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Productivity, cost, and profitability of kale produced in a low tunnel

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Abstract

This study evaluated the productivity and profitability of kale hybrids cultivated either in a low tunnel or an open field. The study was conducted using two hybrids of Hi-crop and Kobe kale and six environments: low tunnels covered with agrotextiles at a weight of 15 $g.m^{-2}$, white organza at a weight of 47 $g.m^{-2}$, 35% red screen, 35% thermo-reflective screen, 35% black screen, or an open field, with four repetitions. The total operating cost and economic indicators related to the cultivation of each hybrid and environment were calculated by estimating the operating profit, profitability index (%), gross margin (%), and leveling points ($kg.h^{-1}$ and price. $pack^{-1}$). Both hybrids showed high productivity and profitability indices in all environments. The hybrid 'Hi-crop' showed the highest productivity when cultivated under the organza tunnel, with a 26% greater value than that in the open field. The use of a protected environment reduced the need for insecticides, which was reflected in productivity and, consequently, in the profitability of the crops.

Keywords: *Brassica oleracea* var. *acephala* (L.); agrotextile; organza; screens

Introduction

Kale (*Brassica oleracea* var. *acephala*) is in high demand worldwide, and together with other brassicas, has a global production of 71.4 million tons (FAOSTAT, 2019). Pests affect crop production and profitability. *Plutella xylostella* (Lepidoptera: Plutellidae L.) is the main pest of kale (IRAC, 2021), causing losses of up to 100% of production (Kahuthia-Gathu et al., 2017), and the cost to control this species can reach 50% (Zalucki et al., 2012).

The use of a protected environment with shading screens allows for greater productivity, improved cultivation in unfavorable times, and efficient input usage. The shading meshes provide a reduction in temperature, luminosity, and radiation, and consequently, the damage caused by photoinhibition (Murata et al., 2007). In addition, they increase the absolute humidity inside the environment, which decreases the evaporative demand of the crop and favors an increase in stomatal conductance and CO_2 assimilation. This results in greater photosynthetic performance (Haijun et al., 2015), which allows for improved productivity and quality of the final crop products.

The protected environment can also be used as a physical barrier against insects, mainly due to interference with UV radiation cause by the materials. Insects, especially suckers, such as whiteflies, thrips, and aphids, are sensitive to UV light (330 – 550 nm). Materials that block UV radiation can decrease the attraction and infestation of crops under protected cultivation (Mahmood et al., 2018; Kumar & Poehling, 2006), thereby reducing the need for pesticide applications (Ponce et al., 2021), and lowering production costs.

In view of the benefits of using shading screens in agriculture, it is necessary to analyze the cost and economic viability of these materials for crop protection to determine whether the production generated meets

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the implementation costs of the protected environment in adverse climatic and environmental conditions. The analysis of production costs allows for the evaluation of important aspects of the economic conditions of the production process, such as the profitability of the resources used, conditions for the recovery of these resources, subsidization of decision-making on the improvement of productive activities, and the attainment of satisfactory outcomes (Reis & Guimaraes, 1986). Thus, the objective of this study was to evaluate the productivity, cost, and profitability of kale hybrids cultivated under low-tunnel and open-field conditions.

Material and Methods

The study was conducted in the municipality of Nova Mutum-MT, Mato Grosso, Brazil (13°49'44" S, 56º04'56" W, 460 m.a.s.l.). The climate was classified as tropical (Aw; Köppen) with dry winters and rains concentrated between October and April. The test was conducted between May and October 2017, with a minimum temperature of 20.5 °C, an average of 29.9 °C and a maximum of 40 °C, and accumulated rainfall of 139 mm. The data collected related to the two Kobe kale hybrids, Topseed® and Hi-crop (Takii do Brasil®) cultivated in an open field and low tunnels covered with 35% black (Sombrite®), thermo-reflecting silver (Aluminet®), or red (Chromatinet®) screens, white agrotextile (15 $g.m^{-2}$), or white organza (47 $g.m^{-2}$). As a support for the structure, 20 mm polyvinyl chloride (PVC) pipes and five types of mesh were used over one hectare with spacing of 1.3 m between rows, 0.4 m between double rows, and 0.5 m between plants, for a total of 59 beds of 100 m in length.

