Livestock Manure Recycling for Vegetable Farms in Hong Kong

Lauren Hsu
Choate Rosemary Hall, 333 Christian Street, Wallingford, CT, 06492, U.S.A; laurenkanru@gmail.com

ABSTRACT: Urbanization and zoonotic disease in Hong Kong have resulted in a shrinking agricultural industry. Locally grown vegetables account for only 1.6% of total vegetable consumption, while imported meats make up a greater percentage of meat consumption each year. Imported meat made up 40% of all meat consumption in 1982 but rose to 78% in 2002. At the same time, years of unregulated livestock manure disposal into waterways have created pollution problems in several rivers. For example, the River Ganges, located in an area with a high concentration of farms, has phosphorus levels of 0.72 mg/L. This far exceeds the recommended limit of 0.05 mg/L established by the United States Environmental Protection Agency in 1986 to control eutrophication. Livestock manure recycling for vegetable farms is explored as an option for supporting the sustainability and growth of the agriculture industry. Using data from literature, the paper estimated the amounts of N, P, and K produced and demanded from clusters of farms in Hong Kong, as well as possible savings in fertilizer if manure is utilized. *Allium fistulosum* was grown with fertilizer and livestock manure to evaluate the differences in treatment. The control, *Allium fistulosum*, grew better than manure and fertilizer-treated plants. The untreated *Allium fistulosum* reached a height of 13 cm, while manure-treated pots reached 7 cm and fertilizer treated reached 3 cm. However, manure and fertilizer improved soil nutrients. This study concluded that the government-backed field experiments must be conducted to confirm the viability of manure application, followed by technical support, financial incentives, and stricter regulations to encourage manure recycling.

KEYWORDS: Hong Kong; Agriculture; Manure production; Manure recycling; Soil quality; Nutrient demand; Nutrient balance.

Introduction

The Hong Kong agricultural industry is facing many challenges, including insufficient workforce and policy support, expensive land, and mountainous terrain.[1] In 2006, agriculture and fisheries workers made up only 0.3% of the working population; by 2016 it diminished to 0.1%.[2] Overall, agriculture, fishing, mining, and quarrying combined only made up 0.06% of the 2019 GDP of Hong Kong.[2] The decline in the agricultural workforce and economic footprint is reflected in local food consumption trends. Between 1982 and 2002, overall beef consumption increased. However, domestically-produced beef consumption decreased from 30.5 thousand tonnes to 12.1 thousand tonnes in 2002 and local production of pigs dropped from 23,200 tonnes in 2007 to 8,443 tonnes in 2016[3] as the city has grown more reliant on chilled and frozen beef.[4] Increases in chilled and frozen meat consumption and decreases in fresh meat consumption were also present in per capita consumption (Figures 1 and 2). The same trend occurred in poultry consumption as avian flu shook the local poultry industry.[5]

Although local vegetable production decreased from 42,500 tonnes in 2000 to 14,200 tonnes in 2016,[3] fertilizer application rates have grown tenfold from 390.8 kg/ha in 2004 to 3,573.9 kg/ha of arable land in 2018.[6] In comparison, the United States applied an average of 128.7 kg/ha of fertilizer in 2018.[6] The decrease in vegetable production and increase in fertilizer consumption suggests that fertilizer is being applied in excess. Over-applying fertilizer for an extended period can damage soil quality by decreasing organic matter, microbial activity, altering acidity, and more.[7] It also pollutes surrounding bodies of water and potentially leads to surface water eutrophication. Depleted soil threatens important ecological services.

One way to support crop production, soil health, and sustainability of the farming industry is by applying livestock manure to the soil.[8] In 2017, 160 tons of livestock waste were produced per day in Hong Kong, of which 43% were disposed of at landfills. The remaining waste was treated through on-site composting, aerobic treatment, or dry muck-out.[9]

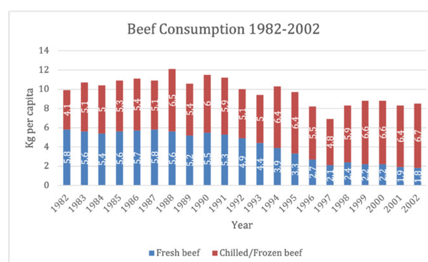

Figure 1: Hong Kong beef consumption per capita,1982-2002.

