaf increments (number/100 m}^2/14 \text{ days}) \times 4.41) + 218.9$ (1)

A practical lookup table based on (1) is shown in Table S1. This practice was repeated until the end of the cultivation. Levels of other elements (P_2O_5 and K_2O) in the liquid fertilizer were not calibrated.

For CV, the fertilization approach was designed according to the guideline index of Iwate Prefecture, based on the results of a soil diagnosis conducted before the initiation of cultivation. A basal fertilization of 1.5 kg 100 m⁻² of nitrogen consisting of a solid fertilizer (CDU Chisso, N-P₂O₅-K₂O: 31 [crotonylidene diurea]-0-0; JCAM AGRI. Co., Ltd., Tokyo, Japan), and 2.5 kg of additional fertilizer (Yasaitsuihi S535, N-P₂O₅-K₂O: 15 [ammonium nitrogen: nitrate nitrogen – 11:4]-3-15; Kumiai Hiryo K.K., Hanamaki, Japan) was applied using top-dressing in two to three doses until the end of the cultivation. Thus, a total of 4.0 kg 100 m⁻² of nitrogen was applied.

2.5. Cultivation

Foliage was trained over a net expanded along arch-shaped stakes. The main stem and first branches were pinched at the fifteenth and the first nodes, respectively. Young, crowded shoots were thinned, and other branches were left uncut. The producers formulated decisions on the spraying of the plants with pesticides and fungicides as required. Marketable fruits over 100 g were harvested twice daily, and yield was recorded daily. Over the course of the investigation, approximately 100 L of water was used for irrigation through a drip tube per day, except on rainy days. Other management practices were performed according to local practices. Field management was completed on 19 October 2016, and 26 September 2017, although the harvest continued until the cucumber plants died in October.

2.6. Soil Diagnosis

As the leaves were counted, the nitrate ion concentration was measured using the Dutch 1:2 soil–water extract method [26,27] on a volume basis. This was performed using a reflectometer (RQflex plus, Merck KGaA, Darmstadt, Germany) with a nitrate ion test strip (Reflectoquant Nitrate test 16971-1; Merck KGaA, Darmstadt, Germany) in soil samples taken at a depth of 15 cm from the drip tube under the mulch film (except on 14 June, 2016, due to technical problems). Additionally, a semi-quantitative ion test strip (Quantofix Nitrate; Macherey-Nagel GmbH & Co. KG, Düren, Germany) was used for comparison in 2016.

2.7. Statistical Analyses

All statistical analyses were conducted using the Excel Analysis ToolPak (Microsoft Corporation, Redmond, WA, USA). Significant differences in leaf number were determined using *t*-tests. The significance level for all tests was set at p < 0.01.

3. Results and Discussion

3.1. Initial Soil Condition at Test Sites

The chemical properties of both fields are shown in Table 1. These values were standard for cucumber cultivation, apart from those in 2016, when the pH was slightly higher than the average. The chemical properties showed gradual improvements within two to three years after restoration. In the Takata field, the soil penetration hardness

increased rapidly at soil depths greater than 10 cm (Figure 1a). This indicated that the use of heavy machinery treaded down the added soil to prevent water leakage and restored the site as a paddy field. After restoration, this field was converted to an upland crop field, but the cultivators were markedly shallow for deep tillage. Soil penetration tests and analysis based on the estimation of soil hardness indicated the presence of soft soil up to a depth of 20 cm in the Yonesaki field (Figure 1b); this was deeper than that estimated in the Takata field (Figure 1a). This was probably because this field was located on a terrace along a slope; hence, less soil was washed away, and heavy machines could not access the investigated area.



Figure 1. Soil penetration hardness of test fields. (a) Takata field. (b) Yonesaki field. Vertical bars indicate standard error (n = 3).

3.2. Growth Conditions

The data on weather conditions in 2016 and 2017 are shown in Figure 2a,b, respectively. Continuous rainfall was observed in 2016 from 14 June, during transplantation, until 26 July. Rainfall from August 15 to 23 was caused by a typhoon and a related weather front. A few stakes collapsed, and the cucumber foliage was physically damaged by the storm. After the typhoon, the stakes were recovered, damaged leaves were removed, and fungicides were sprayed. Owing to its poor permeability, the field was deluged in all instances of rainfall. In 2017, the rainy season commenced in early July, but the rainfall continued until autumn. Unlike the 2016 field site, the 2017 field was not deluged, as it was in the middle of a slope and had a good drainage system. However, the cultivation was completed in late September, earlier than in 2016, when cultivation was completed on 28 October, due to frequent outbreaks of anthracnose and other diseases triggered by the unseasonable weather conditions.

The data were obtained using the Automated Meteorological Data Acquisition System [25].



(b)

Figure 2. Chronological changes of weather conditions in Rikuzentakata city. (a) 2016. (b) 2017.