The experiment was conducted from May to October 2017 in a no-tillage system using millet mulch (*Pennisetum americanum* L.). The seedlings were transplanted 46 days after sowing and fertilized for planting and covering following the recommendations of Trani et al. (1997). The harvests began 76 days after sowing and continued to 136 days, with a total of six harvests and six plants evaluated per repetition.

The total yield, commercial yield, 300 gram (g) bunch yield, and insect damage losses obtained with each hybrid for each environment were extrapolated to one hectare, for a population of 23,400 plants. Harvesting was performed every 10 days, with six harvests performed during the trial. The productive parameters of each environment were calculated using the sum of the averages of the harvests.

In addition to the cost of materials needed to assemble the irrigation structure, tunnels, and covers, the values used to determine the costs were obtained from the local market, and the price of kale (R$ 3.00 per 300 gram bunch) was obtained from the producers.

To determine the need for insecticide application, weekly sampling of plants was performed throughout the crop cycle. The methodology proposed by Castelo Branco (1996) was used for decision-making regarding the application of insecticides in the environment.

To calculate the production cost, the methodology defined by Matsunaga et al. (1976) for the total operating cost (TOC) was used, following the description given by Martin et al. (1997), considering the following:

a) The cost of mechanized operations in Reals per hectare (R$ $.ha^{-1}$) represented by machine hours for harrowing the area to prepare the soil for kale cultivation;

b) The cost of manual operations per hectare including the preparation of the area, beds and seedlings, assembling the irrigation system, transplanting the seedlings, assembling the structure, fertilization, pest monitoring, insecticide application, and harvest Reals (R$) per $person.day^{-1}$ (HD);

c) The cost of consumables multiplied by the purchase price, including seeds, fertilizers, insecticides, and herbicides;

d) The effective operational cost (EOC), which is the sum of the mechanized operations, manual operations, and consumables costs;

e) Other operating costs, which are the part of the general costs of the agricultural company, and can be estimated at 5% of the EOC percentage (Martin, et al. 1997); and

f) The total operating cost (TOC), which is the sum of the EOC and other operating costs, and represents the cost incurred per hectare by the farmer in the short term to produce and replace other expenses and continue producing.

The following economic indicators were calculated (Martin et al., 1997).

a) Gross revenue (GR): The expected revenue for the activity and the respective yield per hectare at a predefined sales price (kale productivity in $kg.bundle^{-1}$ × sales price of the bundle by the producer).

b) Operating profit (OP): The difference between the values of gross revenue (GR) and total operating cost (TOC) per hectare of kale.

c) Profitability Index (PI): The ratio between OP and GR, in percentage (PI= (OP/GR) × 100), which demonstrates the available rate (%) of revenue from the activity after deducting the operational costs.

d) Gross margin (GM): The ratio margin of the

GR to the TOC (GM= (GR- TOC)/TOC ×100), which characterizes the availability (%) to cover the other fixed costs, as well as the risk and capacity of the activity.

e) Leveling Point (Production): This allows the estimation, based on the data of kale production costs, of the sales price (sp) of the product, and the quantity of the product needed to pay the total operating costs (Production= TOC/sp).

f) Leveling point (Price): This allows the estimation based on the total operating costs of kale and the productivity (p) of the system, of the kale marketing price necessary to cover the production costs (Price=TOC/p).

Results and Discussion

The costs of harrowing, irrigating, fertilizing at planting and covering stages, implementing a no-tillage system (SPD: millet seeds and herbicide), manually operating, renting, as well as the seed costs for each hybrid per hectare constitute part of the cost of implantation of the culture (Table 1). The difference between the values observed for each hybrid related to the cost of seeds, in which the 'Kobe' hybrid has a purchase price that was 1.6% lower than that of the 'Hi-crop'.

The highest costs in the open field cultivation occurred with the irrigation system (67.12%), followed by the planting fertilization (14.51%) and topdressing fertilization (9.75%) for both hybrids. The seed costs of the 'Hi-crop' and Kobe' hybrids represented 10.8% and 3.25%, respectively. We chose to use millet mulch to reduce the need for weeding in the cultivation area.

The coverings used differed in value, with the agrotextile having the lowest cost compared to other fabrics. Cultivation under tunnels is inexpensive and readily implemented compared to other types of protected environments. The investment recovery time depends on the crop, and species with high added value, such as tomatoes, peppers, and strawberries, cover the costs of the cultivation structure and generate profit in one year (Monteiro, 2011).