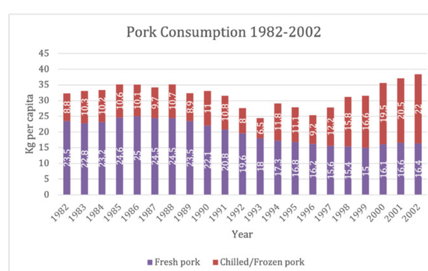

Figure 2: Hong Kong pork consumption per capita,1982-2002.

However, livestock waste from farms is a major source of pollution in waterways (see Figure 3). *E. Coli*, phosphorus, and ammonia nitrogen levels[10] can increase with the presence of livestock waste in the water. Other potential issues include soil contamination[11] and overfertilizing the soil.[12] Therefore, manure management is needed to harness livestock manure as a valuable resource while protecting the environment.

This paper serves to analyze the current situation of manure management in Hong Kong and explore potential policies and infrastructure that will support livestock manure application. First, the paper will estimate nutrient balances, crop nutrient demands, recycled nutrients, and fertilizer savings. The paper will then suggest infrastructure schematics to assist farmers in recycling manure and policies to manage manure application. The aim is to develop management methods that cover the multiple steps of manure application in the context of Hong Kong's urban setting while filling the gaps in knowledge of livestock manure management in urban areas.

Government Policy and Programs:

The Agriculture, Fisheries, and Conservation Department (AFCD) is the branch of the Hong Kong government responsible for facilitating food production, conserving natural habitats, and monitoring disease in animals. It is divided into five branches: Agriculture, Fisheries, Country and Marine Parks, Inspection and Quarantine, and Conservation. In 2004, 2005, and 2008, the AFCD launched a Voluntary Surrender Scheme for poultry farms which paid them to surrender their Livestock Keeping License and cease operations.[13] Figure 4 shows the timeline of government policies and programs. These measures were taken to combat avian influenza outbreaks. As local poultry farms decreased in number, consumption of frozen and chilled chicken went from 58% in 2003 to 85% in 2008.[13] In 2006, the government proposed a Voluntary Surrender Scheme for pig farmers. There were 265 pig farms at the time which produced 520 tonnes of manure per day,[14] along with over 130 poultry farms.[15]

The illegal discharge of livestock manure was one of the main causes of polluted rivers and streams.[10] E *Coli* counts and quantities of ammonia nitrogen, nitrate-nitrogen, and phosphorus were highest in Northwestern New Territories (see Figure 3), where most livestock farms are located. Additionally, farmers indiscriminately dumped dead pigs and illegally slaughtered pigs, and there was public concern over disease transmission through pigs. There are two abattoirs for livestock and seven locations where slaughtered animals can be disposed of and destructed.[16] It appears these resources were insufficient and located too far away for farmers. As a result, farmers would rather illegally slaughter and dispose of pigs than transporting them to the proper sites.[16] Pollution, illegal slaughtering and dumping, and outbreaks of Japanese encephalitis were the leading deciding factors behind the Voluntary Surrender Scheme for pig farming. Heightened public concern over zoonotic disease from livestock before 2006 led the Health, Welfare, and Food Bureau (HWFB) and the Environmental Protection Department (EPD) to conclude that sustainably developing pig farming was not a realistic long-term policy option. In addition to voluntary surrender tection of African swine fever in recent years has resulted in the government culling animals. The Hong Kong government culled 6000 pigs in 2019[17] and 3000 pigs in 2021.[18]

In 2014, the HWFB and (AFCD) released the New Agricultural Policy on Sustainable Agricultural Development in Hong Kong. It stated that the agricultural sector was diminishing as the city became more urban. Additionally, public opinion on the agriculture sector had shifted to a more positive stance, and the government reviewed its position on agricultural policy and developed new policies to support the sector's growth. The initiatives outlined included the Sustainable Agricultural Development Fund (SADF) to support the research and adoption of modern farming practices. The proposal added that the government was looking to boost fruit and vegetable farming, not the livestock sector, though the SADF could help upgrade their operations.[19]

By 2021, there were 43 pig farms and 29 poultry farms.[20] Of these, the Hong Kong Environmental Protection Department provided free livestock waste collection to 68 farms.[21] In Hong Kong, the government classifies the collection of livestock waste into three areas:

1. Livestock waste prohibition areas: urban areas where livestock keeping is banned.

2. Livestock waste control areas: farmers must apply for a license from the ACFD and comply with the Waste Disposal Ordinance.