3.3. Cucumber Growth

In 2016, the number of leaves increased linearly after transplantation until the end of cultivation in DF fields (Figure 3a). The amount of nitrogen applied, based on leaf increments, showed a tendency of reaching a constant value until the end of cultivation. In contrast, although the number of leaves in the CV increased in the same manner as DF until 20 September, it then decreased rapidly, likely due to nitrogen deficiency. Thus, although the yields of DF and CV in July were similar, the differences in yields increased each month. The total yield was 93% higher in DF than in CV, with 734 kg 100 m⁻² for DF, and 380 kg 100 m^{-2} for CV (Figure 4a). In 2017, the transplantation date was ten days earlier than in 2016. Although the minimum temperature was below 15 °C for the first 14 days (Figure 2b), the initial growth was similar to that in 2016 (Figure 3b). Growth showed an acceleration in July; however, it stopped in August due to continuous rainfall, and despite chemical application, the occurrence of diseases such as anthracnose did not cease. Cucumber growth then resumed when the weather conditions recovered in late August. The number of leaves was significantly higher in DF than in CV on 29 August and 12 September, similar to what was observed in 2016 (Figure 3b). The yields of DF and CV in July were similar; however, the difference in yield between DF and CV increased on a monthly basis. DF had a 27% higher total yield than that of the CV (Figure 4b), with a yield of 1170 kg 100 m⁻² for DF, and 919 kg 100 m⁻² for CV. The total amount of nitrogen applied was $3.27 \text{ kg} 100 \text{ m}^{-2}$ (81.8% of the CV) and $3.20 \text{ kg} 100 \text{ m}^{-2}$ (80.0% of the CV) in 2016 and 2017, respectively.

3.4. Nitrate Concentrations

In 2016, the nitrate concentration in CV was the highest on 12 July and decreased gradually until the end of cultivation (Figure 5a). The deviations in nitrate concentration were generally larger among the DF samples than among the CV samples. The nitrate concentrations on 9 August and 6 September tended to be higher than on other dates; however, it might be possible that the producer applied liquid fertilizer immediately before the sampling. In contrast, the nitrate ion concentration reduced on 23 August, which might be attributable to a run-off of nitrate ions, as the field was frequently flooded.



Figure 3. Cont.



Figure 3. Chronological changes of leaf counts and the applied nitrogen amount in DF. (**a**) 2016. (**b**) 2017. DF, drip fertigation; CV, conventional fertilization. Vertical bars indicate standard error (n = 5). * and ** indicates significant difference between treatments according to *t*-test at the 5% and 1% level, respectively.



Figure 4. Effect of drip fertigation on cucumber yield. (a) 2016. (b) 2017. DF, drip fertigation; CV, conventional fertilization.

The Dutch 1:2 soil–water extract method was used to determine the optimum concentration of nitrate as 250 to 350 mg L^{-1} for greenhouse cucumbers [28]. The CV field nitrate levels obtained were below this value, except for those on 12 July. In contrast, values of the DF field often exceeded this value throughout the growing season, and never showed a substantial decrease. In 2017, the chronological changes in nitrate concentrations were similar and remained stable between DF and CV throughout the cultivation period, probably because the field was not flooded (Figure 5b). However, the nitrate levels in DF



reduced below 250 mg L^{-1} from August until the end of the experiment, despite continued drip fertigation, possibly owing to a run-off of nitrate ions occurring due to rainfall.

Figure 5. Chronological changes of nitrate ion concentration in the soil determined using the Dutch 1:2 soil–water extract method. (a) 2016. (b) 2017. DF, drip fertigation; CV, conventional fertilization. Vertical bars indicate standard error (n = 3-5).

Crotonylidene diurea (CDU), a controlled-release nitrogen fertilizer decomposed by soil bacteria [29], was basally applied in the CV fields. The peak concentration of soil nitrate was achieved approximately two months after fertilization in both years. This level seemed to be suitable for cucumber growth; additional fertilizer was not effective in either year, probably because the fertilizer was applied between the beds where they were treaded down and flooded, and also because ammonia volatilization may occur in reduced-state soil after flooding. A sufficient amount of nitrogen fertilizer applied in the later growth stages likely contributed to an increase in cucumber yield. However, the measurement of nitrate concentration in the collected soil from flooded fields was considered inaccurate due to uneven soil conditions. Therefore, it was difficult to adjust the amount of fertilizer applied based on the analytical values obtained. Additionally, the collection and analysis of a considerable number of samples with the aim of reducing the incidence of errors posed obstacles for the producers. However, even if the application of this method is not suitable for the robust control of fertilization, it is possible to determine whether the amount of nitrogen in the soil is sufficient at critical points, such as when growth is poor, or after flooding. Furthermore, if the nitrate ion concentration is less than 500 mg L^{-1} , even a semi-quantitative test strip may be used instead of an expensive device such as a reflective photometer (Figure 6).