Table 1. Implantation, management, and harvest costs of two kale hybrids (Hi-crop and Kobe) grown in open fields and low tunnels covered with agrotextile, organza, red mesh, silver mesh, or black mesh.

Hybrid	harrowing	Irrigation	Planting fertilization	Topdressing fertilization	No-tillage system	Manual operations	Land rent	Seed	Amount R$
Hi-crop	100	1,936.60	6,792.20	4,566.40	138.00	930.00	612.8	2,250.00	17,326.10
Kobe	100	1,936.60	6,792.20	4,566.40	138.00	930.00	612.8	1,500.00	16,576.10

Cultivation environment	Pipes	Pipes*	Shading mesh	Shading mesh *	Amount R$
Open field	-	-	-	-	-
Agrotextile	13,348.70	2,023,6	5,684.00	1,894.60	3,918.2
Organza	13,348.70	2,023.6	46,342.00	15,447.30	17,470.9
Red mesh	13,348.70	2,023.6	105,328.00	5,194.20	7,217.8
Silver mesh	13,348.70	2,023.6	236,000.00	11,638.30	13,661.9
Black mesh	13,348.70	2,023.6	39,904.00	1,967.80	3,991.4

*Value refers to the useful life of each material.

Meshes are used in the cultivation of vegetables with the aim of improving the microclimatic conditions of the environment by reducing the temperature and luminosity, thereby increasing productivity. In addition, these materials can act as physical barriers against insect infestation; however, this has yet to be explored in Brazil. In regions with high rainfall and energy availability, the cultivation of leafy vegetables is possible using shading screens (Seabra Júnior et al., 2012; Neves et al., 2016).

The open field environment required a greater number of pesticide applications, totaling 11 from the rotation of four products based on *Bacillus thuringiensis*, which allowed the harvest to be conducted, since there was no grace period (Table 2).

Table 2. Application number, products used, quantity needed, product value, and required days to perform the applications and the IPM for the environments: open field, agrotextile, organza, red mesh, silver mesh, and black mesh over 90 days.

Cultivation environment	Number of sprays	L/kg	Insecticides	Daily monitoring	Total
Open field	9	9	1.890	3.6	2,680.60
	1	0.1	79.20	3.6	82.8
	1	0.1	78.00	3.6	81.6
Agrotextile	8	8	1,680.00	3.6	1,959.00
Organza	8	8	1,680.00	3.6	1,680.00
Red mesh	7	7	1,470.00	3.6	1,470.00
Silver mesh	8	8	1,680.00	3.6	1,680.00
Black mesh	8	8	1,680.00	3.6	1,680.00

In the open field, there was still a need to use insecticides such as clorfenapyr and spinosad. The former is moderately toxic, classified as class II (very dangerous to the environment), and has a long grace period; therefore, the harvested products could not be commercialized for 15 days. Vegetables are replenished daily on shelves because of their high perishability. Thus, it was necessary to reduce the harvest time for this environment since the duration of the grace period would cause some of the leaves to be unsuitable for commercialization after 15 days.

Spinosad is one of the safest active ingredients currently that is rapidly degraded in the environment and does not persist, with its half-life reduced to less than one day in natural environments, and it has a low toxicity to bees (Biondi et al., 2012). However, due to its high cost, it is not as attractive to producers, and is commonly replaced by active ingredients with greater toxicity or a broader spectrum.

The other environments only received applications of products based on *Bacillus thuringiensis* and with a lower frequency of approximately one application per week. In the low tunnel covered with red mesh, eight insecticide applications were performed because of the low infestation of *H. undalis* (Fabricius) (Lepidoptera: Pyralidae). The red screen provides a decrease in insects within the cultivation environment due to the change in the light spectrum and a reduction of the passage of ultraviolet (UV) light (POLYSACK, 2016). Black and silver screens reduced the need for insecticide application.