3. Livestock waste restriction areas: livestock keeping is banned unless the land has been used for livestock keeping twelve months before 1994, the keeper holds a license, and follows the Waste Disposal Ordinance.

The Waste Disposal Ordinance provides regulations on livestock waste disposal. Farmers must store livestock waste for collection in secure containers intended for livestock waste only. Solid livestock waste used as fertilizer must be stored securely and composted on the farmer's land and the farmer must take all precautions to prevent spillage. Liquid manure must be disposed of through channels, into a collection vehicle, or a soakaway pit greater than 30 meters away from a drinking water source. Treated liquid manure should be disposed of through channels into a soakaway pit, sewer, saline water, or watercourse. Farmers must also construct a permanent barrier to prevent livestock waste from escaping the grounds.[22]

Targeting Breast CSCs' Markers:

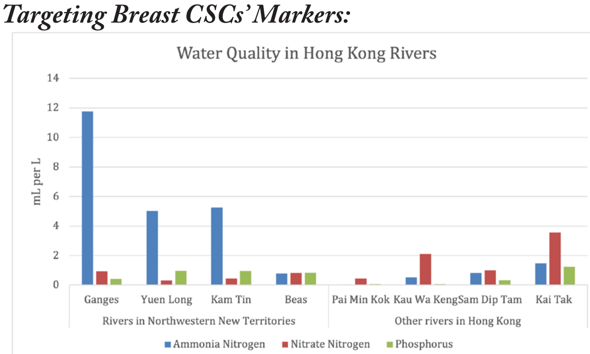

Figure 3: Hong Kong river water quality, 2019.

Failure to follow the Waste Disposal Ordinance or discharging livestock waste into public spaces and drinking water elicits a fine. Prosecutions can only happen when the offender is caught red-handed, thus making it difficult to determine those responsible for pollution.[23]

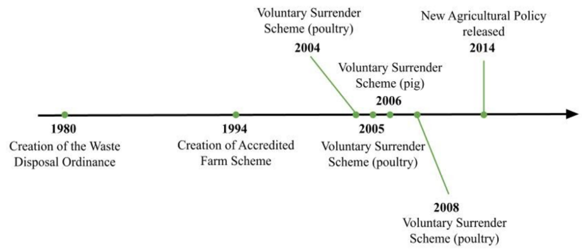

Figure 4: Timeline of government policies and programs. See Appendix A.

Methods

Through government data, we identified the 286 local vegetable farms involved in the Accredited Farm Scheme 1 in addition to 43 pig farms and 29 poultry farms located in the city. In total, these farms have a total rearing capacity of 50,000[24] and 130 million[25] respectively for pigs and poultry. The farms were divided into four zones, or clusters, based on location (Figure 5). Each zone consists of farms close in proximity, allowing for easier transportation of livestock manure to vegetable farms. The area of accredited vegetable farms was 14.80 ha, 25.32 ha, 45.04 ha, and 1.40 ha for zone 1, 2, 3, and 4 respectively, which amounts to 86.56 ha of land.

Next, the NPK input and output flow were identified through the literature. Nutrient balance was estimated by calculating the difference between inputs and outputs. Inputs were both environmental and farm managed, while outputs included the harvested crop and losses to the environment. Manure production per zone was determined with the following equation:[26]

Manure N, P, and K production per zone [kg] = Number of farms per zone * average LSU per farm* average manure NPK per LSU [kg]

Data for the number of farms, average manure NPK per livestock unit, or LSU , and average LSU were found in the literature. The daily manure production per livestock unit was determined based on data in the literature. This helped identify the annual N, P, and K production from animal manure. Manure recovery fractions (RF) were found through literature. RF is the percent of N, P, and K excreted in manure that is recycled. A low percentage indicates poor nutrient management. The RF for N was 22%, and 50% for P and K.[27] The low RF values suggest that there were nutrient losses, possibly during the storing stages through ammonia emissions or because the manure was discharged into a landfill or body of water. Finally, the crop nutrient demand (kg ha-1 year-1) was estimated for each zone. Based on its relevance in terms of production, three major crops in Hong Kong were selected for this analysis: Chinese white cabbage, flowering Chinese cabbage, and Chinese Kale.[28] Fertilizer savings were estimated using fertilizer composition data from Sinofert, China's largest fertilizer supplier. Data for the cost per ton of fertilizer was taken from late 2020 to 2021.