3.5. Availability of the Leaf-Count Method in Outdoor Cucumber Cultivation

Originally, the leaf-count method was a measure of quantitative management in greenhouse cucumber fertilization, which aimed to prevent salt accumulation by increasing nitrogen efficiency and reducing the amount of nitrogen fertilizer applied, while maintaining the yield [17,30,31]. In other crops, drip fertigation is often utilized to reduce the amount of nitrogen applied, for example, in Chinese cabbage [32]. In the present test, our main purpose was not to reduce the amount of nitrogen fertilizer intended to be provided; however, we found that the amount of nitrogen applied could be reduced by approximately 20% compared to conventional cultivation. The yields in 2016 and 2017 were also 93% and 27% higher than in the conventional plots, respectively. The target yield of the outdoor cucumber is 1 t 100 m⁻² in a well-maintained field. Although not verified by the replication plots, the obtained results indicate that DF contributed to the high yield in the field where virgin soil had been added three years previously.



Figure 6. Comparison of two nitrogen measurement methods. ** indicates a significant difference at the 1% level (n = 45, p = 0.294).

On the basis of our results, we suggest that DF has at least three advantages. First, it facilitates the application of a quantitatively optimized amount of fertilizer based on the results of a real-time soil diagnosis. However, as mentioned above, it is not always effective in outdoor cultivation due to rainfall.

Second, DF improves the fertilization efficiency in soil that has not been chemically or physically improved. Nutrient solutions provided by DF may reach the rhizosphere and may be absorbed effectively before leaching or absorption by soil. The initial soil analysis showed both test fields to be appropriate for cultivation. However, the condition of the Takata field was considerably worse in terms of stone contamination and soil penetration hardness, and a considerable amount of undecomposed mushroom beds was applied before the commencement of the experiments. It is possible that this application of undecomposed mushroom beds exerted a negative effect, and during dissociation, the application caused nitrogen starvation. The field was also subjected to flooding several times.

Third, DF prevents the occurrence of nitrogen deficiency by enabling sufficient fertilization from the middle to the late stages of growth. The fertilizer content did not show exhaustion until the end of cultivation; the cucumber plants showed growth, and the development of fruits occurred continuously. When considering the total amount of applied nitrogen, the nitrogen utilization efficiency was higher in DF than in CV. Technically, producers may prefer slow-release fertilizers that can cover the whole cultivation season with a single basal application. However, as shown in Figure 3, the difference in cucumber growth between producers or years is non-negligible. Producers will also typically apply more fertilizer than required as a safety measure.

A combination of real-time monitoring of nitrogen sufficiency and the adjustment of the application amount enables precise and effective nitrogen management, as mentioned previously. If the amount of fertilizer applied for each season or each stage of growth is determined on the basis of the standard cucumber growth pattern in the region, the adoption of certain fertilization practices will be easier for producers, and a higher yield can be expected without an over-application of fertilizer. However, regardless of the adopted fertilization method, in outdoor fields, unlike greenhouses, there is a non-negligible amount of nitrogen leaching due to rainfall. Producers should also harvest and ship cucumbers daily, which renders real-time management of the application amount difficult. Additionally, the cultivation beds were covered with a mulch film, which posed challenges for the fertilizer components to reach the root, and it has been shown that even in conventional fertilization, it is possible to obtain the same yield as DF if a sufficient amount of top-dressing fertilizer is applied in the late growth stage. Therefore, it is debatable whether the precise calculation of required fertilizer based on nitrogen absorption, such as the leaf-count method, is appropriate. One alternative solution could be a semi-quantitative test strip used by producers to determine soil nitrate concentrations and the concomitant adjustment of fertilizer application. However, around 20% of nitrogen was saved from conventional

fertilization by this technique, even with the higher yields in both 2016 and 2017, which suggests this can contribute to the sustainability of outdoor vegetable production. Another possible approach, and potential direction of future study, involves the use of ubiquitous and low-cost technology: some mobile devices or smartphones can be used as an exposure meter by installing an application program. It may be possible to estimate the total leaf area by measuring the illuminance above the canopy and on the ground surface and calculating the difference, which can be used as an alternative to leaf count.

This cultivation problem remains, as water supply has not been restored to the tsunamiaffected areas. The ground water contains salt, even several years after the occurrence of the tsunami. Producers have been compelled to use water from the open channel, and frequent filter cleaning has been deemed essential to protect the drip tube and to ensure uniform DF. Further research and remediation efforts are needed to address the challenges of restoring the agricultural potential of this area.

4. Conclusions

Application of drip fertigation using the leaf-count method is an approximate but robust technique that can be used to improve cucumber yield at a practical level in outdoor fields with inadequate soil improvement after the occurrence of a disastrous tsunami. It is not feasible to expect precise fertilization using the leaf-count method and real-time soil diagnosis, because rainfall adversely affects fertilizer run-off. This is a promising technique that can be applied to the reconstruction of agricultural production in tsunamistricken areas around the world. Furthermore, there may be potential for further simplification of farming practices for producers affected by disasters if quantitative accuracy can be neglected.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/ 10.3390/agriculture11070656/s1, Table S1: Practical lookup table for nitrogen fertilization based on leaf increments.

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