Among the covering materials used, agrotextiles had the lowest acquisition cost, and a useful life of five months. This material has been used previously with positive results in terms of production and protection against pests (Seabra Júnior et al., 2019, Dantas et al., 2010, Otto et al., 2013, Ponce et al., 2021). Organza is a material intended for confection, which, due to its transparency, lightness, exchange of heat and humidity with the external environment, and ease of acquisition, can be an interesting substitute for other fabrics. In the case of kale, it provides high yield and quality, in addition to protection against the main pest of the crop, *P. xylostella* and improvement in the soil and climate conditions of the cultivation environment (Ponce et al., 2021; Seabra Júnior et al., 2019).

In kale cultivation under screen protection, Martin et al. (2006) found less need for insecticides and higher yields in the number of marketable kale heads with the use of the screen as a physical barrier, which is similar to the present study, whereby meshes as physical barriers reduced the need for insecticides.

The total operating cost (TOC) (Table 3) for each environment for both hybrids studied is represented by the sum of the costs listed in Table 1 (implementation costs, driving costs, pipe, and covering costs) and Table 2 (pesticide application costs) for each situation over the course of 90 days, which was the period the experiment was conducted in the field, without considering the seedling stage.

The materials used to cover the tunnels had variable durability, with the agrotextile having a useful life of five months and the organza nine months (270 days), whereas the screens had an average durability of five years (1825 days). The culture remained in the field for 90 days, and the value for the type of coverage was extrapolated to the time of use and used to calculate the total operating cost along with the cost of the irrigation structure that had a useful life of four years (1460 days). The total operating cost of the various environments was directly influenced by the type of coverage, which was the determining factor for the other economic indicators (Table 3).

Table 3. Total operational cost established by the sum of implantation, structural, pesticide application, effective operational, and other costs of the Hi-crop and Kobe hybrids for the six cultivation environments.

Cultivation environment	Deployment and driving	Insecticide sprays	EOC	Other costs	TOC
		Hi-crop			
Open field	17,326.10	2,680.60	20,006.70	1,000.34	21,007.04
Agrotextile	21,244.30	1,959.00	23,203.30	1,160.17	24,363.47
Organza	34,797.00	1,680.00	36,477.00	1,823.85	38,300.85
Red mesh	24,543.90	1,470.00	26,013.90	1,300.70	27,314.60
Silver mesh	30,988.00	1,680.00	32,668.00	1,633.40	34,301.40
Black mesh	21,317.50	1,680.00	22,997.50	1,149.88	24,147.38
		Kobe			
Open field	16,576.10	2,680.60	19,256.70	962.84	20,219.54
Agrotextile	20,494.30	1,959.00	22,453.30	1,122.67	23,575.97
Organza	34,047.00	1,680.00	35,727.00	1,786,35	37,513.35
Red mesh	23,793.90	1,470.00	25,263.90	1,263,20	26,527.10
Silver mesh	30,238.00	1,680.00	31,918.00	1,595,90	33,513.90
Black mesh	20,567.50	1,680.00	22,247.50	1,112,38	23,359.88

The lowest TOC was observed with the kale cultivation in the open field, and the costs with the use of agrotextiles and black mesh were similar. Intermediate values were obtained using the red mesh, whereas the costs of using organza and silver mesh were the greatest. Although fabrics have a much higher value when compared to agrotextiles and organza, their durability makes this material less expensive or equal because other fabrics have short useful lives and need to be replaced.

The hybrids presented variable performances according to the cultivation environment; however, the 'Hi-crop' hybrid obtained greater total and commercial productivity in all environments when compared to Kobe (Table 4). Total productivity was 26.5% higher with 'Hi crop' in the tunnel covered with organza compared to the environment with Kobe in the open field. This superiority was observed in all environments, although less evident in open field cultivation, where the total productivity of the hybrids presented a difference of 2.9% (Table 4).

Table 4. Total productivity, bunch number (Number of bunches), losses from pest damage, and gross revenue of kale hybrids produced in an open field and low tunnels covered with agrotextile, organza, red mesh, silver mesh, and black mesh.