Figure 5: Distribution of livestock (pig farms in pink, poultry farms in yellow)[29] and accredited vegetable farms in Hong Kong,[30] divided into four zones.

Additionally, an experiment was performed to determine the effects of manure on plant growth and soil health (see Appendix B). *Allium fistulusom* was planted in three pots of plain soil, three pots of fertilizer-treated soil, and three pots of cow-manure-treated soil. The plants were watered daily and parameters such as soil type, soil nutrients, and plant growth were recorded. Plants grown without any treatment grew the most, while little growth was seen in manure and fertilizer-treated pots. However, applying fertilizer or manure improved the nutrient content in the soil. The results showed some potential for manure application to crops, though further research is needed to implement the change without impacting crop production.

Results and Discussion

In 2018, the flow of nutrients N, P, and K were found to be 220 kg/ha/year.[31] Data from 2004 was used to calculate the nutrient balance.[32] The results in Tables 1 and 2 indicated a positive N and P balance, but a negative K balance. The surplus of N and P can be attributed to inputs of fertilizer and manure.

Table 1: Nutrient N, P, and K balance.

Nutrient	Input [kg]	Output [kg]	Balance [kg]
N	458,696.55	231,036.80	226,659.75
P	83,198.55	35,517.25	47,681.30
K	189,464.15	204,952.00	-15,487.85

Table 2: Nutrient N, P, and K balance by zone.

Zone	Nutrient Balance N [kg]	Nutrient Balance P [kg]	Nutrient Balance K [kg]
1	39,465.46	8,302.16	-2,696.71
2	67,512.61	14,202.3	-4,613.19
3	120,103	25,265.5	-8,206.74
4	3,733.22	785.34	-255.10

Then, we estimated the following annual manure N, P, and K production per zone as shown in Table 3.[33] The mean N:P:K ratio was 1.2: 1.0: 0.7. Thus, phosphorus levels were high and potash contents were low.

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[1] The Accredited Farm Scheme is a program that has run since 1994. It aims to improve farm management and production by promoting sustainable agricultural practices, production process standards, and pre-sales testing.
[2] A livestock unit, or LSU, is defined as one adult dairy cow producing 3,000 kg of milk per year (Glossary, n.d.)

Table 3: Nutrient N, P, and K manure production by zone.

Zone	N [kg/year]	P [kg/year]	K2O [kg/year]	Total manure [kg/year]
1	176,797.76	146,103.73	100,582.1	20,116,417.8
2	1,063,591.71	836,105.31	555,663.17	111,132,633
3	176,797.76	146,103.73	100,582.09	20,116,417.8
4	16,495.84	14,827.61	10,591.15	2,118,230.05

We found the total NPK nutrient crop demands as shown in Table 4. They were determined by crop type, crop nutrient needs, and the area of each zone. As Zone 4 had the smallest area of farmland, the nutrient demands were the lowest.

Table 4: Nutrient N, P, and K crop demands by zone.

Zone	N [kg/year]	P [kg/year]	K [kg/year]
1	203,520.35	57,531.3	378,950.3
2	347,222.22	98,153.06	646,519.94
3	619,361.93	175,081.74	1,153,237.95
4	192,51.93	5,442.5	35,846.65

The total fertilizer application rate in 2018 in Hong Kong was 3,573.9 kg/ha.[6] Assuming an application rate of 90-296 kg/ha N, 75-180 kg/ha P, and 90-270 kg/ha K based on farmer's traditional practice and application rates determined from yield response, soil testing, and agronomic efficiency,[34] the following amounts of fertilizer N, P, and K are applied per zone (Tables 5 and 6).

Table 5: Minimum fertilizer application rate by zone and nutrient.

Zone	Fertilizer N applied [kg/year]	Fertilizer P applied [kg/year]	Fertilizer K applied [kg/year]
1	1,332	1,110	1,332
2	2,278.62	1,898.85	2,278.62
3	4,053.6	3,378	4,053.6
4	126	105	126

Table 6: Maximum fertilizer application rate by zone and nutrient.

Zone	Fertilizer N applied [kg/year]	Fertilizer P applied [kg/year]	Fertilizer K applied [kg/year]
1	4,380.8	2,664	3,996
2	7,494.13	4,557.24	6,835.86
3	13,331.84	8,107.2	12,160.8
4	414.4	252	378

As is shown in Tables 1 through 6, even with low recovery fractions, livestock manure could potentially account for 100% of fertilizer N, P, and K applied. By replacing fertilizer with manure, between 1,075.05 - 12,193.39 USD could be saved in urea fertilizer[35], 7,328 - 21,984 USD could be saved in diammonium phosphate[36] and 4,950.11 - 18,409.46 USD in potash fertilizer.[37] The overall fertilizer savings over twenty years are shown in Figure 6.

Discussion

Even with low recovery fractions of 22% for nitrogen and 50% for phosphorus and potassium, there is sufficient manure produced to replace the number of nutrients currently supplied by fertilizer. However, differences in nutrient demand and balances mean that manure application alone may not be adequate. The nutrient balance showed a major deficit in potassium and surpluses in nitrogen and phosphorus. Potassium has the greatest nutrient demand and deficit, yet more nitrogen is applied in fertilizer than potassium. With a manure replacement, more phosphorus and nitrogen would be produced than potassium. To avoid a deficiency in nutrients would require overapplying nitrogen and phosphorus to fulfill potassium needs. Therefore, manure should be applied until phosphorus requirements are met since those are the lowest. The remaining nitrogen and potassium needs can be supplemented with organic nitrogen and potassium fertilizer. A different approach would be to fertilize areas of high nitrogen and potassium demand with nitrogen and potassium-rich pig and cattle manure. Phosphorus and some nitrogen fertilization needs would be met with phosphorus and nitrogen-rich manure fractions. If manure replaces all phosphorus fertilizer, that would reduce 11% of all fertilizer imports.

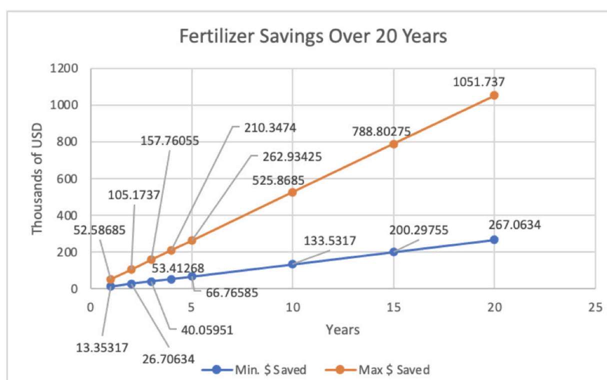

Figure 6: Maximum and minimum fertilizer savings in Hong Kong over twenty years.

There are multiple benefits to increased manure recycling in Hong Kong. Soil pH, electrical conductivity, and nutrients can all increase with higher manure application rates.[8] Livestock manure application increased the nutrient content in *B. Chinensis* and *Z. Mays L.* Pollution from importing and manufacturing chemical fertilizers as well as water pollution could be decreased. Multiple considerations need to be taken to account before applying livestock manure.[38] Emissions and nutrient loss need to be minimized during storage and transportation. Contaminants can be present in livestock manure, making the application of manure to crops hazardous for the environment and human health. For example, Hong Kong experienced zoonotic diseases such as avian influenza and Japanese encephalitis which can be spread through manure. Transporting manure between farms increases the risks of disease exposure, however, it is necessary given that farms have become more specialized, as they either have crops or livestock. The creation of zones in Hong Kong can minimize the spread of pathogens by keeping the livestock manure within a closer range.