Cultivation environment	Total Productivity (t/ha)*	Commercial Productivity (t/ha)*	Number of packs (300 g)*	Losses from pest damage (%)*	Gross revenue (R$)*
Hi-crop					
Open field	27.43	23.46	64,704.79	29.24	194,114.38
Agrotextile	32.43	28.15	94,321.96	12.74	282,965.89
Organza	37.37	31.99	106,639.00	14.38	319,917.00
Red mesh	28.48	26.15	87,162.68	8.19	261,488.04
Silver mesh	34.8	28.71	99,251.75	14.45	297,755.25
Black mesh	26.64	21.27	73,992.29	16.68	221,976.86
kobe					
Open field	26.64	22.20	61,660.24	30,56	184,980.71
Agrotextile	23.7	24.12	70,913.61	10.26	212,740.82
Organza	28.59	23.99	79,995.96	16.06	239,987.89
Red mesh	27.06	24.98	83,281.25	7.69	249,843.75
Silver mesh	29.19	24.94	83,396.63	14.,29	250,189.88
Black mesh	22.3	19.95	66,696.50	10.28	200,089.50

* Values refer to six harvests.

Commercial productivity refers to fully expanded harvested leaves without signs of senescence or serious damage caused by insects, which constitutes the marketable product. For this parameter, 'Hi-crop' presented the best results in all environments when compared to the 'Kobe' hybrid, whereby the most expressive commercial production was obtained with the organza tunnel, with a difference of 42.16% regarding 'Kobe' in the same environment.

The open field had the least productivity for both hybrids due to the greater degree of damage caused by insect pests that required the application of a chemical product with a longer grace period, which influenced the crops and number of packets. The number of bundles was highest with 'Hi-crop' grown under organza protection. The open field and tunnel covered with the black screen provided the lowest yield of kale bunches.

The 'Kobe' hybrid obtained the lowest averages in all environments when compared to the 'Hi-crop', with the highest number of bunches when cultivated under the tunnel with red or silver mesh and the lowest average in open field cultivation and the tunnel covered with black mesh.

The loss percentage, which represents the harvested leaves that were commercial size but damaged by insects, represented values close to 30% for both hybrids evaluated. The cultivation under the tunnel covered by red mesh showed 8.19% and 7.69% for the hybrids 'Hi-crop' and 'Kobe', respectively (Table 4). The lower loss percentage of the red mesh is related to light interference and UV radiation, because some insects are sensitive to a certain spectrum, including sucking insects, such as aphids, which are sensitive to the 330–550 nm range, and any interference in this range results in lower preference, and consequently less infestation (Mahmood et al., 2018), which translates to lower losses and a higher gross margin.

Gross revenue refers to the income generated without deducting production costs. The 'Hi-crop' hybrid under organza protection earned 24.6% greater gross revenue when compared to the 'Kobe' hybrid grown under the same condition. In the open field, both hybrids showed lower productivity, and consequently gross revenue, demonstrating the benefits of using the low tunnel in kale cultivation, regardless of hybrid and coverage.

The parameters evaluated for the economic analysis were revenue, operating profit, profitability index, and gross margin, expressed as percentages, as well as the leveling point in terms of kilograms per hectare and with reference to the commercialization value of the product to cover the costs of production.

For all economic parameters evaluated, the 'Hi-crop' hybrid was more efficient than the 'Kobe', except for the leveling point (kg.ha^{-1}), which required a greater amount of product to be marketed to fund the development of the activity in all proposed environments because of its higher implementation cost.

As for the product commercialization price, the 'Hi-crop' hybrid provided the lowest values; that is, the high productivity allowed for the minimum commercialization price to cover the costs and maintain the activity to be lower. Operating profit (OP) was calculated as the difference between gross revenue and total operating cost, with the highest average observed when the 'Hi-crop' hybrid was grown under an organza tunnel, which was superior to all environments evaluated for both hybrids (Table 5).

Table 5. Operating profit (OP), Profitability Index (PI), Gross Margin (GM), Leveling Point (LP) and Leveling Point (R$/packs) of kale hybrids grown in an open field or a tunnel covered with agrotextile, organza, red mesh, silver mesh, or black mesh.