Experiment on Allium Fistulosum:

The results of the experiment both supported and disagreed with other findings in the literature. A study in Hong Kong found that manure application increased pH, potassium, and dry weight of *B. Chinensis* and *Z. mays L.*[8] However, growth in manure-treated pots was not better than in control pots as manure-treated plants withered and turned white after three weeks. It is possible that the soil was already rich in nutrients, or that manure application increased salt content to a detrimental level. Another study saw increases in nutrients P and K and taller chili peppers with manure application.[39] Levels of nutrient P and K did increase in this paper's experiment, but the tallest manure-treated onion remained 0.5 cm shorter than the smallest control and 5.5 cm shorter than the tallest control.

We believe one significant reason for the lack of growth in manure and fertilizer-treated pots is the lack of technical support in irrigation. The pots were watered twice a day for a total of 115 mL of water. Along with several days of heavy rain on the pots and a humid climate, the pots appeared to be overwatered and lacked a strong drainage system, resulting in algae growth on the soil in manure and fertilizer-treated pots. In addition, there was not enough soil in the pots to buffer the fertilizer and manure. This demonstrates the importance of involving farmers in field experiments with technical support before implementing major policy changes. The 286 farms involved in the Accredited Farm Scheme should receive guidance from the Accredited Farm Scheme program and support from the Sustainable Agriculture Development Fund in manure storage and application. While plant growth was negatively affected by manure application, applying manure did increase the nutrients in the soil, though there was some imbalance as there was a surplus of potassium and phosphorus but not enough nitrogen. To meet all three NPK nutrient requirements with just livestock manure would result in excess potassium and phosphorus. One option to solve this would be applying enough manure to fulfill potassium and phosphorus nutrient demands and supplement the nitrogen requirement with organic nitrogen fertilizer.

Limitations of the paper:

There was not much data available on the farming industry in Hong Kong. As a result, much of the data used to make estimations came from studies run nearby in China. Additionally, this paper does not fully represent every farm and source of animal manure in Hong Kong. There were over 1,200 racing horses in 201940, creating up to 8,443.618 kg of manure per year.[41] However, manure from racehorses should be tested first, as steroids can be present in the manure. The vegetable farms represented in this paper are the ones that are a part of the Accredited Farm Scheme. There are 347 ha, 128 ha, 7 ha, and 273 ha of land used for vegetables, flowers, field crops, and orchards respectively.[42] They may not receive the same support needed to make farm-wide changes or explore new farming practices like those in the Accredited Farm Scheme. However, there is enough manure to replace the fertilizer needed for all vegetable crops. This would save up to 411,365.32 USD in fertilizers per year. In five years, 2,056,826.61 USD could be saved in fertilizer costs.

Conclusion

Nutrient imbalances on farms and in manure production mean that nitrogen and phosphorus fertilizer is still needed, but most nutrient requirements can be fulfilled through manure application. Soil testing can help determine the exact amount of manure and fertilizer that needs to be applied, to avoid nutrient leaching and the environmental impact that comes from it. The experiment with *Allium fistulosum* did not yield results that support the case for manure application. However, this may be a matter of a poor irrigation system and low technical support, which shows that additional field experiments and guidance for farmers in the future are crucial. The benefits of livestock manure application to crops are multifaceted but come with environmental and health risks. Nevertheless, these risks can be mitigated through strong manure management. There remain more options in livestock manure recycling that can be further explored.

To move closer to a livestock manure recycling system in Hong Kong, there first needs to be more field experiments with soil testing done to test different manure application strategies and confirm their viability. These include effects on food production, the more accurate amount of manure needed across a variety of crops, differences between technology used to spread the manure, etc. Second, technical support should be given to farmers to help them adjust practices. To promote manure recycling, fines for the illegal discharge of manure should increase. Monetary incentives for recycling should be created as manure is a valuable resource. Hong Kong currently has regulations for livestock manure handling, these could be revised to further reduce nutrient loss and emissions. Additionally, the government should implement stronger policing in areas where rates of illegal livestock manure discharge into water are known to be higher. They could also market livestock manure to vegetable farmers as a sustainable, more economical option compared to chemical fertilizer. Finally, using the data from field experiments, the government can create a nutrient recommendation system that covers different crops, soils, farm types, etc.[43]

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Author

Lauren Hsu is a student at Choate Rosemary Hall but is originally from Hong Kong. She is interested in the environmental sciences and hopes to further her knowledge in agriculture.