Cultivation environment	OP (R$)	PI (%)	GM (%)	LP (kg/ha)	LP (R$.pack^{-1})
		Hi-crop			
Open field	173,107.35	89.2	824.0	7,002.3	R$ 0.32
Agrotextile	258,602.43	91.4	1,061.4	8,121.2	R$ 0.26
Organza	281,616.15	88.0	735.3	12,767.0	R$ 0.36
Red mesh	234,173.45	89.5	857.3	9,104.9	R$ 0.31
Silver mesh	263,453.85	88.5	768.1	11,433.8	R$ 0.35
Black mesh	197,829.49	89.1	819.3	8,049.1	R$ 0.33
		Kobe			
Open field	164,761.18	89.1	814.9	6,739.8	R$ 0.33
Agrotextile	189,164.86	88.9	802.4	7,858.7	R$ 0.33
Organza	202,474.54	84.4	539.7	12,504.5	R$ 0.47
Red mesh	223,316.66	89.4	841.8	8,842.4	R$ 0.32
Silver mesh	216,675.98	86.6	646.5	11,171.3	R$ 0.40
Black mesh	176,729.63	88.3	756.5	7,786.6	R$ 0.35

The profitability ratio refers to the percentage of operating profitability to gross revenue, and represents the percentage of return-on-activity. The highest profitability indexes of the 'Hi-crop' hybrid were obtained with the cultivation under the low tunnel covered with agrotextile in the open field, and under the red mesh tunnel for 'Kobe'. However, both hybrids showed PIs above 80%, regardless of the coverage used, indicating high profitability of the activity.

Gross margin is an economic indicator that refers to the ratio of gross revenue to total operating cost, defining the funds available, as a percentage, to cover other fixed costs, risk, and return-on-activity. High gross margin values were observed for kale cultivation, regardless of the hybrid or cultivation environment. However, the highest values were observed with the cultivation of 'Hi-crop' under the agrotextile tunnel, and in the open field and red mesh tunnel for 'Kobe'. This is related to the cost of the roofing material in relation to the productivity of the hybrid; for example, agrotextile and red mesh had lower acquisition costs compared to other materials and a higher gross margin. Agrotextiles and red mesh provide higher temperatures in the cultivation environment, which favors the development and foliar expansion of crops (Taiz et al., 2017). In addition, these environments are considered important physical barriers for the management of insect pests as they interfere with the attraction and infestation of crop areas (Ponce et al., 2021).

The leveling points (kg.ha^{-1} and R$.pack^{-1}) represent the required amount of product per cultivated area and the minimum price for marketing the product to cover the related costs. In the open field cultivation, 7002 kg of product was needed to fund the cultivation of 'Hi-crop', while 6,739.8 kg was required for the 'Kobe' hybrid, to produce the lowest leveling points. These results relate to the lower cost of implementing the culture.

As for the commercialization value or PN (R$. pack^{-1}), the lowest value was obtained with 'Hi-crop' cultivated under an agrotextile tunnel. A low PN (R$. pack^{-1}) guarantees the competitiveness of the product in the market, even under conditions of high product supply. The lowest PNs (R$.pack^{-1}) for the Kobe hybrid were observed in the open field, agrotextile tunnel, and red mesh treatments.

The low tunnel protected environment has a low implementation cost and is easy to build compared to other cultivation environments. The return-on-activity is highly dependent on the crop, whereby species with high added value can cover their costs in six months of cultivation (POLYSACK, 2016). In the case of leafy vegetable cultivation, the use of a protected environment is intended to improve soil and climate conditions (Seabra Júnior et al., 2019), but it can also be used to protect crops against insect pests (Ponce et al., 2021; Licciardi et al., 2007). The benefits of using a protected environment are increased productivity and protection; however, the species involved must be adapted to the type of environment or the effect of the cover used in the cultivation environment. When the cultivation environment favors production due to edaphoclimatic improvements, there may still be a compensation effect, and even with losses promoted by insect pests, ideal cultivation conditions favor greater production.

Razin et al. (2021) emphasized that the improvement in production conditions favors the effectiveness of vegetable cultivation and reduces the price disparity between in the acquisition of materials and services by producers and the sale of their products. In addition, higher productivity corresponds to lower prices and increased vegetable sales.

The profitability parameters demonstrated that an activity can be profitable regardless of the combination of hybrid and environment. However, even when the investment in the implementation was high, the gross margin and profitability indexes were greater in the tunnels than those in the open field.

Conclusions

The highest productivity was obtained when the hybrid 'Hi-crop' was cultivated under the organza tunnel, while 'Kobe' was more productive in the tunnels covered with silver or red mesh.

All cultivation environments attained high gross margins, which varied according to the hybrid and cultivation environment.

The use of a protected environment for kale cultivation reduced the need for insecticide-spraying.

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