Appendix A

Date	Name of government program	Description of government program
1980	Waste Disposal Ordinance	"To provide for the control and regulation of the production, storage, collection and disposal including the treatment, reprocessing and recycling of waste of any class or description, the licensing and registration of places and persons connected with any such activity, the protection and safety of the public about any such activity and to provide for matters incidental thereto."
1994	Accredited Farm Scheme	The Accredited Farm Scheme's objective is to promote "good horticultural practice and environmentally-friendly production" as well as "providing a stable supply of high quality and safe vegetables."
2004, 2005, 2006, 2008	Voluntary Surrender Scheme	The Voluntary Surrender Schemes were an effort to reduce pig and poultry farming in Hong Kong. They were a result of outbreaks of zoonotic diseases such as avian flu and African swine fever.
2014	New Agricultural Policy	The New Agricultural Policy was a review of Hong Kong's agricultural policy. The goal was to modernize the industry and maximize societal benefits from farming in Hong Kong.

Appendix B

Allium fistulosum, commonly known as bunching onions, was grown in pots with a diameter of 5.5 inches and 5.5 inches in depth. The pots were filled with 200g of soil and treated as follows:

1. 10g of Fertiplus COW 2-2-2 (cow manure pellets)
2. 10g Manutec 9:2:4 vegetable fertilizer
3. Control

There were three replicas of each treatment, making for nine pots total. The different treatments were mixed into the soil before planting the seeds. Five seeds were planted in each pot. Each pot was watered twice a day using the Claber Oasis Automatic Drip Watering System, for a total of 115 mL of water per day. The soil texture was identified as clay loam using a sedimentation test. The percentage of clay, sand, and loam was determined using the soil textural triangle.[44] See Table 7 for soil characteristics. Soil pH, moisture, and sunlight were measured using a soil detector. An outdoor temperature sensor was used to measure ambient temperature and relative humidity. Plant height was recorded daily. Additionally, the first cotyledon and the percentage of seeds that germinated for each pot were noted. Nitrogen, phosphorus, potassium, and pH were measured using a Luster Leaf 1601 Rapitest soil test kit. The test kit graded nutrient levels on a scale of 0 to 4, with 0 being depleted, 1 being deficient, 2 being adequate, 3 is sufficient, and 4 being a surplus.

Table 7: Soil characteristics. pH, N, P, and K levels were tested with the Luster Leaf 1601 Rapitest soil test kit.

Parameter	Value
pH	7.5
Texture	Silty clay loam
Nitrogen	Deficient
Phosphorous	Deficient
Potassium	Sufficient
Sand	40%
Clay	0%
Silt	60%

Growth of Allium fistulosum and soil quality:

The control pots had an overall germination percentage of 80%, while the fertilizer-treated pots were at 13% and manure at 40%. In all three control pots, the first cotyledon occurred six days after planting. The first cotyledon happened six days after planting for two of the manure-treated pots, and eight days for the third. For fertilizer-treated pots, the first cotyledon occurred six days after planting for one pot and seven days for the second one. The third pot never germinated. Additionally, the onions in one of the manure pots and one of the fertilizer pots withered and turned white after three weeks. Figures 7, 8, and 9 show the growth of the plants over three weeks after planting. The nutrients in fertilizer and manure-treated pots increased (Table 8). According to the results reported by the soil analyzer, manure-treated pots were nitrogen deficient but had enough potassium and phosphorus. Fertilizer-treated pots had a surplus of nitrogen, and enough phosphorus and potassium.

Table 8: Soil nutrient content (C controls, F is fertilizer, M is manure). N, P, and K graded on a 0-4 scale with 0 being depleted and 4 being a surplus.

	C #1	C #2	C #3	F #1	F #2	F #3	M #1	M #2	M #3
N	1	1	1	4	4	4	1	0	1
P	1	3	3	4	2	3	4	3	4
K	2	3	3	3	3	3	4	4	3
pH	6.00	6.00	6.00	5.00	6.5	6.00	6.5	6.5	6.0

Figure 7: Control pot 26 days after planting.

Figure 8: Fertilizer pot 26 days after planting.

Figure 9: Manure-treated pot 26 days after planting.

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